Sabah A. Abdul-Wahab *Editor*

Sick Building Syndrome

in Public Buildings and Workplaces

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Foreword

H.E. Dr. Ali Soud Al-Bemani, *Vice-Chancellor*, Sultan Qaboos University (SQU), Sultanate of Oman

I had the pleasure of looking at this valuable effort by a group of international experts from 16 countries on the topic of Sick Building Syndrome (SBS). Living in an arid region which has witnessed an unprecedented rates of development and changes in all aspects of everyday life, including design of buildings and the introduction of air conditioning, chemicals and synthetic materials into our homes, it is important for us to fully assess the quality of our indoor environments and life styles, with a view to ensure that our homes are health and pleasant to live in. The chapters of this book have elaborated in a clear style, yet scientifically solid, the causes, diagnostic tools, health impacts and mitigation approaches that may be applied to existing and planned buildings. I would like to congratulate the authors and the editor for this excellent effort.

We at SQU are proud of our policy to encourage scientific research that is relevant to health and well being of our community as well as the regional and global environments. Our staff are encouraged to excel both in teaching as well as in carrying research that address issues of concern to our community. We will always provide the support needed for such serious and relevant research programs. I would like to see this line of research is continued and further developed both at SQU level as well jointly with other research teams in our sister universities.

Introduction

Editor of the book, *Prof. Dr. Sabah A. Abdul-Wahab*, Sultan Qaboos University (SQU), Sultanate of Oman

Having worked on air pollution monitoring, assessment and modelling for many years, I felt intrigued when one of my bright students walked into my office to say that she should not submit her project because every time she went to the library to work on the literature she would get a headache and feel sleepy. I took my papers and went to the section where she was looking for papers and sat for about 20 min before I experienced the symptoms my student described. I went to the maintenance department and obtained a drawing of the building. I examined the design, size of the reading hall, light distribution and air conditioning. I read as many published studies on the subject of sick buildings syndrome (SBS) as I could get my hands on. I took the opportunity of participating in a project at the Sultan Qaboos University (SQU) at Sultanate of Oman to design an Eco-House. The SQU Eco-House Project is an initiative taken to demonstrate designs that are energy and water efficient and which can run on renewable energy sources. My role was to work on the indoor and outdoor environments. I started to apply theory and test some of the concepts on sick building syndrome. This was not easy, since it was not possible to totally isolate the indoor environment from the outdoor environment. The lesson learned is that one needs to have a holistic look, taking into account the fact that all factors are related including environmental factors outside, available building materials, types of furniture as well as design of kitchens and cooking practices and other social habits of the community. As a result of gaining this understanding I thought it would be a good idea to bring experts in the various fields together and try to bring to the community a comprehensive overview of sick building syndrome and obtain some ideas of how to mitigate the effects of exposure by building occupants experiencing such conditions.

I am very proud of the product at your hands. This book has been written by colleagues who are knowledgeable in their subjects and dedicated to their profession. We hope that you will find the chapters in this book compressive, realistic and easy to read.

Contents

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Mahmoud Yousef Abdulraheem is Director of the Research Directorate (RD) at Kuwait Fund for the Advancement of Sciences (KFAS). RD is dedicated to provide funding opportunities to Kuwaiti scientists, research institutions, universities as well as government and private institutions and companies in the areas of environment, water, human health, education and petroleum-related topics.

After serving over 27 years as in the Environment Protection Department and the Environment Protection Council Kuwait, Dr. Abdulraheem became Technical Coordinator of the Regional Organization for the Protection of the Marine Environment (ROPME) in 1995. He then served as the Regional Director of UNEP Regional Office for the West Asia (ROWA) until 2004 and then as an advisor to the Secretary General of the Abu Dhabi Environmental Agency, before moving back to Kuwait in 2008.

Dr. Abdulraheem provides consultancy to the Central Committee for the Follow-up of the Environmental Rehabilitation Program established by the Council of Ministers, to coordinate the efforts of remediation of war related environmental damage. He also provides consultancy services to UN organization and environmental agencies in the region. He has written several reports for the Environment Protect ion Council on health related issues, including indoor air quality, health risks associated with air contaminants and developing guidelines for health indoor and work environments.

Syed Uzair Ahmed, Co-author of Chapter 26

Syed Uzair Ahmed is currently a MSc. Student and Research Assistant at the Department of Naval Architecture and Ocean Engineering, University of Ulsan, South Korea. He is a Mechanical engineer having worked with energy and environmental projects. He did his graduation from NED University of Engineering & Technology, Karachi, Pakistan. He also served the university as a Lecturer for a year. His teaching experience is in Fluid Mechanics and Engineering Drawing. He has been very actively involved in the energy related activities. He has also worked on the project of Green Building designs during his studies. He also worked for a short time at Sultan Qaboos University in the project related to Green Building design. Also, he has been a very active member of American Society of Mechanical Engineers (ASME), American society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) and Pakistan Heating, Ventilation, Air-conditioning and Refrigeration (Pakistan HVACR). He was also awarded from AMSE-NED Chapter for his work. His research interests are energy systems, renewable energy, sustainable development and green building, building controls for energy management function and statistical analysis.

Mervi Ahola, Co-author of Chapter 4

M.Sc. Mervi Ahola is currently working as an Advisor at Finnish Association of Mechanical Building Services Industries (FAMBSI). Her current responsibilities include project management and project work related to indoor air quality, thermal comfort and energy efficiency issues. She worked previously as an Indoor Environmental Specialist at Halton Group in Finland. She has also worked as a researcher at Helsinki University of Technology and as a consultant.

Dr. Muge Akpinar-Elci, Co-author of Chapter 22 and author of Chapter 23

Dr. Muge Akpinar-Elci received her M.D. in 1991 from Dokuz Eylul University, School of Medicine in Izmir, Turkey. She completed a Pulmonology internship in 1992 at the Budapest Postgraduate Medical School, Institute of Pulmonology in

Budapest, Hungary. In 1994 she completed a Certificate of occupational health practice from the Turkish Medical Association in Izmir, Turkey. Her residence in Pulmonology and Tuberculosis was completed in 1997 at the Chest Diseases and Surgery Training Research Hospital, in Izmir, Turkey. In 2004 Dr. Akpinar-Elci received a Master of Public Health from Tulane University School of Public Health and Tropical Medicine in New Orleans, LA.

Dr. Akpinar-Elci has clinical and field research experience in occupational health and continues to conduct research in her current position at St. George's University. Her areas of expertise include Occupational Health, Public Health, Epidemiology, Occupational Respiratory Diseases, and Respiratory Research Methods.

She has been the recipient of several awards including: Centers for Disease Control and Prevention, Bullard-Sherwood Research to Practice award, 2008; East Carolina University Division of Health Sciences, Author Recognition Award 2006; On-the-Spot-Award of Department of Health and Human Services, Public Health Service for commitment, initiative, and hard work under difficult circumstances in 2002 and 2006.

Dr. Akpinar-Elci is currently an Associate Professor at St George's University School of Medicine, in the Department of Public Health and Preventive Medicine and Track Director of Environmental and Occupational Health.

Prof. Dr. Sabah A. Abdul-Wahab, Editor of the book and author of Chapters 12 and 26

Sabah A. Abdul-Wahab is currently a Full Professor in the Department of Mechanical and Industrial Engineering, College of Engineering, Sultan Qaboos University in Oman. She is a Chemical Engineer experienced in environmental engineering, with an emphasis on environmental protection. She received her doctorate from Bath University, UK in 1999. Her teaching experience is in the areas of unit operations, mass transfer, transport phenomena, reactor design, thermodynamics, heat transfer, computer programming, numerical methods, wastewater treatment, landfills and environmental engineering. She has been actively involved in environmental chemical engineering research. Prof. Abdul-Wahab has published more than 100 referred international journal articles and around 10 chapters in books. The publications covered chemical and environmental engineering topics as well as various academic and educational issues. She has served as the Editor of a Special Issue on the “The International Journal of Environmental Studies” entitled “Women’s Environmental Activities in the Middle East and North Africa” (in 2009). She has also served as the Editor of a Special issue of the “American Journal of Environmental Sciences”, 2 volumes (in 2006–2008). Also, she has been invited to be a member of editorial boards of many international environmental and engineering journals. Prof. Abdul-Wahab has received several research awards recognitions, the latest of which were First Prize of the Saudi Arabia Environmental Management Award (Arab Administrative Development Organization, ARADO, League of Arab States, December 2008), Distinguished Teaching Excellence Award (College of Engineering, Sultan Qaboos University, 2 May 2007), Environmental Advocacy Award from the Arab Towns Organization Award (30 April 2007), and Distinguished Researcher Award (College of Engineering, Sultan Qaboos University, 2 May 2005). Her research interests are liquid desiccant air dehumidifier studies, monitoring of pollutants in the atmosphere, modelling and assessment, outdoor air quality, indoor air quality, air pollution control, modelling and chemistry of ozone formation, modelling of the dispersion of air pollution in the atmosphere, thermal inversion, particulate pollutants characteristics, environmental impact assessment studies, atmospheric corrosion of metals, neural network and statistical analysis, water desalination, solar and renewable energy.

Emeritus Prof. Dr. Keiichi Arashidani, Co-author of Chapter 15

Dr Keiichi Arashidani is currently an Emeritus Professor in the Department of Environmental measurement and Control, School of Health Sciences, University of Occupational and Environmental Health, Japan. He received the Doctor Degree of Science at Tokyo University Science, Japan in 1976. In 2006, he was presented with the scientific award from Japan Society for Atmospheric Environment. He is a Director of the Japan Society for Atmospheric Environment.

During his educational activities at the university education for 30 years, he has been teaching subjects in the field of working environmental control, industrial health, environmental science, atmosphere environment. His research topics were monitoring of pollutants including the polycyclic aromatic hydrocarbons in the atmosphere, outdoor and indoor air quality, chemical sensitivity, nanomaterial characterization in factory, nanomaterial toxicology, human health estimation of environmental tobacco smoke, estimation of the health effect at toluene exposure, and so on. He is interested in the wide area pollutions as such yellow sand and he has been energetically investigating it recently.

Prof. Dr. Ayşe Balanlı, Author of Chapter 7 and co-author of Chapter 20

Prof. Dr. Ayşe Balanlı is currently a fulltime Professor in Department of Architecture, Faculty of Architecture, Yildiz Technical University, Istanbul, Turkey. She studied in I.D.G.S.A (Istanbul State Academy of Fine Arts) Department of Architecture, got her bachelor and master's degree in the same university in 1973. She started her academic career in 1975 as a research assistant at I.D.M.M.A. (Istanbul State Academy of Engineering and Architecture), Department of Architecture. She has concluded her PhD studies in 1981 in the same university. In 2006 she was appointed Professor at Yildiz Technical University. She has developed and taught a course for postgraduate and doctoral students about Building Biology for first time in Turkey in 1983 and also she has taught a number of other graduate and post graduate courses including "Architectural Design Studio 2", "Application Project 1", "Building Elements 1", "Building Elements 2", "Product Selection Methods 1", "Product Selection Methods 2", "Seminar", "Methodology". She has been and is advisor of many master and doctoral students. She has also been on the juries of many master and doctoral thesis. She has many articles and papers in international and national journals, conferences, seminars about building biology, product selection methods, building materials, building components, indoor air quality and architectural education and she has written two books: Yapı Biyolojisi – Yaklaşımlar (Building Biology – Approaches) and Yapıda Ürün Seçimi (Product

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Andrew Clements, Co-author of Chapter 21

Andrew Clements is a PhD student at the University of Bedfordshire, UK. His research programme focuses on issues relating to the commitment of students training for vocations such as nursing and social work. Other research interests include wellbeing, and organizational and professional cultures. He is also a member of the UK Psychology Postgraduate Affairs Group (PSYPAG) committee as a Section Representative.

Prof. Derek Clements-Croome, Author of Chapter 13

Professor Derek Clements-Croome is founder of the MSc Intelligent Buildings Course at the University of Reading originally funded by EPSRC. The second edition of the book *Creating the Productive Workplace* (Clements-Croome 2000) was published by Routledge in 2005. The book *Intelligent Buildings* (Clements-Croome 2004) became available in 2004 and is also available in Chinese since 2006.

He has a portfolio of many projects including sustainability, building facades, system reliability, building rating methodology (recently with the University of Dundee and Hilson Moran) and design quality (including ventilation) in schools and the effects of design on students learning. All these projects were funded by EPSRC/former DTI. He works in China, Sudan, Hungary, Finland and other countries.

He was Vice-President of CIBSE in 2005–2007 and chairs CIBSE committees on Intelligent Buildings that has over 3,000 members from over 118 countries, and Natural Ventilation of a similar size. He is a member of the College for Engineering and Physical Sciences Research Council (EPSRC) and also has served on the Dynamics of Ageing Panel for the Economics and Social Sciences Research Council.

He was President of National Conference of University Professors in UK in 2006–2008. He is founder and Editor of the peer reviewed journal *Intelligent Buildings International* published by Earthscan since 2009. He is also a member of the UK Green Building Council and sits on the Board for the British Council for Offices.

He is an amateur violinist and violist.

Dr. Omur Cinar Elci, Author of Chapter 22 and co-author of Chapter 23

Dr. Omur Cinar Elci has 25 years of public health, epidemiology, and occupational health field experience and over 15 years of research and teaching experience including funding from National Institutes of Health (NIH) and Center for Disease Control (CDC). While residing in Izmir, Turkey, Dr. Elci received a Doctor of Medicine (MD) from Ege University, School of Medicine, 1986, a Certificate of Occupational Health Practice from Turkish Medical Association, 1988 and a PhD in Public Health from Dokuz Eylul University, School of Medicine, Health Sciences Institute, Department of Public Health, 1997. He was awarded the Fogarty post-doctoral fellowship in occupational epidemiology from National Institutes of Health, National Cancer Institute, Division of Cancer Epidemiology and Genetics, Occupational Epidemiology Branch, Rockville, MD, 2001.

Dr. Elci's teaching career began in 1997 as an instructor and a trained problem based learning tutor at Dokuz Eylul University, School of Medicine, Department of Public Health, Izmir, Turkey. Upon completion of his post doctoral fellowship in 2001, Dr. Elci took a position with the CDC, National Institute for Occupational Safety and Health, Division of Respiratory Disease Studies as Epidemiologist, and was promoted to Branch Epidemiologist in 2003 with the Health Effect Laboratory Division, Exposure Assessment Branch, both located in Morgantown, WV.

Over the course of his career, Dr. Elci has received several awards including the Bullard-Sherwood Research to Practice award, CDC, 2008. He is currently employed by St. George's University as Professor and Chair of the Department of Public Health and Preventive Medicine.

Dr. Eva Gallego, Author of Chapter 16

Eva Gallego, Environmental Sciences, Graduated and PhD by the Universitat Autònoma de Barcelona (UAB). She developed her PhD research in the Consejo Superior de Investigaciones Científicas (CSIC), Spain, in the distribution and the processes that experience natural and anthropogenic pollutants in the ecosystems. Since 2006 Eva has been working in the Laboratori del Centre de Medi Ambient (LCMA), of the Universitat Politècnica de Catalunya (UPC), specializing in chemical air quality research. She also develops different educational activities in the UPC in the areas of chromatography and chemical detection of odours. She has a permanent collaboration with the National Centre for Working Conditions (CNCT) from Barcelona, of the National Institute of Safety and Health (INSHT, Ministry of Labour of Spain), within the program of Environmental and Biologic Analysis for the development of scientific work in the atmospheric environmental area. Dr. Gallego has published 9 referred international journal articles and 4 chapters in books. The publications covered both indoor and outdoor air quality as well as methodologies to determine the origin of odours and chemical pollutants through chemical analysis of pollutants, social participation and numerical modelling. She has worked in 10 research projects, both European and National, and has also participated in 14 projects with special relevance with companies and/or private or public funding bodies. Her research interests are the assessment of pollutants in the atmosphere through chemical control and a posterior modelling of air quality in urban, industrial and rural zones. Indoor air quality, sick building syndrome and multiple chemical sensitivity are also topics of her concern.

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Radha Goyal is currently employed as *Fellow Scientist* at Delhi Zonal Laboratory of National Environmental Engineering Research Institute (NEERI), one of the prestigious laboratories under Council of Scientific and Industrial Research (CSIR), India. She is an *Environmental Scientist* having experience in air pollution and health with special emphasis on indoor air quality and exposure assessment. She received her doctoral degree from Department of Civil Engineering, Indian Institute of Technology Delhi in year 2009 and master's degree from G.G.S. Indraprastha University, Delhi in year 2001. Dr. Radha has published more than 7 articles in international journals of repute and 3 chapters in books. She has presented more than 10 papers in various international and national conferences, seminars and workshops. Her publications are on various environmental issues such as biological treatment technologies for industrial wastewaters, rainwater harvesting, studying properties of fly ash for its reuse as a land filling material, indoor air pollution, health etc. Her research interests are mainly in area of air pollution monitoring, modeling and exposure assessment, climate change and sustainable development.

Dr. Gustavo Silveira Graudenz, Author of Chapter 18

Gustavo Silveira Graudenz Graduated in medicine in 1991, finished medical specialization in allergy and immunology in 1998. Gets the PhD degree from the University of Sao Paulo, Brazil in 2002, in indoor pollution exposure in office buildings. Finishes post-doc in the University of Sao Paulo in a multidisciplinary work on temperature changes exposure to allergic groups in 2006. Clinical Associate Professor of Medicine (immunology and microbiology division), Nove de Julho University in Sao Paulo since 2010.

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Hülya Gül has been working in the Department of Public Health in Medical Faculty, Istanbul University. She got her PhD degrees in preventive oncology and public health from Istanbul University Medical Faculty in 1995 and 2002, respectively. She studied at the Occupational Studies Section of National Cancer Institute in National Institute of Health in USA for a term in 1992. She has been actively involving in research on environmental and occupational health. She is the author of about more than 80 papers in national and international journals and conference proceedings. She has taken 20 projects from the Research Fund of the University of Istanbul and other sources. She has five scientific awards. She is a member of national and international commissions and working groups on industrial safety and environmental health. Her major areas of interest are the chemical and psychological risks in the work environment, risk assessment and management, environmental epidemiology, indoor and outdoor air quality, occupational cancer epidemiology etc.

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Adj. prof. Valtteri Hongisto is a senior research scientist in Finnish Institute of Occupational Health in Turku. Dr. Hongisto works in the indoor environment group which is specialized in acoustic, ventilation and lighting design in office environments. His main task is to create and manage large national applied scientific research projects which aim at better indoor environment in workplaces and at better indoor environment products. Dr. Hongisto has published more than 20 scientific journal articles including peer-review process and, altogether, more than 200 scientific articles. The publications cover room acoustics in workplaces, sound insulation of structures and psychological effects of noise in office environments. The secondary occupation is an adjunct professor and a lecturer of building acoustics in the Aalto University in Helsinki.

Yoshiharu Imai, Co-author of Chapters 6, 14 and author of Chapter 17

Yoshiharu Imai is director of Applied Information Technology Laboratory. He is co-researcher of Dr. Nami Imai's research especially analysis and supports her research from engineering point of view. He researched mainly about reduction of toxic chemicals in indoor air and it was described in "Specifying the Source of the Indoor Air Formaldehyde Contamination and Verifying the Effectiveness of the Radical Measures to Improve the Indoor Air Condition" in 2007. He has a wide field of activity such as technology consulting, technical writing, professional engineer training and translation especially treatise including Dr. Nami Imai's work. His research interest is prevention of IT engineers' death from overwork. He attempts to approach his goal by developing tools for project management such as cost estimation and quality admeasurement tools of software and is researching them at Division of Information Engineering, Graduate School of Engineering, Mie University.

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Nami Imai is currently an Associate Professor in the School of Nursing Faculty of Medicine, Mie University in Japan. She was a registered nurse experienced in surgical unit and emergency unit at Mie University Hospital in Japan. She received her doctorate from Osaka University, Japan in 2005. Her teaching experience is in the areas of human anatomy and structure, basic nursing concepts, nursing theory and nursing process, science and art in nursing and clinical ecology nursing. She is an active researcher in a field of human actions related the environment, and she talked about her researches at IPP-SHR interview at 2008 (listen to the web-site; IPP-SHR, podcast #52). Dr. Imai is managing to the Nursing Counseling Room (NCR) in the city of Tsu, Mie, Japan from 2006. Her research interest are pattern of behavior of sick building syndrome (SBS) and multiple chemical sensitivity (MCS) patients, expansion of nursing with SBS and MCS, establish the clinical ecology nursing. She became a mother of a baby boy at October 2009, and she became increasingly active for the future and health of human beings and also for her son.

Dr Janis Jansz, Author of Chapters 1, 2 and 30

Dr Janis Jansz, RN., Dip.Tch., BSc, Grad.Dip. OHS, MPH, PhD, FSIA is employed as a Senior Lecturer in Occupational Health and Safety Environmental Health at Curtin University and has an Adjunct Senior Lecturer appointment at Edith Cowan University in the School of Management. Since 1996 Janis has been the Director of the International Labour Organisation (ILO) Communications, Information, Safety (CIS) Centre in Western Australia. She has been a member of the Executive Committee of the Safety Institute of (Western) Australia Inc. from 1990 and was the first female President from 1997 to 2000. Janis was Editor of the Australian National Safety Journal from 1994 to 2000. She was awarded the "Safety Institute of (Western) Australia Inc. Member of the Year" in 1994 and in 1999 for her professional work in improving occupational safety. Dr Jansz is a Member of the Curtin Health Innovation Research Institute, the World Health Organisation Collaborating Centre for Environmental Health Impact Assessment, Centre for Research in Entertainment, Arts, Technology, Education and Communications and a Member of the Curtin – Monash Accident Research Centre. Since 1988 Janis has been a Member of the Occupational Health Society and is currently an Executive Committee Member of this organisation. Since 1997 Janis has been Director, World Safety Organisation National Office for Australia, Member of the Board of Directors for World Safety Organisation and Editor of the World Safety Journal from 2002. She continues to hold all of these positions. In 2005 Dr Jansz was awarded the World Safety Education Award for her contribution internationally to providing occupational safety and health education. In recognition of her professional work improving occupational safety and health world-wide through her teaching, research and professional work in improving occupational safety and health Dr Janis Jansz was presented with the award of 'World Safety Person of the Year at the World Safety Conference in the United States of America in 2001.

Dr Jansz began her career working as a registered nurse where she cared for people who were ill, injured and people who died. She enjoys working as an occupational safety and health professional because she has the opportunity to improve people's health, the work environment, work processes, management and business profitability while preventing people from becoming ill, injured or dying due to work related causes. Dr Jansz appreciates being able to share occupational safety and health knowledge with other people through teaching, research and writing activities. Author of over 100 journal articles, textbook chapters and conference papers she has written the distance education material for 18 units of occupational safety and health study for two universities. Research and teaching activities are centred on Occupational Safety and Health Management, Ergonomics, Communicable Disease Control, Health Promotion, Safety Inspections, Audits and Risk Management, Accident Prevention and on developing Safety Management Plans, Occupational Safety and Health Policies, Procedures and Programs.

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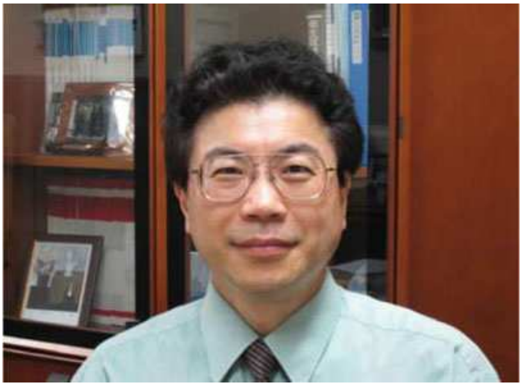
Dr Xiuling Ji is currently an Assistant Professor in the School of Mechatronics Engineering at Beijing Institute of Technology in China. She received her doctorate from Chinese Academy of Preventive Medicine in 2003. She has been actively involved in built environment research and her research interests are human responses to indoor and outdoor thermal environment, CFD simulation of indoor flow fields, heat and mass transfer modelling and environmental impact assessment.



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Mukesh Khare is a full time professor at Department of Civil Engineering, Indian Institute of Technology Delhi since 1990. He is a National Merit Scholarship holder, is graduate in Civil Engineering (1977) and Master in Civil Engineering (1979) with specialization in environmental engineering from the University of Roorkee. Dr. Khare received his doctoral degree in Environmental Engineering from the Newcastle University, UK in 1989, sponsored by the Ministry of Education, Government of India under their National Scholarship programme. Prior to joining IIT Delhi in 1990, Dr. Khare worked as Assistant Environmental Engineer in Uttar Pradesh Pollution Control Board. Subsequently, he was a fellow to CSIR at the National Environmental Engineering Research Institute (NEERI) at Nagpur. He is recognized consultant to many Indian and International bodies e.g. Central Pollution Control Board, Oil & Natural Gas Commission, National Thermal Power Corporation, Nuclear Power Corporation (India); Associates in Rural Development, Virginia, USA. He is a member of Board of Directors in Hindustan Copper Ltd. Dr. Khare has published more than 40 research publications in International & National refereed journals and conferences. He has been offered visiting faculty positions to many university/institutes abroad that includes the Asian Institute of Technology, Bangkok, University of Technology, Lae, Papua New Guinea and University of Swaziland, Southern Africa. Dr. Khare is listed in several prestigious biographical sources published by the American Biographical Institute, USA and International Biographical Centre, UK. His areas of interest are: Air Pollution, Dispersion Modeling, Indoor Air Quality, and E.W.T.

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Dr Gail Kinman is Professor of Occupational Health Psychology at the University of Bedfordshire, UK. She is a Chartered Psychologist with the British Psychological Society, a Chartered Scientist, a member of the American Psychological Association and a Fellow of the Higher Education Academy. Dr. Kinman received her doctorate from the University of Hertfordshire, UK for a dissertation that examined well-being and work-life balance in academic employees working in UK universities. Her primary research interests focus on work-related stress, work-life balance, emotional labour and emotional intelligence and how they relate to the wellbeing of employees. Dr. Kinman is currently working with groups of health and social care professionals with a view to enhancing their resilience and wellbeing. Other research interests include lay theories of health and illness and aspects of psycho-oncology, including the role played by health-related cognitions in the wellbeing of cancer patients, and how people with cancer might be best supported in their return to work. She has published numerous journal articles and written several book chapters on these topics. Dr. Kinman's work is regularly presented at national and international conferences. She is a member of the BPS Press and Media Committee which aims to promote psychology to the lay public and speak regularly on behalf of the Society to radio, newspaper and magazine journalists.

Dr. Anne Korpi, Co-author of Chapter 19 and author of Chapter 24

Dr. Anne Korpi, Ph.D., Docent, is a Research Specialist at University of Eastern Finland, Kuopio, and currently holds an Indoor Environmental Specialist position at Halton New Ventures Business Area in Helsinki, Finland. Her research interest has addressed exposure and health risk assessment of indoor air contaminants, particularly microorganisms, allergens, MVOC, and SVOC. She has published about 30 peer reviewed articles in international scientific journals and conference proceedings and about 60 other publications.

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Naoki Kunugita is currently a Director in the Department of Environmental Health, National Institute of Public Health in Japan. He graduated from School of Medicine, University of Occupational and Environmental Health (UOEH) in 1985 and received his doctorate from UOEH, Japan in 1991. He is studying and teaching in the areas of environmental health, occupational medicine, public health and radiation biology. Recently he and his colleagues have published many papers about not only chemical analysis of indoor air quality but also biological effects in animals exposed to low dose of volatile organic compounds. He has served as a member of the board of directors of "Society of Indoor Environment, Japan" and "Japan Society of Risk Management for Preventive Medicine"

Dr. Mariasanta Montanari, Co-author of Chapter 11

Dr. Mariasanta Montanari Graduated in Natural Sciences at "La Sapienza" University of Rome in 1970. From 1974 to 1989, she has been Researcher at the biological laboratory of the ICPL with duties of scientific research with the aim of preserving, safeguarding and restoring cultural heritage. Purpose of the work was to find links between bio-deterioration, the nature of the materials and interactions existing with microclimate variations. From 1989 to 1991, she has been in charge of the biological sector of the Restoration Laboratory at the "L. Pigorini" National Prehistoric and Ethnographic Museum, studying the problems of bio-deterioration of ethnographic materials, storage conditions and the disinfecting and disinfestations systems suitable for use in museums. From 1991 to 2003, she has been director of the museum's Conservation and Restoration Laboratory, as well as co-coordinating restoration work and policy-making as regards the display and transportation of objects. Since 2003 up to now, she is the director of Biological Laboratory of the ICPL (now ICPAL) with duties of scientific research and consulting on bio-deterioration problems of cultural heritage. She is also a University lecturer at the "Accademia di Belle arti" of Bologna.

Dr. Milos Nedved, Author of Chapter 28

Dr. Milos Nedved is now a full time safety consultant, whilst holding an adjunct assoc. Professor appointment at the School of Management, Edith Cowan University in Western Australia. Previously he held several senior academic appointment including two professorial positions at European universities. He has also worked as a United Nations Expert in occupational safety and health, attaining the highest professional level in the United Nations system, that of Chief Technical Advisor. He is the author of over 150 journal articles, conference papers and a number of textbook chapters. In the early part of his career, he spent 15 years in the chemical industries of several European countries. He has been widely lecturing overseas, and delivered conference papers and/or run training courses in the USA, Czechoslovakia, England, Federal Republic of Germany, Philippines, Thailand, Indonesia, Hong Kong, Japan, China, Singapore and Malaysia.

Dr. Dan Norbäck, Co-author of Chapter 8

Dan Norbäck is currently an Associate Professor in Occupational and Environmental Medicine, at Department of Medical Sciences, Uppsala University. It is combined with employment at the University Hospital in Uppsala, Sweden. His main research field is environmental epidemiology and indoor exposure assessment. The focus has been on associations between indoor environmental exposure and health in children and adults, especially asthma, respiratory health, allergy, and sick building syndrome (SBS). The exposures have included various chemicals, VOC, microbial compounds, moulds, bacteria, allergens, particles, building ventilation and indoor climate. Various indoor environments have been studied, e.g. dwellings, schools, day care centres, offices, hospitals, hotels, and the cabin environment in aircraft. Some studies have covered respiratory health in relation to outdoor air pollution and dietary factors, as well as early life exposure. Comparative epidemiological school environment studies have been performed in many countries in Europe and Asia. He has a basic university education in chemistry, especially analytical chemistry, biology, and environmental science at Uppsala University, and a governmental education in safety engineering at the Swedish Labour Inspectorate. He has been teacher at the course in occupational and environmental medicine for medical doctors at Uppsala University. He received his doctorate in 1990 from the Medical Faculty at Uppsala University with the title "Environmental exposures and personal factors related to sick building syndrome". He has published more than 200 original articles in international journals with peer review and around 30 scientific book chapters or review articles. He has been main tutor for seven doctoral theses, and co-tutor for three doctoral thesis, and chairperson at various workshops and international scientific conferences. Member of several international scientific co-operation projects within the European Union, including the European Health Respiratory Survey (ECRHSII), aircraft environment (CABINAIR), indoor environment in nursing homes for elderly (GERIE), and three school environment projects (HESE, HESEINT and SINPHONIE). Bilateral co-operation with researchers in Norway, Iceland, Slovenia, Iran, China, Korea, Malaysia and Japan, mainly on epidemiological studies in relation to the school and the home environment.

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Armando C. Oliveira is Head of the New Energy Technologies Research Unit, which exists within the Institute of Mechanical Engineering – FEUP (Faculty of Engineering of the University of Porto). He has coordinated and participated in 13 European research and development projects related to the development of new and sustainable energy systems, especially solar thermal systems (heating, cooling and CHP systems). Nowadays, he is Secretary-General of the World Society of Sustainable Energy Technologies and co-responsible for the conference series on Sustainable Energy Technologies, with several editions held in Europe, Asia and America.

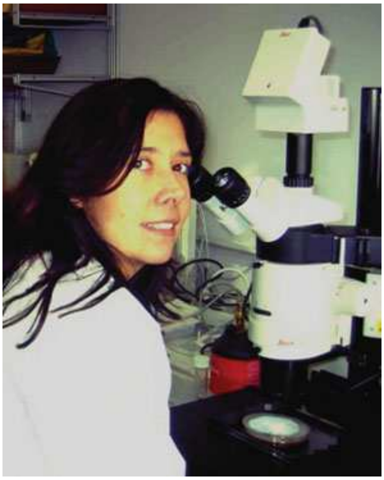
He is Executive Editor of the Int. Journal of Low Carbon Technologies (Oxford University Press, UK) and member of the Editorial Board of the Int. Journal of Ambient Energy (Ambient Press Ltd, UK). He is a Member of the Engineering and Physical Sciences Research Council Peer Review College (UK).

Prof. Dr. Jose Antonio Orosa Garcia, Author of Chapter 27

Jose Antonio Orosa Garcia is a PhD in Marine Engineering and graduated in Marine Engineering and Naval Architecture from the University of A Coruña. His research is related to indoor ambiences and energy saving. In the recent past, he has participated in the International Energy Agency Annex 41 and collaborated with the University of Porto in research on energy saving and work risk prevention in indoor ambiences. Presently, he is Professor of HVAC and Head of the Department of Energy and Marine Propulsion of the University of A Coruña (Spain). He is a member of the Society of Naval Architects and Marine Engineers (SNAME) and ASHRAE.

Dr. José-Francisco Perales Lorente, Co-author of Chapter 16

José-Francisco Perales Lorente, PhD., an Industrial Engineer, has been associate professor at the Polytechnic University of Catalonia (UPC) and is accredited as lector professor in engineering for all Catalan Universities. He is currently developing its research activity at the Laboratory of Environmental Centre (LCMA/www.upc.edu/lcma/) in air quality mathematical modelling. Dr. J-F Perales is also a member of a consolidated research group at the Science and Technology Ministry of Spain. He is currently studying the incidence of odour episodes caused by volatile organic compounds (VOC) under a very complete prospective that includes: the characterization of VOC emissions (chemical characterization), the transport of the pollutants through air dispersion, and the study of VOC immission levels throughout the validation of the modelling results using field work and social participation. Dr. Perales has managed several European projects on environmental topics and in renewable energy areas (pyrolysis and gasification of coal, biomass and waste materials) with international partnership, and national and regional projects under the state and autonomic governments. He has also developed technologies and modelling in fluidization (fast and bubbling fluidization) for multi-size particle distribution applied to pyrolysis and gasification reactors, and in kinetics and thermal studies of combustible materials.



Dr. Flavia Pinzari, Author of Chapters 9 and 11

Dr. Flavia Pinzari is a biologist specialised in mycology and applied microbiology. Is Researcher at the Laboratory of Biology at the Central Institute for Restoration and Conservation of Archival and Documental Cultural Heritage (ICPAL, Ministry of Cultural Heritage, Italy), and Contract Professor of Microbiology at the University of Tor Vergata in Rome. She received her doctorate in Ecological Sciences from the University "Sapienza" of Rome and she specialized in Plant Biotechnologies at the University of Pisa (Italy) and in Chemistry of the Organic Natural Products in Rome. Her teaching experience is in the areas of ecology, microbiology, biodeterioration of cultural heritage, applied mycology, and statistics applied to biological sciences. Dr F.Pinzari has extensively published international journal articles on mycology and biodeterioration and biodegradation of organic materials, as well as several educational and technical issues. Her research interests are currently focused on early detection of fungal and microbial contamination in the indoor environment, indoor air quality, scanning electron microscopy techniques applied to the study of biodeterioration phenomena, microbial ecology in manmade environments.

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Dr. Shelly Rodrigo, Co-author of Chapter 22

Dr. Shelly Rodrigo, BSc, MSc, M.Phil., PhD is employed as an Assistant Professor in the Department of Public Health and Preventive Medicine at St. Georges University, Grenada. She has written material for Epidemiology and Population Health for Medical and Biomedical students. She has over 8 years teaching at the College and University levels and in 2009 was recognized by the Medical students with the receipt of a Teaching Excellence Nomination (Monash University). Dr Rodrigo specializes is Environmental and Infectious Disease Epidemiology. She is the author of several journal articles and conference papers specializing in public health risk of zoonotic pathogens, waterborne illness and emerging infectious diseases. Her research and teaching activities include Epidemiology, Emerging Infectious Diseases, and Data Management and Analysis. She is a member of the Australasian Epidemiological Association and the American Public Health Association.

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Berndt Stenberg, MD, PhD, is currently Professor in the Department of Public Health and Clinical Medicine, Umeå University, Sweden. He is an occupational dermatologist with special interest in health problems associated with indoor air quality.

He presented his thesis "Office Illness – the Worker, the Work and the Workplace" in 1994 and has a PhD in epidemiology. Besides indoor air quality research, he is conducting studies in the fields of contact dermatitis and quality of life in skin disease. He is a senior lecturer at the medical faculty of Umeå University teaching medical students, nurses, occupational therapists, dental medical students and environmental inspectors. Within the Swedish Dermato-Epidemiology Network (SweDEN) he is giving courses in epidemiology and biostatistics for dermatologists. He is a member of the Swedish Contact Dermatitis Research Group since more than 20 years. Dr. Stenberg has published about 60 peer-reviewed papers in international journals and around 12 chapters in books. He is a member of the Editorial Board of INDOOR AIR, International Journal of Indoor Environment and Health since 2005 and he has served as guest editor of a special issue of INDOOR AIR in 2004.

Dr. Moroko Takaoka, Author of Chapter 8

Motoko Takaoka is currently an associate professor in the Department of Biosphere Sciences, School of Human Sciences, Kobe College in Japan. She is a biochemical experienced in food sciences fields. She received her doctorate from Kobe University, Japan in 1992. The main aim of her research is to study the association between environmental factors and asthma/allergy among the young generation. There has been a global increase of asthma and allergies, especially in the younger generations in industrialized countries. There is little information on association between school and home environmental factors and asthma/allergy in Japan. Her research objectives are to clarify the school environmental risk and protective factors for asthma, airway infections, pollen allergy, furry pet allergy, food allergy and mold allergy among school students.

Eng. Tarja Takki, Co-author of Chapters 4, 24 and author of Chapter 19

M.Sc. (Eng.) Tarja Takki is a Director of New Ventures Business Area at Halton Group. She has worked in international planning, development and management positions in HVAC design and manufacturing industry especially in Finland and in the USA. In 2001 she founded a company that launched a tenant centric and holistic indoor environmental management program for offices to enhance worker wellbeing and productivity. Currently, she directs Halton New Ventures Business Area that develops, markets and delivers tenant driven and sustainable indoor environmental solutions for commercial buildings.

Ph.Lic. Kirsi Villberg, Co-author of Chapters 4, 19 and 24

Ph.Lic. Kirsi Villberg, is currently Director of Halton Solution at Halton Group in Finland. Her research experience is indoor air quality and correlations between VOCs and building related symptoms. She has published several referred international journal/conference articles covered indoor air quality. In previous jobs, she has worked over 8 years as a researcher at Technical Research Center of Finland and about 4 years as a scholarship researcher at University of Jyvaskyla.

Maija Virta, Co-author of Chapter 24

M.Sc. Maija Virta works currently as CEO at Green Building Council Finland. Her main responsibilities are HVAC-systems for green buildings and also innovative and energy efficient indoor environment solutions. Maija Virta is a vice-president of the Federation of European Heating and Air-conditioning Associations (REHVA). She is also the president of the Finnish HVAC-association (SULVI) and a member of ASHRAE. Maija Virta has contributed to the development of chilled beam technology and applications over two decades. She was the main author of REHVA's Chilled Beam Application Guidebook No. 5. Maija Virta has been a lecturer in many international workshops and she has presented technical papers in several conferences covered wide area of HVAC-technology, energy efficiency and indoor environmental quality. She is also an author of many technical articles in various international HVAC-magazines.

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Assist. Prof. Dr. S. Müjdem Vural is currently a fulltime lecturer in Department of Architecture, Faculty of Architecture, Yildiz Technical University, Istanbul, Turkey. She was born in Istanbul (Turkey) in 1972; she studied in Yildiz Technical University Faculty of Architecture, and started her academic career as a Research Assistant at Yildiz Technical University, Department of Architecture. She has concluded her master's studies in 1997 and got her PhD Degree in 2004 with thesis entitled "Risk Assessment in Indoor Air Quality" from the same university. In 2006 she was appointed Assistant Professor at Yildiz Technical University. She was a visiting scholar in Virginia University, School of Architecture during 2005 for a semester. She was the advisor of the graduate and last year student project EcoMod, Ecological Modular House for low-income people. She has taught a number of graduate and post graduate courses including "Architectural Design Studio 2", "Application Project 1", "Building Elements 1", "Building Elements 2", "Building Biology", "Indoor Air Quality" and she has been and is on the jury of number of master and doctorate students. She was in the design group of the Building for the YTU Faculty of Civil Engineering at Davutpaşa Campus. She was the advisor for the EcoMod project (held in University of Virginia), which was awarded in the USA. She was also the advisor for the student team in the Competition for Ecological Hotel in Ilgaz, Turkey and the design was awarded for the second prize. She has served as a jury member for national architectural competitions. She has many papers in international conferences and journals about building biology, indoor air quality, LCA models and architectural education. She has been in UPV-Spain, TU/e – Netherlands, School of Architecture, Amsterdam – Netherlands, ESA-France, Brno Technology University-Czech Republic, Ecole Nationale Superieure d' Architecture de Lyon-France, on behalf of LLP-Erasmus Teaching Staff Mobility program to give lectures and as the Erasmus Coordinator for the Department of Architecture had some meetings. Currently she is holding the titles Vice Head of the Architecture Department and Erasmus Coordinator of the Architecture Department. She is a Member of the CIB task group WorldWide Healthy buildings (TG77).

Dr. Yufeng Zhang, Author of Chapter 29

Dr. Yufeng Zhang is currently an Associate Professor in the Department of Architecture at South China University of Technology in China and the director of Building Environment and Energy Efficiency Laboratory at State Key Laboratory of Subtropical Building Science. He received his doctorate from Tsinghua University in 2006. He has been actively involved in built environment research and his research interests are human responses to indoor and outdoor thermal environment, building energy efficient technologies, heat and mass transfer experiment and modelling and building & urban simulation. In 2008 he achieved the Best Paper Award of Journal of Building and Environment.

Chapter 1
Introduction to Sick Building Syndrome

Janis Jansz

1.1 Introduction

> I've been experiencing frequent headaches since I started working in an office again – and it very well could be a combination of factors – ergonomics/eyeglasses/different stressors working with home/school/work schedules (!)... but given that we live in a 'drafty' house and spend quite a bit of time outdoors normally, am not usually exposed to concentrations of emissions from electronic equipment/chemicals, from carpets/ furniture/perfumes (!) etc. I've had my suspicions and would be interested in what our building/room concentrations would be.... Is our building a 'sick building'? Am I suffering from Sick Building Syndrome? Jane.

The above request was sent from an employee. Jane asked a question that other people have asked. Like many people Jane has heard of Sick Building Syndrome, but was not sure if her ill health effects were due to factors in the building that she works in, or not. What triggered Jane asking this question was that she had just read the following article sent by email to her by a work colleague.

May 18, 2010 (The Straits Times). Indoor polluted air kills 2 m Chinese youths yearly. Half are below age five; threat from harmful chemicals in furniture flooring.

> BEIJING: More than two million Chinese youths die each year from health problems related to indoor air pollution, with nearly half of them under five years of age, state media cited a government study as saying. The study released by the China Centre for Disease Control and Prevention (CCDCP) said indoor pollution levels can often be five to ten times higher than those measured in the nation's notoriously bad outdoor air, reported the China News Service (CNS). This indoor pollution causes respiratory and other conditions, said the study released on Sunday. According to the study, dangerous indoor pollutants include formaldehyde, benzene, ammonia and radon, reported the Agence France-Presse news agency. Among the pollutants, formaldehyde posed the biggest threat, the study said, adding that the chemical is often found in building materials and new furniture in China and can be released slowly into indoor environments over the course of several years. The study said long-term

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S.A. Abdul-Wahab (ed.), *Sick Building Syndrome*,
DOI 10.1007/978-3-642-17919-8_1,

> exposure to such substances can cause a range of health problems including respiratory diseases, mental impairment and cancer, including leukaemia, with young children, foetuses, pregnant women and the elderly at most risk.
>
> China's Ministry of Science and Technology has listed the management of indoor air pollution problems as one of the priority areas on which it would devote intensive research, reported the CNS. The ministry also announced in the study that households could now use a purifier developed by the CCDCP for removing formaldehyde from indoor air as it has been proven to produce results. The environmental bureau of Shijiazhuang, capital of northern China's Hebei province, recently advised its residents to be careful of materials used to design their houses as these might be the cause of their daily discomforts such as dizziness and fatigue. Construction materials, such as granite and marble, could be radioactive, or contain formaldehyde like in the case of laminate flooring and particle board, reported the Yanzhou Evening News, quoting the city government's notice.
>
> China's massive economic expansion of the past three decades has made it one of the world's most polluted countries as environmental and health concerns are trampled on, amid an overriding focus on industrial growth. Countless cities are smothered in smog while hundreds of millions of citizens lack access to clean drinking water. In a separate study by China's Interior Designers Association, more than 11 million Chinese are killed every year by diseases related to indoor pollution, which translates to 340 people per day, reported the Beijing News last week. 'Lung disease cases are growing by about 27 per cent a year in China because of deterioration in indoor environment, while about 80 per cent of leukaemia cases are related to air problems,' said the newspaper.
>
> Partly to make indoor air cleaner, China will ban smoking in all indoor public places starting next year, including offices and public transport, in accordance with a World Health Organisation convention. According to health ministry statistics, China now has 350 million smokers, mostly men. But smoking has also become a trend for young women. A 2007 World Bank report said 750,000 Chinese die prematurely each year due to air and water pollution - a figure edited out of final versions of the report, reportedly after China warned it could cause social unrest.

On the following day the China Centre for Disease Control and Prevention sent an email confirming that the above information was wrong and that the above report could no longer be found on the internet. This email stated:

> The Global Times newspaper reported that the 'misinformation' had been released by the manufacturer of an air filter developed by a CDC agency. A news conference was held on Sunday to publicize the filter. 'We didn't announce any survey results on Sunday. Some worker made the mistake on a news release,' Mr He Jiukun, an official from the environment department of the CDC, told the Global Times. A worker at the Standardization Administration told the newspaper the health guidance centre does not exist.

However, reading this article had triggered Jane's question "Am I suffering from Sick Building Syndrome?" What information would you need to answer Jane's question? How would you obtain the knowledge to answer this question?

This book is about Sick Building Syndrome. It provides information about how the term Sick Building Syndrome originated, many factors that have been associated with Sick Building Syndrome including causes and risk control measures. The Editor of this Book is Prof. Dr. Sabah Ahmed Abdul-Wahab. She conducted a research study to identify if a library building was a "Sick Building" and found that there was a need to publish a book for people worldwide to read that provides information, in a language that is easy to understand, about Sick Building

Syndrome. Prof. Sabah Ahmed Abdul-Wahab contacted experts in the field of Sick Building Syndrome from around the world to write individual chapters in their area of expertise for this book. To be able to answer Jane's question there is a need to have a definition of Sick Building Syndrome.

1.2 Definitions of Sick Building Syndrome

A syndrome is a collection of signs or symptoms of ill health. A building is a constructed enclosure with walls, a roof, doors and windows. A building is constructed to protect people and/ or objects from the outdoor climate. Many people work, or have a home, in a building. A person with ill health is sick. Buildings cannot really have ill health, but the indoor environment enclosed space can have airborne contaminants that do cause ill health in the people who work, or live, in the building.

Sick Building Syndrome has been defined by World Health Organisation (Hedge and Ericson 1996, p. 3) as "a collection of nonspecific symptoms including eye, nose and throat irritation, mental fatigue, headaches, nausea, dizziness and skin irritations, which seem to be linked with occupancy of certain workplaces."

Greer (2007, p. 23) states that "Sick Building Syndrome refers to a group of non-specific symptoms with a temporal connection to a particular building, but with no specific or obvious cause." Murphy (2006, p. 79) adds that the symptoms of Sick Building Syndrome are mostly minor, can vary with each episode of exposure and that there is no objective proof (such as would be shown in a blood test or by the finding of a particular substance on monitoring the air) available for Sick Building Syndrome. Sick Building Syndrome is defined by "the density of worker complaints." According to Murphy (2006) World Health Organization has defined this density as 20% of the building occupants presenting with the symptoms of Sick Building Syndrome. If the cause of Sick Building Syndrome is located in one office, or only by one machine that is used by only a few of the building occupants, defining Sick Building Syndrome affecting 20% of the building occupants may not be appropriate.

TSSA (2010, p. 1) records that Sick Building Syndrome is "a generic term used to describe common symptoms which, for no obvious reason, are associated with particular buildings." Similarly Milica (2009. p. 80) describes Sick Building Syndrome as "an environmentally related condition with increased prevalence of non-specific symptoms among the population of certain buildings, often without clinical signs and objective measures of symptoms."

The Environmental Illness Resource (2010, p. 1) quotes the Environmental Protection Agency (EPA) as identifying Sick Building Syndrome being present if:

- Symptoms are temporally related to time spent in a particular building, or part of a building
- Symptoms resolve when the individual is not in the building
- Symptoms recur seasonally (heating, cooling)
- Co-workers, peers have noted similar complaints.

The Environmental Protection Agency (2010) states that the symptom complaints may come from employees throughout the whole building, one department, one room or one location. The cause of Sick Building Syndrome is thought to be the building and/or its services and/or equipment and/or products used in the building. The symptoms of sick building syndrome are relieved within in minutes to hours of leaving the building.

On the Google internet site there are 37,000 definitions of Sick Building Syndrome. A common theme that comes from these definitions of Sick Building Syndrome is that people develop ill health effects due to being in a specific building, or part of a building. If a cause of the health effects is identified, such as happened with Legionnaires' disease [1st documented case occurred in 1947 (Chin 2000)] that is caused by the gram negative bacilli *Legionellae* which can live in air conditioning system cooling towers, evaporative condensers and in water from hot and cold water taps, then it is no longer Sick Building Syndrome, but is called an illness caused by a specific microorganism, chemical, or other known factor.

This is similar to when only Hepatitis A (in which the infection to people is transferred from contaminated food, water and other people via the faecal oral route) and B (in which the infection to people is transferred from other people's infected blood, other body fluids or other body tissues) were identified as being caused by a specific microorganism. Any other forms of Hepatitis were called non A non B Hepatitis as the microorganism causing other forms of hepatitis was unknown, even though people were becoming sick due to infection by these microorganisms. As an identified microorganism caused Hepatitis A and caused Hepatitis B a vaccine was able to be developed for Hepatitis A and for Hepatitis B. The next form of Hepatitis microorganism identified was Hepatitis C. This blood borne form of Hepatitis is now the most commonly known form of Hepatitis transmitted by intravenous drug users (Carruthers 2010). The cause of this infection was only diagnosed in the late 1990s (Chin 2000). Hepatitis D (which is caused by infected blood and other body fluids and only coexists with Hepatitis B as the Hepatitis D virus is unable to infect the human cell by itself) and Hepatitis E (which has a similar cause to Hepatitis A) have now both been identified. The term non A non B Hepatitis is no longer used as the other forms of hepatitis are now known to be caused by the Hepatitis C, D and E virus. The same may happen with Sick Building Syndrome as the causes of building related ill health are gradually identified.

Many thousands of currently manufactured chemicals have not had their health effects tested and no effects of exposure studies exist for these chemicals. Odle (2010) records that, in 2010, there were more than 700,000 chemicals in common use in the world. Some of these chemicals may be a cause of what is currently called Sick Building Syndrome. Once the causes of the health effects related to Sick Building Syndrome are known, risk control measures can be implemented as has been done through occupational safety and health legislation related to preventing Legionnaire disease. As there is a different virus that causes each form of Hepatitis there may be a variety of causes of Sick Building Syndrome.

The methodology used to locate the above definitions and to obtain the information included in Chaps. 1, 2 and the last chapter of this book is described below.

1.3 Research Methodology

In 2010 a flyer was emailed out to Members of the Occupational Safety Profession who belonged to the Safety Institute of (Western) Australia Inc., to Members of the Occupational Health Society of Australia, to the Industrial Foundation for Accident Prevention Safety Practitioners' Club Members, to students attending the Technical and Further Education Institutions in Western Australia and to Curtin University Students to ask these people to send the author any stories that they had that were related to Sick Building Syndrome. About 700 people were contacted. This resulted in the author receiving 10 stories about sick building syndrome. Of these stories 6 were related to workplace buildings, 2 stories were related to employees' houses, one story was related to a barge on which employees worked and lived while the other story received documented some risk control measures to be used to prevent sick building syndrome. All of these stories have been included in either Chap. 2 or in the last chapter.

A review of literature related to sick building syndrome was conducted using OSH UPDATE. Eight hundred and fifty eight published literature works were identified. Included literature was limited to English language and literature published up to, and including, July 2010. This search was conducted using the key words "Sick Building Syndrome". Sixty two of the 858 publications identified and reviewed are cited in Chaps. 1, 2 and in the last chapter. The key words "Sick Building Syndrome" was typed into the search function on the legal web site www.austlii.edu.au. Twelve publications were obtained from this web site. Six of these publications are cited. A seminar on Sick Building Syndrome that was presented by the Australian Institute of Occupational Hygienist was attended. Information obtained at this seminar is included. The Curtin University library collection of books was searched for publications related to sick building syndrome with nine books, one Code of Practice and four Australian Standards being suitable to be included in the literature review. One of these books, *Sick Building Syndrome and the Problem of Uncertainty: Environmental Politics, Techno-science, and Women Workers* by Murphy (2006), was found to have a comprehensive description of the history of Sick Building Syndrome.

1.4 History of Sick Building Syndrome

1.4.1 Introduction

One of the earliest descriptions of unhealthy buildings and the risk control measures to be used is included in Chap. 14, verses 34–57 of the book of Leviticus in the Bible which was written in about 3,000 BC (Before Christ). In these verses the Israelites are told that if they think that there is the plague of leprosy in their house they are to report this to their priests. A priest then asks everyone to leave the house and checks the house walls. If the walls are greenish or reddish then the priest shuts the door and no one is allowed to enter the house for 7 days. The description of the greenish or reddish growths on the house walls is suggestive of mould. When the priest checks the house 7 days later, if the greenish or reddish growths on the walls has spread then the house is pulled down and the stones put in an unclean place outside the city. The house owners were then instructed to rebuild the house using new stones and to plaster the house walls to seal these walls.

If the people living in this rebuilt house also developed the plague of leprosy then the rebuilt house was to be pulled down and the building materials disposed of outside the city in an unclean place. The people who lived in this building were then instructed to wash their clothes and another house was not to be built on this piece of land. If the occupants of the rebuilt house did not develop leprosy, then the priest pronounced the house clean and the occupants could continue to live in this house after sprinkling the house 7 times with bird blood, running water, cedar wood, hyssop and scarlet.

The treatment for leprosy today is different. Today it is known that Leprosy is caused by the bacilli bacteria *Mycobacterium leprae*. This disease can be manifested as lepromatous leprosy or as tuberculoid leprosy. With untreated lepromatous millions of the microorganisms are spread through nasal discharge and they can live in dried nasal secretions for at least 7 days. The skin ulcers of people with leprosy shed a large amount of *Mycobacterium leprae*. The treatment today for leprosy is not to pull the building down and safely dispose of the building materials, but to treat the person with leprosy. Leprosy today is made non infectious within 3 days of treatment of the person with the drug Rifampin. If a person with leprosy has developed a lesion then a single dose of multidrug therapy using the drugs 600 mg rifampin, 400 mg ofloxacin and 100 mg minocyclon is sufficient to cure the disease if it is caught early. If the disease is more advanced then the treatment with these drugs is continued over a longer period of time (Chin 2000).

In 1863 employees working in the Ohio State Capital building in Columbus, Ohio, became sick with a "mysterious disease." The source of the employees becoming sick was "traced to basement air passages that were clogged with debris, and to raw sewage flowing from water closets into an air duct, instead of into the sanitary sewage system" (Jennings 2007). Jennings (2007, p. 1041) states that this was the first documented case of sick building syndrome. While the story from the book of Leviticus is more about building related disease as the cause of the illness was related to an identified micro organism, the Ohio story is a sick building syndrome story because the cause of the employees' illness symptoms were unknown. However, upon investigation, the cause of the Ohio employees' illness was suspected to be due to poor sanitation. The symptoms that these employees reported were similar to the symptoms reported today for sick building syndrome.

According to Murphy (2006, p. 83) "The term *sick building syndrome* was first used in 1984 by a Danish – born Yale biophysicist in a Swedish publication and quickly proliferated in the English language medical literature and in media accounts of problem office buildings" (Stolwijk 1984).

However, the Health & Safety Executive (1996) states that Sick Building Syndrome, as a medical condition, was recognised by World Health Organisation in 1982 (WHO 1982).

Kreiss et al. (2006) record that in the 1970s many public health agencies were requested to investigate complaints by office workers about their indoor environment that some employees thought was making them sick. By the 1990s, Sick Building Syndrome was one of the most commonly investigated occupational health problems. Why these investigations relating to perceived "Sick Building Syndrome" were requested was partly due to the technological advancements of the twentieth century which resulted in changes to office and other building designs, new types of materials available and used to build buildings, new equipment and products used in office and other work buildings and new climate control measures used in buildings, all of which changed the indoor air quality.

1.4.2 Building Comfort to Improve Employee Productivity

Electricity has been recorded as being identified in nature by Thales of Miletus in 600 BC (Buzzle.com 2010) but at this time electricity was not used to power machinery and to produce light to enable people to work for long hours in buildings. In 1831 Michael Faraday built the first electric motor which enabled equipment, driven by an electric motor, to be invented. Faraday was also the first person to build an electric generator and an electric transformer (National Electrical Manufacturers Association 1946). On 31st December 1839 Thomas Edison provided the first public demonstration of his incandescent light bulb. He found that by using a carbonised bamboo filament his light globe could provide light for over 1,200 h. In 1880 Thomas Edison patented a system for delivering electricity and over his life time established 121 Edison power stations in the United States of America (Wikipedia 2010). Having a reliable source of electricity and having continuous light that could be delivered to buildings enabled buildings to be used for work 24 h a day. Having electricity available for public and private use, and having electric driven motors invented, enabled people to invent new ways for climate control in buildings.

Prior to the twentieth century, building ventilation was simply opening a window to let fresh air into the building. In summer, in some countries, this air could be very hot, while in winter the air could be very cold. In the 1919 members of the American Society for Heating and Ventilation Engineers (ASHVE), led by the researcher Wallis Carrier (who has been called the "Father of Air conditioning") worked in research laboratories to determine a comfortable indoor air temperature for work, particularly in an office environment. To gain this comfortable temperature they researched temperature, humidity and air flow factors by conducting experiments in environmental chambers on mainly young, white male engineering students. The ideal climate for these people, while pedaling a stationary bike, was determined as being the best climate for office and other workers. In the 1930s there was a problem with human body odour in buildings. Further experiments were then conducted using people of all ages and classes to determine the minimum ventilation required in a building to remove these body odours. The researchers did not look at the micro organisms that could grow in the air in this human comfort zone, or at the health effects that their invention could cause. Instead they marketed and sold comfort through science to owners of public and private buildings to create a business for themselves that generated high profits (Murphy 2006).

Many office buildings constructed today are made for climate control and usually include an air conditioner to keep the building temperature at about 22°C, have between 40 and 60% humidity and to have a minimum air flow rate of 15 cubic feet per minute (cfm). This temperature, humidity and airflow rate was determined by the ASHVE researchers to be an optimal standard. To keep this even temperature many office and other buildings were designed and built with glass windows that did not open. This meant that these buildings were sealed environments that relied on the air that was circulated by the building air conditioners for air quality. Buildings became confided spaces.

Joshi (2008) reported that in the 1970s building designers were making buildings more airtight to improve energy efficient as a result of an oil embargo by Arab Nations. Ventilation rates were reduced from 15 to 5 cfm per person to save fuel and to be more cost efficient. In order for developers to make higher profits in the 1970 office buildings became open plan for most employees as this eliminated the cost of walls and doors in the internal part of the building and more people could be fitted into smaller spaces in the building. Open plan buildings were marketed as improving interaction between employees. Managers still kept closed offices so that they had status and privacy for their work.

Murphy (2006) wrote that these new buildings were made of new kinds of building materials that included concrete, particle board, solvents, adhesives, plastics, tiles, synthetic carpets and other man made building products. These office buildings were fitted with new office equipment that included first typewriters then computers, printers and fax machines. Late in the nineteenth century the employment of women to operate office machinery began.

1.4.3 The Role of Women in Raising Awareness of the Existence of Sick Building Syndrome

By 1930 95% of office work employees in the United States of America were European American women (Murphy 2006). In 1911 Fredrick Taylor wrote a book called *The Principles of Scientific Management*. To make a business profitable Taylor recommended breaking work tasks down to discrete elements so that employees performed a small number of short cycle repetitive tasks (Pheasant 1994). The work of these women was managed by male office managers using the principles of Taylor's scientific management. Women employees were mainly confined to their work desk during working hours and could often work on a single task on a single machine all day. The work desks were arranged in rows facing the area, which could be a raised platform, where their supervisor sat to keep watch over their work.

In the 1950s the women office workers became two classes. The highest class was the women who became the personal secretary to a manager. The lower class was the women who operated the office machines. Liquid paper to white out mistakes began to be used in offices in 1956. In 1959 Xerox started to sell photocopiers to businesses. By 1965 computers were replacing typewriters in offices and by the 1980s most office workers used a desk top computer to type documents and carbonless paper was used. The use of computers enabled electronic surveillance by managers of employees' work efficiency as their managers "created statistics on error, speed, idle time, and seconds per customer" (Murphy 2006, p. 55). Working for hours sitting in front of a computer caused employees to report having headaches, eyestrain, sore muscles, repetitive strain injury and these women worried about the low level radiation from the computer causing reproductive problems or miscarriages. Like sick building syndrome, when women computer operators first began complaining of repetitive strain injury they were considered by employers, medical practitioners and others to be "psychogenic, hysterical or frank malingering" (Pheasant 1994, p. 80).

Pheasant (1994) wrote about an Australian epidemic of repetitive strain injury cases in office workers that began in 1980 with the introduction of computer use in Australian workplace offices. This epidemic peaked in 1986. In 1985 Leon Straker, a physiotherapist who was employed at Curtin University, ran a support group for repetitive strain injury victims in Australia. This support group looked for ways to minimise the incidences of repetitive strain injuries in office workers. When typing on typewriter a reasonable amount of force was required to press each key. With the event of computers only a light amount of force was required for each key stroke. This enabled employees to type faster. Faster typing resulted in more repetitive use of muscles. In Australian offices work was reorganised so that computer typist were allowed to take 5 min break each hour to allow for muscle rest and the build up of lactic acid in these muscles to be reduced. Identifying the cause of repetitive strain injury enabled the incidences of this illness to be reduced.

In 1968 Eberhard and Wolfgang Schnelle began designing and selling open plan offices to improve office workers' communication. Executive and high level managers still had their private office. Open plan offices were popular with company owners in America as they allowed the employer to squeeze more workers into a smaller space. Typically a manager was allowed 154 square feet of work space while a typist was allowed 41 square feet. Low level partitions were sometimes put between desks to allow typist to have their own work space. In the 1970s the average salary of clerical workers was below that of all types of laboring workers in America; outsourcing of office tasks was beginning to occur and continuing employment for officer workers was becoming more insecure. "In 1970, office work in the United States employed 13.7 million clerical workers; 74.6% of whom were women" (Murphy 2006, p. 65). By the 1980s 36% of white and 29% of black American women worked in an office.

In the 1960s new synthetic building materials that included polyurethane, fiberglass and formica were used in buildings. Much of the office furniture of the 1970s was made from plastic, steel, particle board, laminate or plywood. Hard surface floors were replaced with carpeted floors. Walls were painted cheerful colours. Potted plants were included in offices to improve the environment. Many of the companies in America were now owned by stockholders who did not work in the building (Murphy 2006). Identification of health problems of employees in the office building environment was not made by company owners originally but was made by the women who worked in these buildings.

1.4.4 Gaining Evidence

In the 1910s a group of women office workers organised membership of the Women's Trade Union League but this union had few members so was not very effective in improving women office workers' working conditions. The women's liberation movement began in the 1970s in America. A variety of small women's organisations were formed in a variety of cities and in a variety of large companies to deal with inequalities in their workplace. One of these organisations that were formed was called 9to5. This group was formed in 1972 by Ellen Cassedy and Karen Nussbaum, who were both Secretaries at Harvard University School of Education (Murphy 2006). The group's name was based on the film 9to5 which was about a group of disgruntled women office workers (staring Dolly Parton, Jane Fonda and Lily Tomlin) who, in the film, formed a group to exchange experiences by *conscious raising* after smoking marijuana. In this film these women office workers all found that they had similar work related problems and did something to solve their problems.

Women's groups used the film 9to5 technique (without the smoking of marijuana before), called *conscious raising* to share work related problems and by the end of the 1970s every major city in America had conscious raising women's groups. The term *conscious raising* was first used by Kathie Sarachild who was a member of the New York Radical Women group (Murphy 2006). A conscious raising group was composed of small groups of women who met regularly to share their work related experiences and to analyse these experiences. Today these would be called research focus groups. In New York an organisation called WOW (Women Office Workers) advertised in its Newsletters that members of this organisation were willing to come to women's homes, or workplaces, to talk to groups to exchange experiences and ideas. The home meetings were like Tupper Ware parties, except that nothing was sold but ideas were exchanged. The WOW members helped the women that they talked to form their own groups of women office workers to exchange ideas on improving work in their own workplace. Each group began with 2 or more women exchanging ideas and discussing work related grievances.

Conscious raising was considered by these women's groups to be *truth telling* rather than to be generating scientific knowledge which, in the 1970s, was considered to be something that men did. The women's shared personal office experiences began to form a common body of knowledge which did not rely on medical authorities. The women considered their experiential knowledge to be more authentic than "Expert" knowledge. They stated that their knowledge was gained by experiencing oppression in the seemingly trivial experiences of their day to day work, which was something that male managers, sociologist and scientists would not understand. This was a problem. Most men did not understand and considered the office problems to be just women's complaints.

In 1977 Jeanne Stellman wrote a book called *Women's Work, Women's Health: Myths and Realities* that was published by Pantheon in New York. The following year Jeanne Stellman, an occupational health researcher, founded the Women's Occupational Health Resource Centre in New York. This Centre became a clearing house, a centre for information on women's occupational health issues, it published a newsletter, produced fact sheets, conducted occupational health research and held occupational health training sessions. On a fact sheet that was published in 1980 Jeanne listed ozone and organic solvents in the atmosphere as office hazards. She wrote that there had not been any epidemiological or other research studies to determine the health effects of these chemicals on office workers. In this fact sheet Jeanne highlighted problems that could occur with indoor air quality.

In 1977 many of the small groups amalgamated together to become the national group called 9to5, the head office of which was based in Cleveland, in America. On reading Jeanne's fact sheet on indoor air quality the 9to5 group discussed office work, technology and identified that office workers were surrounded by many products that could potentially contain toxic substances. For many of the identified chemicals there was just a small quantity found in the indoor air, but the cumulative effects of these chemicals had not been investigated. For the 9to5 group, after reading this fact sheet in 1980, occupational health became a core research issue and the organisation founded a research group called Project Health and Safety.

Project Health and Safety researchers conducted research on office chemicals and the building materials. They identified a case of a successful workers compensation claim for an employee's ill health being due to inhaling photocopier exhaust fumes, formaldehyde poisoning of office workers and the fact that a teenager died from inhaling correction fluid, but they did not find that any specific chemical or technology was the cause of common illnesses associated with office work. What they did find was that possible toxic exposures were everywhere in office buildings. The following is a story from Nussbaum (1983) recorded by Murphy (2006, p. 69) that describes office work in 1983. Possible toxic exposure is shown in the details of the work performed by this office worker.

Let me give you a guided tour of the hazards in sending out one letter:

> Alice prepares to type a letter for Mr Big. The carbonless typing paper she uses is made with abietic acid to fill the pores, and PCB's – polychlorinated by-phenyls. Abietic acid has been found to cause dermatitis and PCB's are extremely toxic, causing irritation to eyes, skin nose and throat, can cause severe liver damage, and are suspected carcinogens. The typing ribbon she uses contains PCB's. To correct an error she uses correction fluid containing trichloroethylene – TCE. In high doses, TCE can have a depressing effect on the central nervous system and can cause liver damage and lung dysfunction.
>
> Alice goes on to make a copy of the letter on the photocopy machine, which may omit ozone, a deadly substance. In poorly ventilated areas it is not hard to raise ozone to at least twice the federal standard. The black powder in the machine – the toner – may have

> nitropyrene or TNF, trinitroflourenone – suspected mutagens. While in the copying room, Alice breathes methanol from the duplicating machine, which can cause liver damage. She ends her hazardous journey by filing Mr. Big's copy of the letter in a plastic file containing polyvinyl chloride, which can cause skin lesions and dermatitis.

The 9to5 women's efforts to provide evidence of possible toxic exposure of office workers to air borne contaminants were made difficult by the National Institute of Occupational Safety and Health (NIOSH) which was founded in 1971. The NIOSH occupational hygienists were used to measuring high levels of chemical exposures in the atmosphere of manufacturing and other industrial workplaces. They detected only low levels of chemicals in office air and often their equipment was not able to detect any chemicals in the atmosphere. As NIOSH investigators did not detect high levels of acute chemical exposure in offices, which is what they considered was required to fit the toxicology model of chemical exposure and effect, the NIOSH investigators labeled the office workers' symptoms of illness as being due to "gender psychological responses to life stresses" or due to "mass hysteria" or to "mass psychogenic illnesses" (Murphy 2006, p. 71).

1.4.5 Survey Results

As the women's conscious raising body of knowledge was not accepted by governments, media and employers as being a sound body of knowledge, and as NIOSH was not supporting the Project Health and Safety indoor air quality research considerations, the 9to5 members decided to use surveys (a social science research tool) to ask workers questions about their work surroundings, work processes and health effects that occurred when women were working in their office. As a survey was a recognised form of research it was considered that the survey results could be given to the media, governments and experts, like NIOSH to demonstrate that working in some offices did cause recognised health effects and to raise awareness of the office work environment air quality. It was considered that the results of surveys would change experience into quantitative evidence. The survey tool was used by 9to5 members as a tool to identify non specific health events that occurred to office workers.

In 1981 the first large survey was conducted by the 9to5 Project Health and Safety Researchers. The survey was distributed to 8,000 office workers who lived in the Cleveland or in the Boston area. 1,300 office workers completed this questionnaire. This research survey included questions about office air quality, office machines, employee stress level and on the office environment. This research was sponsored by Occupational Safety and Health Administration (OSHA). The results of analysing the data collected from this survey helped to identify the symptoms of occupational illnesses that occurred in office environments. World Health Organisation used the results of this survey to help define the symptoms of sick building syndrome.

Survey results were included in books that were published about office occupational hazards. Each of these books published by members of 9to5 included, as an appendix, a comprehensive survey tools which could be used by office workers to assess their own workplace. Office workers no longer talked in groups about their work but now completed surveys about the working conditions and the health effects of their work and workplace. The results of the surveys could be analysed and provided to their employer as objective data. The survey results were able to identify a "phenomenon that was nonspecific and only discernable in clusters, not in an individual" (Murphy 2006, p. 74). Sick building syndrome became defined through survey questionnaire answers. Survey results had the benefit of being evidence that both women and men could understand.

In 1982 Project Health and Safety used women's magazines to send out a stress survey to over 40,000 people. This survey asked questions on 34 possible sources of stress that could occur when working in an office work environment. There are 3 major causes of stress.

- *Psychosocial.* These stressors are a function of the complex interaction between social behaviour and the way a person's senses and mind interpret this behaviour. Examples are work overload, deprivation of information or resources required to perform work tasks effectively, work related frustration, adaption to new technologies and work situations.
- *Bioecological causes*. Bioecological stressors are basically biologically related and arise out of a person's relationship with their work environment. Examples include excessive noise, nutrition (for example are employees allowed enough time to eat to maintain a satisfactory blood glucose level), heat, cold, biorhythms (hours of work), muscle overload or static position strain and physically or chemically caused body trauma.
- *Personality causes*. These reflect the dynamics of an individual's self-perception, characteristic attitudes and behaviours which may contribute to excessive stress. Examples of personality stressors are self-perception, behavioural patterns, anxiety and control.

Surveys were also included in the 9to5s newsletter and given out at meetings 9to5 members attended or at lectures that members presented as they considered stress to be part of the computer age of work. These women tried to prove that stress was a biological reaction to social workplace conditions as they wanted office work restructured to have better environmental conditions and work management. Project Health and Safety Researchers aimed to prove that "bodies did not react only to low level chemical exposure but also to unjust social factors" (Murphy 2006, p. 78).

By 1983 the organisation called 9to5 had over 10,000 members. Karen Nussbaum, a founder of this group, was now the Executive Director. 9to5 had a Board whose members chaired committees and the group had a Staff Director who hired other staff to work for 9to5. 9to5 became a professional activist group who lobbied politicians, testified at American Congressional Hearings and who presented lecture tours. 9to5 members used the results of their surveys' findings as powerful tools for making office workers non specific health problems visible to employees, employers, government agencies, politicians and the media.

1.5 The Role of Tobacco Companies in Promoting and Publicising the Existence of Sick Building Syndrome

In post war Britain there had been tests on animals to determine if exposure to cigarette smoke caused cancer, but these "tests on animals appeared to rule out a link" (BBC 2004, p. 1). However, the tobacco industry was aware that in 1954 Richard Doll and Austin Bradford Hill had published a paper documenting the results of a research study that used a short questionnaire, administered by social workers to 1,400 patients in London, Bristol, Cambridge, Leeds and Newcastle hospitals. The results of analysing the questionnaire responses confirmed the link between smoking and lung cancer (BBC 2004). *"Nobody believed us," said Sir Richard. "They though there may be other explanations"* (BBC 2004, p. 2).

After the publication of the 1954 paper in the British Medical Journal Richard Doll was visited by the Chairman of Imperial Tobacco who disputed Doll's research findings. Not deterred Doll went on to conduct further research studies that showed cigarette smoking also caused cardiovascular diseases, bladder cancer and other cancers. In the 1950s 80% of the United Kingdom men smoked cigarettes (Richmond 2010). The tobacco companies did not want to lose their customers so they looked for another cause of ill health to demonstrate that illnesses were caused by substances other than tobacco smoke.

The results of the women's surveys in relation to the existence of sick building syndrome were read by tobacco company managers. "Beginning in 1986, two tobacco industry organisations, the Council for Tobacco Research (CTR) and the Tobacco Institute (TI) quietly supported ACVA Atlantic (later renamed Healthy Buildings International, HBI) to promote the industry's message that 'sick buildings,' not SHS (Second Hand tobacco Smoke), accounted for poor air quality in workplaces" (Barnes and Glantz 2007, p. 996). For example, the President of Health Buildings International, Gray Robertson, in 1986, was sent by the Tobacco Institute on a National Media tour of America to promote the concept of Sick Building Syndrome on many radio stations, television stations and through newspaper interviews. As this media campaign was so successful the Tobacco Institute launched similar media campaigns to publicise sick building syndrome in Hong Kong, Canada and in Venezuela. What the tobacco industry liked about Sick Building Syndrome was that it had a multitude of causes that were difficult to identify. The effects of tobacco smoke could be hidden in this multitude of causes.

The Tobacco Industry Labor/Management Committee ran a coast to coast road show from 1988 to 1990 in America for union members on indoor air pollution to promote sick building syndrome. In this road show there was no mention of tobacco smoke being a cause of indoor air pollution or sick building syndrome.

The tobacco industry sponsored conferences, newsletters and professional associations concerned with indoor air pollution or independent building investigators to ensure that as much as possible tobacco smoke was not mentioned as an indoor air pollutant.

In 1988 the Tobacco Institute produced a glossy brochure that was distributed to the general public, regulators, decision makers and government organisations that blamed the occurrence of sick building syndrome on poorly designed and maintained ventilation systems in buildings that had sealed windows to conserve energy. They also blamed sick building syndrome on contamination of buildings by fungal and other micro organisms as well as the recirculation of chemical and other air contaminants by building ventilation systems. Sick Building Syndrome, not tobacco smoke, was promoted as the cause of ill health in people who worked in buildings. Hodgson (1989), a researcher who was not connected to the tobacco industry, conducted research that showed that cigarette second hand tobacco smoke produced a dose-related increase in the reports of sick building syndrome symptoms by employees exposed to this smoke.

Murphy (2006) recorded that sick building syndrome achieved the prominence that it did in the last 2 decades of the twentieth century mainly due to the efforts of the tobacco industry who promoted an ecological (management of the micro organisms in the building) and systems approach (pre-planning during the building design stage not to include any toxic materials and to have adequate building ventilation, preventative maintenance, walk through inspections, proactive risk assessments and risk control measures, etc) to prevention indoor air pollution causing sick building syndrome.

Ragnar Rylander, a researcher who worked for the Philip Morris Tobacco Company, conducted research to prove that the cause of sick building syndrome was endotoxins in the air. An endotoxin is a poisonous substance that is contained in the cell walls of gram negative bacteria and other micro organisms. This toxin is released when the bacterium dies. The release of the endotoxin can cause fever, shock and other symptoms of ill health (Anderson et al. 1998). In 1988 Professor Rylander presented his findings at a conference in Argentina and in 1989 at a conference in Brussels. Rylander's research publications proposed that tobacco smoke protected employees and other people from endotoxin caused inflammation of cells. From 1989 to 1994 Rylander published research findings that demonstrated the sick building syndrome was caused by exposure to indoor airborne fungal (glucan) and bacterial (endotoxins). His research work was sponsored and publicised by Philip Morris. Rylander's research findings promoted that the building ecology was the cause of sick building syndrome.

OSHA, in 1991, published a notice of request for information on occupational exposure to indoor air pollutants so that it could be determined if there was a need for any regulatory action. Included as indoor air pollutants were endotoxins, which were thought to be the cause of sick building syndrome, and passive tobacco smoke exposure. The tobacco industry produced the following response to this OSHA request.

> Four large databases on sick-building syndrome investigations, including data bases from NIOSH, Health and Welfare Canada, T.D. Stirling and Associates, Ltd. [a long time industry consultant], and Healthy Buildings International [another industry consultant], do not reveal significant correlations between IAQ [indoor air quality] complaints and symptoms and specific types of causative agents. In over 50 percent of all sick building cases, symptoms and complaints are abated by increasing the ventilation to levels comparable to those specified in ASHRAE 62-1989 [an engineering standard for indoor air quality]. In addition, the four data bases indicate that complaints and symptoms can be correlated to tobacco smoking in only two to four percent of all sick-building investigations (Barnes and Glantz 2007, p. 997).

What was not recorded in this submission was that the Tobacco Institute had paid Gray Robertson, President of Healthy Buildings International, a monthly retainer to work for the Tobacco Institute. Gray Robertson's business had previously been a small ventilation cleaning service called ACVA Atlantic. As Robertson was paid this retainer Healthy Buildings International was able to expand the ventilation cleaning business to conducting investigations into the causes of sick buildings and underbid the prices of other companies. Robertson's company became the largest sick building syndrome investigating company in America. The company never identified tobacco smoke as a cause of sick building syndrome. Instead this company produced and distributed free glossy magazines in many languages that promoted the cause of sick building syndrome as being due to "the improper operation and maintenance and faulty design and construction of buildings, causing the structure to trap polluted air" (Murphy 2006, p. 147). In the submission to OSHA Robertson said that "virtually every indoor decoration, building material or piece of furniture sheds some type of gaseous particulate pollutant" (Murphy 2006, p. 148).

The tobacco industry also sponsored and promoted other sympathetic indoor air quality experts to tell people about sick building syndrome and to promote sick building syndrome as being due to a multitude of causes. The Healthy Buildings International researchers collected published literature that identified substances (such as fungi, dust, bacteria, formaldehyde, humidity, etc) rather than tobacco smoke as the causes of sick building syndrome. This is the published literature that was used in the above submitted response to OSHA.

OSHA did not go ahead with having a proposed indoor air quality standard. The tobacco industry continued its sick building syndrome publicity campaign in as many ways as possible to prevent the regulation of smoking in workplaces and public places. The tobacco industry has now stopped promoting endotoxins as a cause of sick building syndrome as it has been identified by the researchers Hasday, Bascom, Costa, Fitzgerald and Dublin that endotoxins are an active component of cigarette smoke (Barnes and Glantz 2007).

In Western Australian workplaces in 2010 there are very few cases of sick building syndrome reported. In workplaces and public places cigarette smoking is not allowed by law. In Western Australia only 4.8% of young people smoke cigarettes. In the general population less than 15% of Western Australians smoke cigarettes. It is anticipated that by 2025 there will be practically no one left in Western

Australia who smokes cigarettes (O'Leary 2010). However, in some other countries cigarette smoking is still allowed indoors and could be a contributor to "sick building syndrome."

1.6 The Influence of Corporations on Denying the Existence of Sick Building Syndrome

1.6.1 Introduction

While the tobacco companies promoted the existence of sick building syndrome most employers did not. Instead some employers and building owners promoted that Sick Building Syndrome was due to psychological factors, or did not exist. In the United States of America in the 1970s and 1980s property owners were strongly supported to hold this point of view by their government.

1.6.2 Government Position on Indoor Air Quality in the United States of America

In the 1970s Environmental Protection Authority (EPA) was the organisation that was responsible for establishing regulations and standards for indoor air quality in America. The scientists who worked for this organisation had difficulty measuring sources of indoor air pollution in office settings because exposure of people to airborne substance was often transient or of a low level and the EPA hygiene monitoring instruments had only been designed to detect high levels of chemical exposure in factories, rather than chronic or transient exposures. Office workers were affected by air borne pollutants, even at low levels, as the worker's length of exposure could be for long periods of time, or the individual could be hyper-sensitivity to the pollutant.

An additional problem was that, as government paid scientists, EPA scientists were "tightly restricted in their ability to communicate findings or design studies by politically appointed administrators whose ideology often rejected the notion that the state should regulate capitalism" (Murphy 2006, p. 116). In the 1970s and 1980s the Environmental Protection Authority developed a reputation as an organisation that did not tell the truth.

Once Ronald Regan was elected the President of the United States of America he cut the EPA staff numbers by 40% and the EPA budget by 60%. In 1981 Regan appointed Ann Gorsuch as EPA Head. She in turn appointed professionals, to upper management positions, who had previously been engaged by industry to defend their industry against government regulation. Under Ann Gorsuch's leadership EPA career "scientists who resisted pressure to repress damning data or acted as whistleblowers could find themselves fired, harassed, or transferred to positions in which their only tasks would be answering phones or filing paper" (Murphy 2006, p. 117).

Orders were given by Ronald Regan that the EPA was not allowed to collect any information on any chemical unless a cost-benefit analysis had shown that to collect this information was beneficial for the company and the industry. Economic considerations were deemed to be more important than scientific evidence and population health.

Under the leadership of Ann Gorsuch (1981–1983), William Ruckelshaus (1983–1985) and Lee Thomas (1985–1989), who were all business representatives, EPA Inspectors fined some organisations that polluted middle class neighborhoods, but did not fine industries that caused pollution in the poorer neighborhoods. This was perceived as being unfair by some community environmental activist in America who began to lobby EPA scientists about the requirement for perceived environmental justice. Civil rights legislation was used by these activists against these inequalities. There also arose toxic waste activist who used epidemiology findings to demonstrate chemical exposure and its effects as they distrusted the EPA scientists.

"Caught between the activists' criticism and an anti-regulation administration, a small group of EPS scientist, many with 'backgrounds in environmental, political and labor activism,' took the unusual and impressive step of organising a union of 'toxicologist, chemists, biologist, attorneys and other environmental professionals' in the name of scientific ethics" (Murphy 2006, p. 119). This organisation, which was chartered in 1983, was called the National Federation of Federal Employees (NFFE).

The NFFE Union was joined by about 1,200 EPA workers who held the view that the corruption of the EPA was due to the influence of industry sponsored organisations and large companies. For example, if an EPA scientist had a research finding that was unfavourable to, or critical of, a large company then the scientist was unable to go public with the findings. If a scientist did go public with the findings it meant that this scientist's career was ruined. As well as ruining the career of the scientist the EPA administrators were also able to "counter almost any positive findings made by an EPA scientist by pointing to a nearly identical, corporate sponsored experiment that produced a negative or more ambivalent result" (Murphy 2006, p. 120). Following a different finings from the subsequent research there would need to be many other research studies conducted each of which would generate more and more uncertainty and so make it impossible for the EPA to have a regulation for the problem identified by the first scientist.

An example of a scientific problem that the EPA did this with was related to the potential toxicity of new carpet. At the independent Anderson Laboratory scientists blew air over new carpet on to mice. As a result of inhaling this air some of the mice developed severe neuromuscular and severe neurological reactions. A member of the NFFE Union videotaped this experiment. When the EPA, carpet and rug industry scientist replicated this study they modified the research procedures to use bottled air that was bubbled through water to conduct their experiment. The bottled air had no effect on the mice so the EPA, the rug and the carpet companies stated that there were no problems with carpets or rugs that needed regulation.

1.6.3 Psychological Issues

An EPA scientist, Lance Wallace, in 1987 conducted research on university students. His research identified that the time that these students spent indoors, not the student's proximity to industrial sites, was most strongly correlated with accumulated chemical exposures. As a result of the publication of these research findings the American Congress established an Indoor Air Division at the EPA. This Division was responsible for the investigation of incidences of indoor air pollution. Lance Wallace was given the title of the "Father of Indoor Air Quality Research".

At the EPA the NFFE Union was concerned with the condition of the building at Waterside Mall in Washington that was the EPA Headquarters. This building had originally been apartments. It now housed offices for about 5,000 EPA employees. The building had windows that did not open. The air was stale as the air vents were clogged with dirt and fibrous matter. Black powder dropped from the ceiling onto the occupants and their work stations. Cockroaches and mice infested the offices which were filthy. In 1987, when the NFFE Union complained about the state of the physical workplace the building owner, on instructions from the EPA Administration, installed new carpet to improve the physical work environment. "Immediately, some EPA staff, including scientists, began to complain of acute symptoms: tearing eyes, irritated throats, burning lungs, shortness of breath, crippling headaches, and dizziness. As the carpet installation pushed its way through the building, the trickle of complaints turned into a torrent" (Murphy 2006, pp. 123–124). When this air was monitored 68 different chemicals were detected. These employees were told that this was not a problem as none of the chemicals were present in a high enough concentration to affect their health. Some of the employees wore masks to work as they could not function with the level of indoor pollution.

In 1988 a Committee of Poisoned Employees (COPE) was formed by some of the sickest employees who asked the NFFE Union and the American Federation of Government Employees (AFGE) to help them organise a protest about the way that their indoor air pollution caused illness was dismissed by the EPA Administration. In May 1988 a protest was held by 60 EPA employees who carried placards stating "Canaries in a coal mine" or that had the EPA logo upside down, or that recorded "EPA is a superfund site" or other comments. These employees handed out building surveys for employees to complete.

The Indoor Air Division of the EPA did not investigate their employees' complains about the EPA indoor air quality until 2 years after the carpets had been laid. The investigation of the EPA indoor air quality was conducted by Lance Wallace due to the lobbying of the NFFE Union Members. As such a long period of time had passed since the carpets were laid, and as he only had stationary monitoring equipment, Wallace did not expect to find any physical evidence of air pollution so, as part of his indoor air quality investigation, Wallace gave out a questionnaire. A response to his questionnaire was received from 3,955 EPA employees. Most of these employees suffered ill health when in the building, but no single cause was identified by the questionnaire response data analysis. As an Appendix to Wallace's research report the NFFE Union Members added newspaper articles, internal memos, previous air monitoring reports and the results of independent air monitoring research on the EPA building's carpet. The NFFE wanted to show the world how the political climate at the EPA hid facts.

Six of the sick EPA employees, who had been affected by the air pollution from the carpet, sued the owner of the EPA Building for damaging their health. A jury awarded these employees US$948,000 in damages. This was the biggest indoor air pollution award at the time. As a defense the EPA building owner said that the illnesses that these employees were suffering were not due to the building, but to psychological problems brought on by the management conditions under which these employees worked. In 1995 the District of Columbia Superior Court over turned the original damages ruling by deciding that the landlord could not be responsible any psychogenic illnesses. Following this court decision and, "thanks to industry advocacy groups, sick building syndrome became a means to disable accountability" (Murphy 2006, p. 149) for landlords when their property caused tenants ill health effects as property owners are not responsible for tenants psychological health.

Claiming that employees' sick building syndrome health effects were due to their employer's management provided an opportunity for Marsha Coleman-Adebayo, a senior policy analyst at the EPA, to sue the EPA on the grounds of racial and gender discrimination. She won $600,000 in settlement. Mismanagement of employees was now considered a cause of sick building syndrome. In 1998 the EPA employees were relocated from the Waterside Mall building to a new building called the Ronald Regan Building. After relocating to a new building there was no further sick building syndrome problems at the EPA.

1.6.4 Law Cases

Subsequent to the findings in the EPA employees' law case it has been very difficult in a court of law to prove that an employee's ill health is caused by sick building syndrome. Of the four sick building syndrome law cases obtained from the legal web site www.austlii.edu.au one was successful and three were unsuccessful.

The 1st unsuccessful case was between Duff and Australian Telecommunications Corporation 1992. In Mrs Duff's workplace there was a lot of dust, biological contaminants, the air-conditioning system was poorly maintained, the building temperature was poorly controlled and Mrs Duff said that her workplace caused her to have 26 respiratory infections with sick leave between 1974 and 1988.

The 2nd unsuccessful case was Milic Milenkovic and Comcare (1993). Mr Milenkovic stated that he became incapacitated due to a nose and throat allergy problem due to environmental exposure to toluene (a solvent used in his workplace), phenol, nitrous dioxide, formaldehyde that was omitted from particle board and textiles, the components of polyester fabrics, rubber, polyurethane foam and poor ventilation from the air conditioner at his workplace.

The 3rd unsuccessful case was Anderson v Accident Compensation Corporation (2006) in New Zealand. In this case Shona Anderson experienced nausea, a persistent cough, breathing difficulties, a dry mouth and itchy skin when at work. When away from work these symptoms resolved. In court Shona Anderson had three medical practitioners who gave evidence that she had sick building syndrome. Many other employees at Mrs Anderson's workplace complained of experiencing the same symptoms as Shona Anderson as well as experiencing headaches, general malaise and being chronically tired at work. These health effects were relieved when these employees left work. It was suggested that the cause of their ill health was volatile organic compounds from the workplace printers and poor workplace ventilation. Sometime success in a court of law depends on how well a lawyer can present a case to the Judge.

A successful case was Janice Mary Gordon and Australian and Overseas Telecommunications Corporation (1992). When at work Janice Gordon suffered from allergic rhinitis, nausea, flu, sore throat, sore eyes and a general feeling of being unwell. These symptoms were relieved when she was away from the building. Janice was awarded workers compensation for her case.

The first successful workers compensation case in Australia related to an employee experiencing sick building syndrome was the case of the Accident Compensation Commission (Victoria College) v Bradley (29 May 1989). This case was reported by Pengilley (1994). Bradley was a librarian employed by a School of the Victorian Technical and Further Education (TAFE). This librarian claimed to be suffering from sick building syndrome after being exposed to formaldehyde fumes from the building materials in the new library building. These fumes were recirculated through the building air conditioning system in the school library. The building owner said in court that the level of formaldehyde in the atmosphere was within the acceptable standard range. The applicant was just highly sensitive to this air contamination. "The Judge was satisfied as to the causal connection between the applicant's injury and the building's air conditioning system, and, under the Act liability was strict." (Pengilley 1994, p. 22) The librarian was successful in this court case and was awarded workers compensation under the Accident Compensation Act 1984 (Victoria). Apart from these five cases no other court cases related to sick building syndrome were found for Australia or New Zealand.

1.7 Occupations Generated by the Recognition of Sick Building Syndrome

Despite it being very difficult for employees to prove in a court of law that sick building syndrome is the cause of their ill health many building owners were keen to have healthy buildings. One motivator for having a healthy building was to prevent industrial action as had occurred at the EPA building. The emergence of sick building syndrome has generated a whole new group of industries and occupations that rely on its existence.

Following publicity about sick building syndrome large buildings began to have a facilities manager to attend to building maintenance. Being a Private Building Inspector became a profession. Building Doctors to identify and treat the causes of sick building syndrome arose. Building management and building inspection firms earned a living from identifying and treating sick building syndrome. Building Ecologist arose to identify, and where necessary eliminate, microorganisms, chemicals, etc that are in a building and cause health effects in the building occupants.

Building wellness consultants emerged to promote managing buildings proactively through good pre-planning in the design stage of a building, using natural, non-polluting, energy efficient building materials, conducting regular preventative maintenance for the building and equipment, conducting regular walk through inspections and risk assessment activities to identify any opportunities for improvements. Incidences of sick building syndrome still occur today, so there will be a continuing need for these occupations.

1.8 Conclusions

The answer to Jane's question that was asked at the beginning of this chapter is no; Jane is not suffering from sick building syndrome. While the building in which Jane is located had its walls painted and new carpets put down in January 2010, there was no reports in May 2010 of any odors or ill health effects from these. There had been no recorded reports of building atmosphere pollutants in this building prior to Jane asking if she had sick building syndrome. No one else in this building reported frequent headaches while working in the building. This was the only symptom that Jane stated that she had. Without the email being sent to her, Jane would not have considered that she had sick building syndrome. The cause of sick building syndrome can be traced to many factors.

This introduction chapter has reported some of the many definitions of sick building syndrome. It has traced the recorded history of sick building syndrome and looked at the effects that man made building materials and poor building ventilation has had on the emergence of sick building syndrome. The role of women in raising awareness of the existence of sick building syndrome through communication and research activities and the role of tobacco industry's publicity in raising the profile of sick building syndrome was examined. Research conducted by people who the tobacco companies paid to do the research identified that there was no one cause of sick building syndrome, but it could have multiple causes. This chapter has documented that sick building syndrome having multiple causes, including being classed in the American law courts as a psychogenic illness and being due to poor work related management practices has allowed some building owners to escape their responsibilities to maintain a high standard of indoor air quality in their buildings.

The next chapter looks at the health effects that are attributed to sick building syndrome and current theories and knowledge about sick building syndrome that can occur in old buildings and in new buildings.

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Chapter 2
Theories and Knowledge About Sick Building Syndrome

Janis Jansz

2.1 Introduction

In 2005 I commenced work in the offshore oil and gas industry in the South East Asia region. The rig allocated was an old tender barge that was built in 1976. The décor had remained the same for many years until "refurbishment" in 2005. A majority of the upgrade was purely aesthetic without review of ceiling or wall panels. In fact, new wall panels were placed directly over the old ones. The installation of a new industrial ducted air-conditioning system was well received in the hot and humid region of the equator. However, little thought was given to any other requirements of the incoming air. After all, it was nice to be cool for once.

In 2009, on the same tender barge, several of the catering and office crew started to contract some severe dermatological conditions that presented similar to anything from tinea corporis to eczema. Several crew members contracted severe upper and lower respiratory infections with two requiring hospitalisation onshore and the remainder retained and treated onboard. As the frequency of dermatological and respiratory conditions in crew members increased over approximately two to three months, I discussed the cases with the onboard Medic. Through investigation of the medical documents and identifying the specific personnel involved, it was realised that a majority of the patients were those with office/accommodation type appointments such as cleaners, catering staff, and supervisors to name a few.

Approximately two weeks later the beloved air-conditioning unit failed and required repair from a specialist tradesman. It was at this point the specialist identified that UV lighting had not been installed with the ducting system. This allowed an extraordinary amount of spores, moulds, and fungus to populate within the ducting system. It was during the inspection of the ducting system that several small leaks from piping were found within the ceiling panels with the water being directed down into the wall panelling. Small bulges had been noticed in the walls but had not been investigated. On removal of the wall panels, "friends" of those living in the air-conditioning duct had made quite a home within the walls.

The identification of these two "fields" prompted the removal, cleaning, and reinstalment of all wall panels, cleaning, sterilising, and installation of UV lighting in the air-conditioning

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Fig. 2.1 Pictures of the wall panelling onboard one of the rigs

> duct and repair of the leaking pipe work. All dermatological & respiratory conditions deteriorated quite rapidly after the cleaning took place. The exact type of bacteria, fungus, and mould was not identified/reported back after the episode.
>
> Pictures of the wall panelling onboard one of the rigs are shown in Fig. 2.1. The photos are all of the lower accommodation in which there are approximately 75 personnel accommodated. The capacity of the vessel is 112 personnel. Some photos I have highlighted with a red circle just to point out the bulging in the walls as it may be hard to see due to the quality of the photos. (Lee)

This Occupational Safety Professional's story is a typical sick building syndrome story. Sick Building Syndrome has been defined as "a generic term used to describe common symptoms which, for no obvious reason, are associated with particular buildings" (TSSA 2010, p. 1). Clayton Utz's Property Issues (1996, p. 25) records that sick building syndrome is "a clinical diagnosis without any cause, or causes, having been specifically identified." Thorn (1998) reported that the diagnosis of Sick Building Syndrome is made when all other building related causes of ill health are eliminated. The Property Council of Australia (2009) states that as air quality measurement techniques improve and are more widely used, and as knowledge of the causes of sick building syndrome grows, the term building related illness is being used more commonly than sick building syndrome.

In the first part of this story from Lee the cause of the employees becoming sick at work was unknown. In this case the health effects experienced by employees were respiratory and skin effects. These are typical sick building syndrome health effects. When the air conditioning system was examined it was found that mould and other fungus in the duct system and in the building walls was the cause of these employees' ill health. These employees were now suffering a building related illness as the causes of the employees' illnesses were determined. It is notable that not all employees who entered the accommodation became ill. This frequently happens with sick building syndrome as not all employees may have been exposed to the same level of the hazard, and because there is an individual difference in people's susceptibility to environmental contaminants. In a research study conducted by Hedge et al. (1995), 4,479 health survey questionnaires were completed and returned from the occupants of 27 office buildings. The results of analysing the responses identified that over 76% of the 4,479 respondents reported at least one work-related symptom of Sick Building Syndrome at least once a month.

The most common theories about the cause of sick building syndrome are that it can be caused by some of the following factors.

- Building materials (identified in the book of Leviticus in the Bible). The building materials may allow micro organisms to grow on or in them, or the building materials may have chemicals or other substances in them or off gassed from them that may irritate the person's skin or pollute the building air that people breathe.
- Poor sanitation (identified in the Ohio State Capital Building investigation).
- Ozone, organic solvents and formaldehyde in the atmosphere (Jeanne Stellman of the Women's Occupational Health Resource Centre).
- Office equipment, furnishings and other materials and products located or used in the building which can produce fumes or contact dermatitis (Jeanne Stellman of the Women's Occupational Health Resource Centre).
- Air borne chemical fumes or gasses from anything in the building (these cause were publicised by Gray Robertson, President of Healthy Buildings International, and supported by the tobacco industry).
- Building air conditioning, inadequate ventilation (which could cause a buildup of carbon dioxide, carbon monoxide or other gasses) and pollutants from inside or outside the building that were circulated by the air conditioning system (these cause were publicised by Gray Robertson President of Healthy Buildings International, and supported by the tobacco industry).
- Mould, bacteria, dust mites, other micro organisms; endotoxins and other microbial products (these causes were publicised by Professor Ragnar Rylander of the University of Geneva, and supported by the tobacco industry).
- Poor building cleaning and maintenance resulting in air borne dust and fibres (Environmental Protection Authority (EPA) building investigation).
- Inadequate light and /or space for work tasks (EPA building investigation).
- Vermin (particularly mice, rats and cockroaches) infestation (EPA building investigation).
- Poor indoor air quality (this cause was brought to prominence by the research work of Lance Wallace of the EPA).
- Other environmental factors that include building temperature, humidity, lack of negative ions in the workplace atmosphere, building odours, noise, electrostatic charges, electro-magnetic fields and/or vibration in the building (Godish 1995).

- Psycho social issues (identified in an American court decision).
- Poor management practices (identified in an American court decision).

The first dot points are factors that affect the air quality and physical environment in the building. The last two points are people factors. When building occupants become sick due to sick building syndrome causes there can be legal implications.

2.2 Legal Implications

The following information on legal implications refers to Australian and American laws and cases, but other counties in the world have similar laws to protect the health of the people in their country.

Pengilley (1994) highlighted the legal responsibilities of the building owners and tenants in New South Wales (NSW) in relation to indoor air quality. There is a general duty of care for an employer, under the Occupational Health and Safety Act 1983 of NSW, to provide a safe workplace that does not harm the health of employees or anyone else who comes to the workplace. There are Common Law requirements and the Occupier's Liability Act that require the air that people breathe in a building to be safe.

In Australia there are Australian Standards. Two Standards that are relevant to the air quality in buildings are AS3666-1989 Air-handling & water systems of buildings- Microbial control, and AS1668.2-1991. The use of mechanical ventilation and air-conditioning in buildings, Part 2: Mechanical ventilation for acceptable indoor-air quality AS1668.2-1991 includes looking at the occupancy space and ventilation requirements for people. For example, in a commercial organisation and in office areas the requirements are 10 meters square (m^2) per person occupancy space with an air flow in the building of 10 litres/person/second. In a library each person requires 5 m^2 of floor space per person with the same air flow rate. In a conference room the air flow is required to be 15 lps/person. In an Australian court of law the building owner and the tenant (s) would have been expected to have met the requirements of these Australian Standards.

In a court of law the person who would be prosecuted for poor indoor air quality would be the person who had ownership and control of the air conditioning unit. Pengilley (1994) states that the case of Cunard v Anifyre [1993] 1 KB 551, the case of Taylor v Liverpool Corporation [1993] 3 ALLER 329 at p. 337 and the case of Wheat v E. Lacon & Co Ltd (1966) AC 552 provided precedence for this decision.

As an example of a court case related to a building's air quality, Pengilley (1994) cites the case of Carey v Australian Telecommunications (1985) 2 AAR 457. In this case a postal clerk, who had a history of having asthma, claimed that on being changed to working in an air conditioned office his asthma became worse. He produced evidence in court that mould and dust found in the building's air conditioning system aggravated his respiratory condition.

> Telecom presented evidence that the air-conditioning system had been well maintained and clean. On this point the Tribunal stated:

> Irrespective of the state of maintenance and cleanliness, the fact is that certain moulds, fungi and other substances are being circulated by the system and, for whatever reason, they have an adverse effect on the applicant… If every component was cleaned daily, if every nut and bolt was tightened regularly, if the system was a paragon of punkahs, he would still be incapacitated. (Pengilley 1994, p. 22)

In this case the employee was awarded Worker's Compensation for his asthma becoming worse when in his employer's air conditioned building.

Clayton Utz's Property Issues (1996, p. 25) records that in the United States of America "law suits arising from sick building syndrome causing personal injury have been brought against manufacturers, distributors, employers, real estate brokers, contractors, lenders, engineers, architects and building owners." Evans (2008, p. 39) stated that there were five possible ways that a person with sick building syndrome in Western Australia (WA) could find to instigate legal action against building architects, builders, engineers, employers or product manufacturers.

1. *Breach of contract*. For building construction the materials used should be of good quality and fit for purpose. For the building owner to ensure that these requirements are met there are warranties for most building materials and equipment purchased. If these requirements are not met then there is a breach of contract.
2. *Negligence*. The Civil Liability Act 2002 (WA) applies to ill health that occurs due to products purchased. However, with new and innovative materials, that the product may cause harm needs to be reasonably foreseeable. For example the potential health hazards, associated with volatile organic compounds (VOCs) which can be released from fibreboards and particle boards, has been known since the 1980s so it is reasonable foreseeable VOCs will be released from these building materials. VOCs are a cause of sick building syndrome symptoms so these building materials need to have a warning as to the health effects that they can cause so that employers, building owners and other people are aware of this.
3. *Occupiers' liability legislation*. The Occupiers' Liability Act 1985 (WA) requires the building to be safe for everyone who enters the building. This includes the air that people breathe.
4. *Occupational health and safety legislation*. The Occupational Safety and Health Act 1984 (WA) requires the employer to keep a safe workplace for everyone who comes on to the business premises and to have safe work processes for employees.
5. Actions against manufacturers and importers under the *Trade Practices Act 1974 (Commonwealth)*. For example, this law could be used to make product manufacturers liable for the health effects caused by formaldehyde-based building materials, if there is no warning of the effects of formaldehyde provided with the product as the health effects of formaldehyde (a cause of sick building syndrome) are well known.

For claims to be successful the person making the claim would have to prove that the building owner or employer or others had a duty of care to the building occupant. The person would then have to prove that a breach of this duty had occurred. They next must prove the cause of their illness was due to factors in the building and lastly the occupant would have to demonstrate the company or person to be liable to pay damages for a breach of this duty and that "the breach produced the claimed injury by a natural and continuous sequence, unbroken by any efficient intervening cause, and they must establish that the claimed injury would not have occurred without the breach" (Air conditioning and indoor air quality 2006, p. 4). Air conditioning and indoor air quality (2006) describes two cases in the United States of America where this proof has been successful in relation to a person, or people, suffering sick building syndrome. In both cases the cause of sick building syndrome was identified to be mould in the building.

Case 1. Copper piping leaked water underneath a 22 room mansion in which Melinda Ballard lived. She suffered adverse health effects from the mould that grew in this area. When this case was taken to court a Jury awarded Melinda Ballard US$32 million. This compensation was paid to Melinda by her building insurance company.

Case 2. A mould related ill health case in California was settled for US$18.5 million.

Air conditioning and indoor air quality (2006) described two other cases that were before the American courts. In one case a New York employee had initiated a claim for US$65 million against his employer for ill health suffered due to exposure to mould in his workplace. In the other case Richard Kramer had brought a complaint for compensation and punitive damages of US$2 billion against 28 defendants. In the building in which Richard lives he stated "that mould infestation has resulted from massive leaks and other water problems throughout the building, which the defendants knew about for well over a year, but concealed from apartment owners and failed to remedy." Not remedying these problems caused Richard Kramar's 3 year old daughter, Alana, to develop "severe and disabling respiratory and other illnesses attributable to toxic mould exposure as well as affecting Mrs Kramer, who had developed severe allergic reactions to this toxic mould" (Air conditioning and indoor air quality 2006, p. 4). In Australia there are also sick building syndrome stories where the cause of this ill health can be attributed to mould as is documented in the following story.

2.3 Health Effects Attributed to Sick Building Syndrome

2.3.1 Introduction

As an Agency Registered Nurse I went to work a shift at a nursing home because there were registered nurses on sick leave due to having respiratory infections. One of the first

Fig. 2.2 Pictures of the *Stachybotrys* Trichothecenes mould that grow on cellulose rich material

> things that I noticed in the nurses' hand over room was that there was water damage on the ceiling and the walls. In the water damaged areas there was mould growing. The staff told me that when it rained the roof leaked and water came through the ceiling and ran down the walls. All of the windows in this nursing home were made so that they stayed shut to keep the building at a comfortable air conditioned temperature for the residents. As well as staff frequently becoming ill some of the residents had respiratory and other symptoms of ill health. I completed a hazard report form on the mould, but did not return to work at this nursing home to find out if any steps were taken to eliminate this biological hazard.
>
> The picture shown in Fig. 2.2 comes from Google Images. It is of the *Stachybotrys* Trichothecenes mould that grows on cellulose rich material, particularly if there is a moist environment and causes health complaints including eye, nose and/or throat irritation, headaches, dry cough, dry itchy skin, difficulty in concentrating, dizziness, nausea, fatigue & sensitivity to odours. This looks like the mould that was on the nursing home ceiling and walls. The ill health effects caused by this mould resemble symptoms that some of the nursing home residents and staff were experiencing (Patricia).

This is a Sick Building Syndrome story because the cause of the employees' and of the residents' ill health was not determined, but seemed to be related to being in the nursing home building. Many of the symptoms of exposure to the *Stachybotrys* Trichothecenes mould are similar to the symptoms of sick building syndrome.

2.3.2 Ill Health Effects

The Environmental Protection Agency (2010), Environmental Illness Resource (2010), Odle (2010), Kipen (2010), Roy (2010), Unionsafe (2009), Milica (2009), Property Council of Australia (2009), Gomzi and Bobic (2009), Joshi (2008), Evans (2008), Tyler (2007), Greer (2007), Marmot et al. (2006), Kreiss et al. (2006), Shoemaker and House (2005), Burge (2004), Hodgson (2002), Unionsafe (2002), Mendelson et al. (2000), Workplace Services (2000), Niven et al. (2000), Thorn (1998), Brinke et al. (1998), Redlich et al. (1997), Bachmann and Myers (1995), Hedge et al. (1995), the Health and Safety Executive (1992), Stenberg (1989) and Finnegan et al. (1984) state that Sick Building Syndrome can cause the following ill health effects.

1. *Respiratory*
   - Runny nose
   - Sneezing
   - Dry sore throat
   - Blocked nose
   - Nose bleeds
   - Allergic Rhinitis (repetitive sneezing and a runny nose)
   - Sinus congestion
   - Colds
   - Influenza like symptoms
   - Dry Cough
   - Throat irritation
   - Wheezing when breathing
   - Shortness of breath
   - Sensation of having dry mucus membranes
   - Hoarseness of the voice due to inflammation of the throat and larynx
   - Sensitivity to odours
   - Increased incidences of building related asthma attacks
2. *Eye irritation*
   - Eye dryness
   - Itching of the eyes
   - Watering of the eyes
   - Gritty eyes
   - Burning of the eyes
   - Visual disturbances
   - Light sensitivity
3. *Dermal irritation*
   - Skin rashes
   - Itchy skin
   - Dry skin
   - Erythema (Redness or inflammation due to congestion in, and dilation of, the superficial capillaries of the skin.)
   - Irritation and dryness of the lips
   - Seborrheic dermatitis
   - Periorbital eczema
   - Rosacca
   - Uritcaria
   - Itching folliculitis

4. *Cognitive complaints*

- Functional headache that affect a person's performance, but which fail to reveal evidence of physiological or structural abnormalities
- Migraine headache
- Tension headache
- Sinus headache due to swelling of the mucus membranes
- Mental confusion

5. *Lethargy*

- Lethargic (The word "lethargy" comes from the Greek word *lethargos* which means *forgetful*.)
- Difficulty in concentrating
- Mental fatigue
- General fatigue that starts within a few hours of coming to work and which ceases after the person leaves the building
- Unable to think clearly
- Drowsy

6. *Gastrointestinal symptoms*

- nausea

7. *Other*

- Dizziness
- Unspecified hypersensitivity reactions
- Personality changes (that may be due to stress or ill health)
- Exacerbation of pre-existing illnesses such as asthma, sinusitis or eczema.

Redlich et al. (1997) found that the duration of time spent working in the building could affect the occurrence of the symptoms of sick building syndrome. For example, clerical staff may spend a longer period of time at their desk than management staff and so be more likely to be affected by adverse building conditions. Finnegan et al. (1984) found when studying sick building syndrome symptoms in 9 buildings that the incidence of the symptoms were much higher in buildings that were air conditioned than in buildings that were not air conditioned.

The Property Council of Australia (2009) has grouped the symptoms of sick building syndrome into three groups with each group having a common set of symptoms and a set of likely causes or sources to be investigated (Table 2.1).

Roy (2010) reported his investigations into causes of sick building syndrome identified that *irritant*, or *allergic dermatitis* is usually due to fibreglass dust or to formaldehyde particles in the building air. Fibre glass is a skin irritant and is commonly found in building insulation. Fibreglass particles can be blown into the air through the building ventilation system. Roy also identified that a common cause of *hay fever* is mould spores in the building.

Table 2.1 The three groups of the symptoms of sick building syndrome

Common symptoms	Likely causes or sources
Group A Headaches Lethargy Nausea Drowsiness Dizziness	Outdoor air rates and distribution. Possible air pollution. Carbon monoxide may be entering from outdoor air intakes. Other obvious pollutant generators from neighbouring or industrial sources may be present.
Group B Congestion Swelling Itching or irritation of eyes, nose or throat Sub-clinical symptoms (e.g. headache, fatigue, nausea)	Pollutants entering air stream from local pollutant generators; the outdoor air quality; HVAC related problems; building materials. Be aware of hypersensitivities and other pre-existing medical conditions in individuals. Lighting problems, e.g. flicker caused by magnetic ballasts and computer glare, which contribute to eye irritation. Ergonomic problems e.g. muscle strain, eye strain and fatigue.
Group C Cough Shortness of breath Fever, chills and/or fatigue after return to the building Diagnosed infection Discomfort and/or health complaints that cannot be readily ascribed to air contaminants or climatic conditions	Stimulated by thermal discomfort factors including temperature and humidity settings, outdoor air rates and distribution. Particulate pollutants such as dust are often irritants. More serious fever/chill problems can point to microbial contamination in the building. Microbial problems – Acute case scenarios relate to Legionnaires' disease and acute asthma. Chronic cases of asthma, infection and irritation are more wide spread. Examine cooling towers, HVAC system [including ducting] or outdoor air. May be related to problems with environmental, ergonomic or other job related psychosocial factors.

HVAC in this table is an abbreviation for Heating, Ventilation and Air Conditioning system.

According to the World Health Organisation (1993), definition of sick building syndrome and the Environmental Protection Agency (2010) the symptoms of sick building syndrome fade away after the person leaves the building. The cause of these signs and symptoms are unknown but they can reduce work efficiency, cause employees to take sick leave and to resign their employment position. Stenberg in a Chap. 25 in this book writes comprehensively about the symptoms of sick building syndrome but disagrees with the statement that the *symptoms of sick building syndrome fade away after the person leaves the building*. Stenberg's research (Chap. 25, this volume) has found that sick building syndrome can have a gradual onset and long duration of the symptoms, even when the person has left the building. This author found no research based studies that demonstrated that the person's symptoms resolved immediately on leaving the building; rather the studies examined by Stenberg (Chap. 25, this volume) identified that many of the symptoms remained for years after the person had left the building.

Diagnosis of Sick Building Syndrome is usually made by a Medical Practitioner based on the employee's self reported history of symptoms and of the Medical Practitioner's physical and clinical examination findings. The Medical Practitioner's diagnosis needs to be corroborated with an examination of the building in which the employee works.

To do this a trained occupational safety and health professional is required to perform a walk through survey of the building to identify if any other occupants of the building have the same symptoms, to check building factors (such as building ventilation, cleaning, maintenance, work station layout, if the employee works in an open plan offices with more than 10 work stations, if there are large areas of soft furnishing and open shelves, new furniture, carpets, painted surfaces, air conditioning, lighting levels, particularly if there is glare or flicker that the employee is exposed to when working), environmental factors (such as high temperature or excessive temperature variation, very low or high humidity, noise) and for pollutants (such as tobacco smoke, ozone, volatile organic compounds, dust particles, chemicals or fibres in the atmosphere, microbiological or fungal contaminants), work related factors (such as variety and interest in the work performed by this employee, employee's ability to control particular aspects of their work or work environment), personal factors (such as job satisfaction) and to conduct environmental monitoring to identify any pollutants in the air.

Most office workers spend 70–90% of their work time indoors so are affected by any indoor air pollution. Roy (2010) reports on a NIOSH (National Institute of Occupational Safety and Health) survey of 100 office buildings. This survey found that 23% of the occupants of these 100 buildings reported recurrent Sick Building Syndrome symptoms that included ear, nose and throat irritations and asthma.

2.3.3 Building Related Illnesses

Although Sick Building Syndrome is the popular term used in published literature and common language, building related illness may be a more accurate term because a building cannot get sick as it is not alive. However, building related illness is a term that is used to describe illnesses that occurs in a person in a particular building for which a cause is known. According to Passarelli (2009) some common building related illnesses include Mass Psychogenic Illness where a large number of people believe that they are affected by a particular set of symptoms where no known microorganism is identified as causing this illness. The difference between Mass Psychogenic Illness and Sick Building Syndrome is that Mass Psychogenic Illness is spread through social networks and the symptoms do not fade away when the person leaves the building. Mass Psychogenic Illness usually occurs in workplaces where there is a lot of tension and employees feel stressed.

Passarelli (2009) states that Neurotoxic Disorder is a building related illness that is caused by the presence of heavy metals and other neurotoxic substances in the building in which employees work. The list of building related illnesses is added to by Kreiss et al. (2006) who include rhinosinusitis, hypersensitivity pneumonitis, inhalation fever and other infectious disease as building related illnesses.

Roy (2010) states that building related illnesses are more serious than sick building syndrome as they do not subside when the person leaves the workplace. Roy lists building related illnesses as including the following.

- Building-related asthma. This is a hypersensitivity illness that has the symptoms of wheezing, coughing, shortness of breath and a tight chest. The symptoms may not appear until up to 12 h after exposure to the allergens in the building (The Property Council of Australia 2009).
- Irritant or allergic dermatitis. Skin rashes are most commonly caused by fibreglass or formaldehyde.
- Humidity fever. This can occur if a humidifier is used with the air conditioner and bacteria or fungi are aerosolized in the air through the humidifier. Humidity Fever is a flu-like illness the symptoms of which are fever, chills, muscle aches, cough, dyspnoea and fatigue. The symptoms usually occur 4–8 h after exposure. The symptoms usually subside once the person leaves the building but, in severe cases, can last 2–3 days.
- Hypersensitivity Pneumonitis. This is usually due to high fungal exposure in the building. It may also be due to regular dust exposure. It can be acute or chronic.
- Pontiac Fever. This is caused by inhaling the antigen of the gram negative bacilli *Legionellae*. Symptoms of Pontiac Fever are a rapidly rising fever alternating with chills. The infected person usually has anorexia, abdominal pain, malaise, myalgia, headaches, a non productive cough and diarrhoea is common. Pontiac Fever usually affects healthy young people and they recover spontaneously in 2–3 days with no treatment (Chin 2000).
- Legionnaire's Disease. This is a more severe form of Pontiac Fever and is caused by the same micro organism. The gram negative bacilli *Legionellae* (of which there are 35 species and at least 45 serogroups) lives in hot water systems, air conditioning cooling towers, evaporative air conditioners, hot and cold water taps, showers and anything in the building that has running water as the transmission of this micro organism from the water to humans is via the air that the person

breaths. Legionnaire's Disease occurs more commonly in people who are over 50 years old. As well as causing a severe form of pneumonia with Legionnaire's Disease there may also be brain, bowel and liver damage and kidney failure (Chin 2000; The Property Council of Australia 2009).

- Aspergillosis. *Aspergillus fumigates* causes allergic bronchopulmonary aspergillosis in the lungs if a person is immune compromised or has a pre-existing illness that lowers the effectiveness of the person's immune system. This micro organism can cause lung abscess, emphysema or fungus balls to grow in the person's lungs (Chin 2000).
- Other opportunistic fungal infections.

Research by Greer (2007) and by Chester and Levine (1997) identified that sick building syndrome can cause Chronic Fatigue Syndrome with the suffers of this Syndrome having health improvements when no longer working in the building that was causing their illness. Another building related disease is Multiple Chemical Sensitivity.

2.3.4 Multiple Chemical Sensitivity

Nakazawa et al. (2005) wrote a case study analysis of a woman clerical worker in Japan who developed sick building syndrome due to exposure to formaldehyde and other volatile organic compounds in her building workplace. This clerk's symptoms began when she was shifted to work in a new building that was being refurbished. Like her work colleagues she was aware of strong odours in the refurbished rooms. In May this employee developed nausea and had headaches at work. In June she developed a nettle rash, fever and pharyngeal pain. In July she developed a severe cough and nausea. This employee then took holidays as she felt that she was too sick to continue working. Her symptoms improved to some extent, but then she started reacting to chemicals outside the company building. She reported her medical condition and was diagnosed by a Medical Practitioner as having Multiple Chemical Sensitivity. She was awarded Workers Compensation for her illness and treated with Tachion 150 mg a day. Her symptoms then resolved and she was able to return to work. Not everyone with Multiple Chemical Sensitivity recovers as quickly.

Multiple chemical sensitivity is a building related illness that affects people who are highly sensitive, or allergic, to substances in the environment. Odle (2010, p. 2) states that Multiple Chemical Sensitivity was "recognised by World Health Organisation (WHO) as a medical condition in 1992." Multiple chemical sensitivity has proven difficult to diagnose as the symptoms seem to vary between one person and another as different people are sensitive to different chemicals.

Cullen (2002, p. 6), states that for a person to be diagnosed with Multiple Chemical Sensitivity this person should meet the following case definition requirements.

1. The syndrome is acquired, usually after the occurrence of a more clearly evident (although not necessarily serious) health event caused by environmental exposure, such as solvent intoxication, respiratory tract irritation, pesticide poisoning, or non-specific building related illness.
2. The patient experiences multiple symptoms referable to several organ systems, almost always including the central nervous system.
3. Although there may be persistent complaints between exposures, the symptoms are characteristically and predictably precipitated by a perceived environmental exposure.
4. The agents that may precipitate the symptoms are multiple and chemically diverse.
5. The doses of these agents that precipitate the symptoms are at least two orders of magnitude lower than the established thresholds for acute effects.
6. No test of physiologic function can explain the symptoms. Although there may be clinical abnormalities, such as mild bronchospasm or neuropsychologic dysfunction, these are typically non-specific and insufficient to explain the full scope of the illness pattern.
7. No other organic disorder is present that can better explain the pattern of symptoms.

Murphy (2006) states that some of the symptoms of multiple chemical sensitivity include shortness of breath, memory loss, dizziness, fainting, fatigue, depression, moodiness, nausea and skin rashes. A problem with multiple chemical sensitivity is that the person with this illness finds it difficult to leave a safe space without chemicals that they react to and to go to a workplace or any other building as they may have hypersensitivity reactions to the chemicals in the buildings and any products that are made from the chemicals that they are sensitive to. The American Academy of Environmental Medicine claims to have treated over 30,000 patients with multiple chemical sensitivity. Multiple chemical sensitivity is more likely to have affected people who worked in new or refurbished buildings.

2.4 New and Refurbished Buildings

Building emissions concerns. This account is based on observations at the time of the incident. There is much more information, documented evidence, e-mails and explanations available on file about the incident that could be argued might change the views indicated here.

Late in the year part of a building was refurbished. The refurbishment included new furniture laminates, carpets and painting. Staff were moved into the newly refurbished area and almost immediately started to complain of various health difficulties including (as written in an e-mail by a staff member in the area):

- Headaches/migraines over multiple days;
- Itchy eyes;
- Nose bleeds;

- Running nose; and
- Difficulty breathing – Pain in chest, wheezing, cough, blocked sinuses, heavy feeling in your lungs.

Subsequent checks in the building did detect some odours that could have been the cause of the staff health complaints. An occupational Hygienist was engaged to look into the concerns of the staff. Air monitoring was carried out to measure for Volatile Organic Compounds (VOC's) including formaldehyde, a known by product of the manufacturing process of chipboards and foam furniture. The results of the air monitoring did not find any high levels of any VOC's including formaldehyde.

Advice from the hygienist was that "off gassing"** of the materials and glues that make up some types of new chipboard can produce low level emissions. If the timeframe between manufacture and delivery is short, emissions from the manufacturing process could still be occurring. If furniture is then left in an un-ventilated area, the emissions could build up to a point where the smell could be sufficient to effect individuals depending on their susceptibility and tolerance of those emissions.

Other observations by the Hygienist were that the air conditioning intake and out take vents in this location of the building were positioned so close together that fresh air was being immediately removed from the building without first circulating through the building.
In conclusion:

- Generally speaking the conclusions of the investigation were that due to the use of glues to stick laminates and carpet/vinyl, newly painted surfaces, foams that had been used to manufacture new chairs and fresh air circulation in this part of the building, that the building following the refurbishment did have a strong smell, something that could be described as a "new building smell".
- A chip board that had been used to manufacture office furniture and the "off gassing" of new chairs were identified as the two main sources of the odours that were apparent in this part of the building.
- There is evidence that some staff in the area did suffer from the ailments that they claimed they were suffering from.
- One person's tolerance to emissions and vapours may differ from another so for those people the odours in the building may have been enough to set off the health effects that they experienced.
- There was some allegation that the staff in the area did not want to move into the building and that the claims that were being made were exaggerated.
- Air monitoring did not detect high levels of any VOC's.

The staff in the area were moved out of the building, the building air conditioning was turned up to 100%, doors and drawers were left open and the building odours were reduced to such an extent that staff returned to work in the building approx 2 weeks later.

**"Off gassing" is a term to describe the process that when foam and chipboard is manufactured, the glues and processes that are used continue to release odours for some time after their manufacture. (Malcolm)

This Occupational Safety Professional's story explains some of the effects that building products can have on the health of building occupants. There were two main causes of employees experiencing these health effects. The first cause was that many of the building's new furniture and fittings produced air borne chemicals that contaminated the atmosphere. Brinke et al. (1998) identified that often the fumes from volatile organic compounds (VOCs) in a building, when measured with hygiene monitoring equipment, are below the threshold level that is supposed to cause health effects when each VOC is measured individually. This is what was reported in the above case study. When Brinke et al. (1998) conducted research in 22 office areas in 12 buildings these researchers identified that the combined effect of 39 VOCs when measured together produced irritant symptoms and other sick building syndrome symptoms in the building occupants that each substance on its own did not when present in the building at low levels. The combination of VOCs together produced a synergistic effect that caused the symptoms of sick building syndrome in the building occupants. This seems to be a similar situation to what respondents report in this case study.

A second problem in this case study was that the building ventilation was inadequate as the intake and outlet vent for the building's air conditioner were located so close together that air that as air entered the building it was immediately sucked out without circulating throughout the building. For the building odours to disperse the building doors had to be left open for 2 weeks as the windows did not open and the air conditioner was ineffective in dispersing the chemical pollutants.

2.5 Chemical, Gas and Fibre Pollutants

In the 1980s new buildings in Australia started to have chip board, and then particle board, used as a building material instead of real wood. The fibres in chip board are held together by formaldehyde. Out gassing of this formaldehyde occurs for months after manufacture. Formaldehyde is one of the most common indoor air pollutants. Roy (2010) records that common indoor contaminants that can cause sick building syndrome include volatile organic compounds (VOCs) including formaldehyde from building furnishings, coatings and adhesives, building materials and equipment and airborne particulates that include dust and synthetic mineral fibres (SMF) – fibreglass, asbestos, etc.

The Property Council of Australia (2009) identified the indoor air pollution shown in Table 2.2 as causes of sick building syndrome symptoms.

Table 2.2 Indoor air pollution as causes of sick building syndrome symptoms (Property Council of Australia 2009)

Pollutant	Sources
Carbon dioxide (CO_2)	CO_2 is produced from human respiration. If there are too many people in the building space, or if there is inadequate ventilation, then CO_2 levels can rise. If CO_2 remains below 800 ppm 95% of the building occupants find the air acceptable.
Carbon monoxide (CO)	Levels above 2 ppm cause headaches, dizziness, nausea, fatigue, flu-like symptoms, breathlessness & decreased work capacity. CO binds to red blood cells to prevent them from carrying oxygen. CO may originate from tobacco smoke, vehicle exhausts, gas appliances, propane refrigerators, solvents, etc. CO can enter buildings through poorly located air intake ventilation ducts, basement car parks and doors or windows.
Nitrogen oxides (NO) & Nitrogen dioxide (NO_2)	Produced by tobacco smoke, vehicle exhaust, gas appliances and incinerator combustion. Is a deep lung irritant and is carcinogenic. Causes irritation of the eyes & upper respiratory tract. In asthmatics it can cause swelling and reduced lung function. Long term low level exposure can lead to emphysema and make people more susceptible to respiratory infections.
Sulphur dioxide (SO_2)	Can enter ventilation system from external industrial environments. SO_2 is an irritant to the respiratory system, reduces lung function, constricts the blood vessels in the lungs and increases mucus flow.
Polycyclic aromatic hydrocarbons (PAHs)	A large family of complex organic substances; includes tobacco smoke. Cause general sensory irritation, cancer and affects the cardiovascular system.
Volatile organic compounds (VOCs)	Over 5,000 VOCs have been identified in indoor air. VOCs are organic (carbon based) substances that evaporate into the air at ambient temperatures. VOCs have widely varying toxicity, irritant and odour properties. Some cause irritation of the mucus membranes of the eyes, nose & throat, dizziness, nausea and headaches. Some are carcinogens and mutagens. Common sources of VOCs include tobacco smoke, office equipment, solvents, cleaning agents, particle board, carpets, floor polishes, furniture, adhesives, paint, printer & photocopier cartridges and emissions, printed materials, marker pens, electronic equipment and air fresheners. Comprehensive information about VOCs in indoor environments is provided in this book in a Chap. 16 written by Gallego et al.
Formaldehyde	Contained in glues, particle boards and bonded mineral fibre insulation. Is a nose, throat & eye irritant, causes headaches & fatigue and is an allergen to asthmatics. It is a carcinogen.
Ozone	Formed by electrical discharges from photocopiers, laser printers, air filters, electric motor brushes and air ionisers. Is toxic even at low exposure levels. Can cause respiratory irritation, shortness of breath, coughs, eye irritation and headaches.
Asbestos	Until the late 1970s was used in more than 3,000 products. Is often present in old buildings. Is hazardous if the fibres become loose and airborne. Can cause lung cancer.

Table 2.2 (continued)

Pollutant	Sources
Synthetic fibres	Synthetic mineral fibres include fibreglass, slag fibre insulation, rock/mineral wool all of which can be used as building insulation. There are other synthetic fibres that can be found in ceiling tiles. Air borne fibres cause skin irritation, eye irritation and aggravate asthma symptoms.
Dust	General dust, construction dust, paper dust, soil particles. Air borne dust causes irritation of the throat, lungs and eyes.
Pesticides & biocides	These are used in some building air conditioning systems. The effects of these chemicals have not been studied in relation to being a cause of sick building syndrome symptoms.
Odours	Odours do not usually cause health effects but can cause discomfort and may be a sign of air borne contaminants. Common building odours can include off gassing from building materials and furnishings, chemical cleaning residues and mould odours.

This is a brief summary of common indoor air pollutants that can affect air quality. As well as being found in new buildings these indoor air pollutants can be found in old buildings.

2.6 Old Buildings

I have a number of proven instances of sick building syndrome with police buildings. A classic example is the situation at a Capital City Central Police Station and Watch House. This is a facility that was built in 1965 and has been in continuous 24×7 use ever since. The building has concrete cancer. The faults in concrete pillars, walls and floors is caused by the reinforcing rusting through the plaster walls and a general break down of the concrete aggregate leaking through the plaster into toilets, change rooms and other areas where dampness is present. The risks associated with health are undetermined regarding silica dust in the atmosphere. Mould spores and bacteria problems are clearly present in the following areas.

1. Spaces between concrete floors and metal ceiling panels. The panels have small holes where the dust debris is able to filter through into the internal areas of the building.
2. Door vents where there has been a gradual build up and blockage of the vents. Dust and bacteria is blown out by the air conditioning air flow.
3. Floor tiles that have asbestos content. Asbestos particles have become loose through rubbing by ill fitting doors and are free to float around the atmosphere.
4. All areas where taps and sink drains have not been cleaned thoroughly, causing mould and bacteria to build up.
5. Build up of mould and bacteria in areas that have been very difficult to clean.

An extensive occupational hygienist report recorded numerous other associated health risks. The situation is not helped by the constant flow of customers who bring with them individual health problems that can spread throughout the complex via the air conditioning; it too is 44 years old, or by lack of complete and thorough hygiene and cleaning practices, which should match those that exist in a hospitals, but fall well short. This is a particular problem in the kitchen facilities that attract slack habits. Fresh air cannot be released into the building. Security considerations demand that the windows are barred and closed.

Another example is the older part of a suburban Police Station built in 1897 from construction methods that did not include damp courses or cavity walls. The building, including the extensions built in 1980, has numerous sick building syndrome issues.

1. Mould spores are emitted through the plaster walls and ceilings in wet areas.
2. Old fire doors have asbestos sheeting.
3. Floor joists, floor boards, skirting boards and doors are constantly attacked by white ants causing collapse.
4. Lead paint is exposed to the environment.
5. False ceiling spaces harbour all sorts of debris and mould that has dropped from the original ceiling (Probably horse hair and fibrous) material. This is exposed to the atmosphere through ceiling vents and manholes.
6. The concrete extensions has an asbestos roof, currently unsealed and presenting difficulties for sealing under the exposed eaves on the third floor. Movement between the asbestos sheets can cause the fibres contained in the sheets to break free and float around the atmosphere.

> Although there has been no official comparison research conducted, working in the affected places exposes employees to increased health risks for general illness compared to working in modern facilities that can cope with the hectic nature of contemporary 24×7 policing. (David)

These two stories, told by the same Occupational Safety Professional, highlight problems with the police officers working in old buildings that can cause employees to take sick leave related to experiencing sick building syndrome symptoms. The documented problems in these two stories include police officers inhaling dust debris, asbestos fibres, lead (in Australia both lead and mercury were used in paint prior to 1990 and both can be toxic to humans), mould and other micro organisms.

2.7 Biological Hazards

There are biological contaminants in many buildings. Biological contaminants can include bacteria, fungi and animal products. Air Conditioning and Indoor Air Quality (2006, p. 2) reports that "there are over 200,000 species of fungi and microbes known, of which approximately 60–100 are a cause of concern in the indoor environment." A common contaminant that causes sick building syndrome is mould. Excess humidity with poor ventilation in a building allows mould to grow. The presence of mould is usually associated with water leakage, condensation or a relative humidity in the building of above 70%.

> My sick building story involves a former home in Midland. The house was built around Federation (1900). I moved in and noted that the walls were continually damp, so I researched methods that would be cost effective to combat rising damp. I chose reverse osmosis, not knowing the residual health problems this would cause me. For months I had a terrible cough, so bad in fact that on one occasion the cough was so severe I knocked my head on the floor and I was out cold. I recall the ambulance drivers taking me to Swan Districts Hospital. On my return home I decided to investigate what was going on (by now I had been referred to a specialist at Royal Perth Hospital.) I lifted the skirting boards and it was infested with mould. You could actually see the spores in the air. I was so sick. I put the house on the market and moved out straight away. I recovered within days of leaving the place. There is no doubt that this house was sick and made me very unwell. It still stands today, however it is now used as a psychologist's suite. (Jeremy)

This story, provided by an Occupational Safety Professional, illustrates the health effects that can occur from having mould in a building. This private home would have required extensive renovations to make it safe and healthy to be used as a workplace for a group of psychologist to see and treat patients in the building rooms. When investigating causes of sick building syndrome in Western Australia Peter Roy (2010, p. 2) identified that a common cause of sick building syndrome in the buildings that he investigated was poor ventilation and mould in the buildings. He provided the following three stories to illustrate these causes.

> **Pilbara** – two Australian energy companies managing large holdings of housing and accommodation units had significant problems with widespread and reoccurring mould growth that contributed to adverse health risks for workers and their families. Although much time and effort had been spent on mould remediation, the major root cause of mould

growth – inadequately designed HVAC equipment – had not been identified or adequately addressed.

South Western Australia – a Public Primary School had wide spread worker complaints and one severely affected staff member in newly refurbished offices. The investigation uncovered problems with lack of effective ventilation, reoccurring moisture leakage and condensation, and presence of an apparently toxigenic form of the mould *Fusarium* sp.

Perth – a large religious organisation had problems with wide staff complaints linked to deficiencies in building ventilation systems (split units) and poor humidity control. Localised moisture infiltration also lead to mould growth in one area of the facility. Corrective actions included mould remediation, interim humidity control measures, building modifications to masonry walls and planned installation of modified HVAC systems.

In these three stories by Roy (2010) it is clear that having inadequate ventilation and excessive moisture can lead to mould growth in buildings. It is also clear that building occupants can have allergic reactions to mould toxins.

The Property Council of Australia (2009) divides biological building pollutants into those that are living and those that are non living. Living biological pollutants are viruses, bacteria, moulds and other fungi. These are capable of causing infections. Viruses are usually introduced into the building by humans, but the stability, concentration and distribution of the viruses may be influenced by the building's ventilation rate and relative humidity level. Bacteria and fungi become established and proliferate in humid conditions and on wet surfaces, particularly if there is dust present or if the building has been water damaged. Components of the air conditioning system, particularly if poorly designed or maintained, may be a site of bacterial, fungal or protozoan growth and may spread these micro organisms throughout the building atmosphere. People can have allergic reactions to micro organism mycotoxins, endotoxins or antigens (Shoemaker and House 2005). Protozoans and dust mites can be present in building air and these usually cause allergic conditions such as asthma. There are two chapters in this book, one by Pinzari (Chap. 9, this volume) and the other by Pinzari and Montanari (Chap. 11, this volume) that provide further detail about biological hazards, particularly mould, that can grow in buildings and cause sick building syndrome.

Bholah and Subratty (2002) conducted research in 23 buildings with offices in Mauritius to identify if there was any relationship between bio-contaminants in these buildings and the incidences of sick building syndrome symptoms. These researchers collected viable colonies of micro organisms from the researched buildings using a Casella slit sampler and gave a self report health questionnaire to the occupants of these buildings. The researchers identified that there was a strong association between offices that had moderate to heavy microbial contamination and the symptoms of sick building syndrome as the occupants of these offices experienced headaches, excessive mental fatigue, loss of concentration and forgetfulness, particularly if there was high fungal spore counts in the building atmosphere.

Cooley et al. (1998) conducted a 22 months research study in 48 schools in the United States of America in which there were complaints of sick building syndrome symptoms by the building occupants. The indoor air quality of these buildings was tested. In all cases it was identified that the cause of the occupants experiencing the symptoms of sick building syndrome were either fungal contamination with *Stachybotrys* species or *Penicillium* species of mould. In all cases it was determined that the initial microbial growth commenced after a water leak occurred and wetted the building materials. Following this the HVAC system had become contaminated with the microbial growth. Based on the findings of this research it was determined in these 48 schools the cause of sick building syndrome symptoms in the building occupants was due to the *Stachybotrys* or *Penicillium* species of mould. Remedial action was under taken to remove the mould in these schools building materials and air conditioning systems.

Non living biological pollutants can also cause sick building syndrome symptoms as they are associated with allergic conditions in susceptible people. These pollutants can originate from both inside and outside the building. If the outdoor air filtration system is inadequate or damaged then outside air contaminants, such as pollen, can enter the building. Inside the building dead skin cells, animal excreta, insect body parts (such as parts of a dead cockroach that are an allergen for some people) and dander may be circulated, particularly where the filtration of recycled air is inadequate. These factors do not just affect old buildings they can affect the occupants of all buildings.

2.8 All Buildings

2.8.1 Introduction

In all buildings the indoor building environment is affected by the air quality, lighting, building windows, acoustic comfort, radiation, layout of the building rooms and equipment and by ergonomic factors. Indoor air quality is important to the occupants of all buildings. Hedge et al. (1995), when analysing health survey results from 4,479 respondents from 27 air conditioned office buildings, reported that claims of sick building syndrome symptoms increased when employees perceived that the indoor air quality was poor. Indoor air quality is affected by the environmental factors of temperature, humidity, amount of carbon dioxide in the air, air contaminants, air circulation and the ratio of outdoor air to recirculated air. All of these can affect the building occupants' health, comfort and productivity. For all indoor areas having adequate ventilation is important in preventing the occurrence of sick building syndrome symptoms.

2.8.2 Ventilation

An experienced medical practitioner commenced work in a new building. This building had 4 air conditioners. Each air conditioner was used for a group of rooms. A problem with this sharing arrangement was that some rooms were too hot for the occupants while other rooms

> were too cold. The medical practitioner's room shared that air conditioning with the patient waiting room. Some of the people came to see the medical practitioner because they had respiratory infections. While sharing the same air conditioner as the patients the medical practitioner constantly had viral infections. As a risk control measure this medical practitioner first blocked the air conditioner with cardboard. His health improved immediately. He then organised for his room to have a sky light and a separate air conditioner. He has had good health ever since. (Andrew)

This story, provided by a Medical Practitioner, illustrates problems that can occur when a ventilation system is shared in a building and micro organisms are recirculated throughout the building by the air conditioning system. It also highlights that not all building occupants are comfortable working in the same indoor air temperature.

Roy (2010) provided two stories about the effects of having inadequate ventilation in a building. His first story, which was reported in the Lewiston Morning Tribune, concerned the students and teachers at Pomeroy High School in Washington where 12 of the 21 staff members reported experiencing sore eyes, dry throats, coughing and other symptoms of sick building syndrome. An investigation determined that the school's ventilation system was not operating properly and that this was the cause of the building occupants' symptoms. The second incident, which was documented in the Boston Globe Newspaper, occurred at the University of Massachusetts in Boston. In two incidents at this University that occurred a few days apart first 8 people, then 27 people, from this university were treated for burning lips, nausea and tight throats. The Boston Health Department closed the entire campus so that indoor air quality investigations could be conducted. The problem was identified as buildings in this University having an inadequate ventilation system.

From these stories it can be seen that having adequate ventilation in a building is important. Roy (2010) states that in the United States of America between 1978 and 2005, when NIOSH investigated the causes of sick building syndrome in more than 700 problem buildings, in 53% of the cases the root cause, or the contributing root cause, was inadequate ventilation in the building. For best practice Roy (2010) recommends that the fresh air ventilation flow rate should be 15 litres per second (lps) per person for an office or for other building rooms that are occupied by people who are performing work tasks.

In Australia, New Zealand, the United Kingdom and the USA the minimum acceptable air flow rate is 10 litres of fresh air per second (lps) per person for each person working in an office. Research by Roy (2010) identified buildings with higher than the minimum fresh air ventilation rates have lower employee absenteeism and fewer complaints of employees experiencing adverse health effects while working in the building. For each increase of 0.5 lps/person in fresh air employee absenteeism was decreased by up to 2%. It was found that there was a decrease in sick building syndrome symptoms of 33% when the ventilation rate was increased from 8.5 to 25 lps/person. Conversely, when the fresh air flow rate was decreased from 8.5 to 5 lps/person there was a 15% increase in employee reports of sick building syndrome symptoms.

Roy (2010) reported that research work conducted by Seppanen (2006) demonstrated that with a ventilation rate of 15 lps/person workers performance in typing, maths problem solving and in proof reading was much higher than when this work was performed with the minimum ventilation air flow rate, but a flow rate of above 17 lps/person made little additional improvements in employees' work productivity. This knowledge is important to have when designing building ventilation systems and when maintaining ventilation systems.

Roy (2010, p. 9) had been told by some employers that "More fresh air and greater capacity HVAC systems are just too expensive to operate!" His answer to this was that employee salary, staff turnover costs, recruitment and retraining costs are much higher than the cost of having adequate ventilation in a building. Roy's calculations demonstrated to employers that staff costs are 100 times the total building energy costs to provide adequate ventilation. He demonstrated that even a 1% increase in employee productivity would offset a 50% increase in building energy costs. Dingle (2010) supported Roy's comments and provided the following information. On average employees' salaries are \$100–\$200 per ft^2 of a building. Energy costs are \$1–\$2 per ft^2 of a building. For increasing employee productivity and comfort, as well as having adequate ventilation, it is important to also consider the building's indoor air temperature and humidity as complaints of being either too hot or too cold can be associated with mucosal irritation, headaches and fatigue (Hodgson 2002).

2.8.3 Thermal Comfort and Humidity

The most comfortable temperature inside a building is between 20 and 23 degrees Centigrade (°C) in winter and 20–25°C in summer with relative humidity of 40–60%. An indoor building temperature above 25°C can cause headaches and fatigue while indoor temperature below 18°C is likely to cause chills and influenza like symptoms. In Australia the building temperature of an air conditioned building is usually set at 22°C. Indoor air comfort can also be affected by radiant heat from the sun coming through windows on the west or north side of the building in the afternoon. Comfort of building occupants is also subjective as some people like a warmer room temperature while others prefer the temperature to be cooler. Individuals have different metabolic rates; some people are over-weight and some are under-weight, some employees are very active performing physically demanding work while other employees perform sedentary work, but in many air conditioned public buildings all people are subjected to the same building temperature. The higher the humidity in the building air the warmer the air feels.

Humidity is the amount of water in the air. The humidity ratio in the air is the mass of water in each kg of dry air. Relative humidity is "the percentage of water vapour in a gaseous mix of air and water vapour, compared to the vapour pressure of water within the mix when saturated at the same temperature" (The Property Council of Australia 2009, p. 17). At 20% relative humidity the air would readily take up water. It would be considered dry air. At 50% relative humidity the air would hold about half as much water vapour as it can hold. At 100% relative humidity the air could no longer absorb any more water vapour as it would be saturated and the air would feel heavy and oppressive. Indoor building air humidity outside the range of 35–65% can cause adverse health effects.

The Property Council of Australia (2009, p. 18) identifies that excess indoor air humidity can cause the following problems.

- Fatigue, reports of "stuffiness", headaches and dizziness (particularly when relative humidity exceeds 80% and temperatures are also high);
- Favourable conditions for the growth of micro-organisms, especially when condensation is present; and
- Increased rate of "off-gassing" from building materials, especially in the case of formaldehyde and other volatile organic compounds.

The following problems may occur where humidity levels are too low:

- Dryness of the eyes, nose and throat;
- Increased frequency of static electricity shocks;
- Increased rates of ozone formation;
- Stabilisation of certain viruses, such as influenza; and
- Allergic responses by asthmatics.

As can be seen from these two lists building humidity can very much affect the health of the building occupants. For most of these environmental effects, once the person leaves the building, they should no longer be affected by the building humidity and their ill health symptoms should resolve. Building occupants are also affected by noise (acoustic comfort) in the building. The health effects due to building noise may also resolve when the person leaves the building.

2.8.4 Acoustic Comfort

When building occupants have individual offices or work areas that are enclosed and sound proof the noise that occurs in a normal building is not a problem. However, particularly in open plan offices and reception areas with telephones ringing and with increasing volume of people and the conversations that these people hold, noise (unwanted sound) can become difficult and even irritating to people who are trying to think and concentrate on completing their own work. Too much distracting noise interferes with short term memory processes, can cause headaches and even personality changes as the building occupant becomes increasingly frustrated and irritated with their inability to concentrate.

In a research study by Niven et al. (2000), the researchers conducted significant environmental monitoring, that included building air monitoring and noise monitoring in 5 different buildings. These researchers gave a self report health questionnaire to the occupants of these buildings. Completed questionnaire responses were received from 1,131 people. Analysis of these questionnaire responses identified that that low frequency noise in these buildings was a significant cause of sick building syndrome symptoms. As well as noise levels lighting levels can affect the health of building occupants.

2.8.5 Lighting

Where ever possible there should be natural lighting in a building as this improves occupants' comfort and health while reducing energy costs. Due to the design of some buildings natural lighting alone is insufficient for work tasks to be performed effectively so artificial lighting is also required, particularly if the building is to be used outside of day light hours. When considering building indoor lighting there are two Australian Standards that should be followed. The first is AS/NZS 1680:2006 Interior lighting, Part 1: General principles and recommendations. The other is AS/NZS 1680.2.2:2008 Interior and workplace lighting – Specific applications – Office and screen-based tasks. Both of these Standards provide appropriate recommendations on the illuminances required for various types of work tasks, activities and building interiors. Passarelli (2009) identified that a significant lack of natural day light, flickering mechanical lights or lights that are too bright or too dull for the work that needs to be performed can contribute to causing sick building syndrome symptoms.

According to the Property Council of Australia (2009, p. 24) common problems that can occur with artificial lighting can include the following:

- inadequate lighting design or intensity leading to widespread or localised dark areas;
- inappropriate lighting for specialised tasks;
- flicker arising from the oscillation of fluorescent lights typically associated with using magnetic rather than electronic ballasts;
- the colour of the lamp source;
- poor configuration of lights; and
- unsympathetic colour schemes can contribute to lighting discomfort.

Inadequate lighting can cause headaches, eye strain and other symptoms of sick building syndrome. Most of the health effects due to poor lighting should cease when the person leaves the building, but continued eye strain may contribute to long term vision problems More details about how lighting can affect the occurrences of sick building syndrome symptoms occurring in building occupants and ways to prevent this occurring are included in the chapter in this book written by Abdul-Wahab and Ahmed (2011) titled "Improvement of the illumination levels combined with energy savings for a residential building."

When looking at the occurrence of sick building syndrome symptoms and building related illnesses a group of people that the Property Council of Australia (2009) recommends considering are the building maintenance workers. The following story was supplied by a building maintenance worker when asked if he had a story about sick building syndrome.

2.9 Building Maintenance

I have worked in a major metropolitan hospital in Australia as the maintenance fitter with responsibilities for the general upkeep and maintenance of the HVAC air conditioning system. I can say with certainty these systems don't get better with age. The upkeep/service and maintenance to wearing equipment for an ever growing system that must function efficiently on a tight streamline budget have consequence. I will cite a couple of examples I experienced at the hospital.
The hospital was built in the 1980s. The four chillers (one large and three small) operate in sequence as the need arises, that is to say the large Chiller due to its capacity to cool a greater volume of water and push it out and around the hospital plus the nursing home is the main operating system and functions alone, on its own. They are expensive to run, more so during start and warm up prior to going into service, The second chiller is basically there to "take up slack" and supplement the larger to supply additional cooling water to the system when the core temperature of the hospital rises. This is most noticeable in the warmer months. When the desired temperature of 23°C is achieved the second chiller drops out. For this second chiller to start up and drop out many times during the day is cost prohibitive. The three smaller chillers are all electronically attached to the larger and are controlled automatically.

Power consumption in the hospital runs into tens of thousands of dollars per month and as a cost saving measure the three smaller chillers are removed from the system, placed into manual mode to remain in the off position. During the cooler months this is not problematic to the extent that it requires constant vigilance and is left to the monitoring system.

The hospital expanded and renovation work was undertaken in its second decade of operation increasing the patient capacity from approximately 180 to 260 beds in addition to the private practice located north of the building and a significant user of the ventilation system. The problem is the existing large chiller was not upgraded to cope with the extra work load and went from 70% running capacity to nearly 90% and for a machine that is being pushed to its limit.

In the warm months as soon as the outside temperature reached 25°C it became problematic in that the system was unable to keep with demand. This is due to the new larger areas drawing more cooling water at a faster rate, the cooling chiller unable to produce any more fluid into the system, therefore the rate of flow to area's further away have a slower rate (trickle) of water insufficient to fill the coolers and in some instance not at all.

An example of this is one of the operating theatres that was used by Dr X has the cooling system at the end of two larger theatres and when the draw on the system occurred there was no water left in the system for his operating theatre. In a normal situation his theatre temperature is steady at 18°C with the air taken directly from outside, filtered and cooled. On a hot day when a draw occurs and zero water flows through the cooler the temperature can rise equivalent to the outside and on occasion it was 36–40 degrees Centigrade and the temperature rose inside of ten seconds while the doctor was in the middle of a procedure. I know of two occasions where the doctor moved out of the theatre and into another further down the hall that was on a different cooling line while the patient was still on the table.

As areas become cooler the system draws less cold water and the flow to the hot areas slowly returns. The time period for this is usually between 30 minutes and 1.5 hours. The quick solution is obviously to start the second chiller. Unfortunately only the assistant engineer had authority to do this and his familiarity with the system made the judgment call cost verses quick comfort gain.

The higher areas of building and extremities are always the first to suffer. The third story of the building can take a long time on a very hot day to cool down and to see staff and patients alike who are hot, lethargic, sweaty, irritable and generally uncomfortable does not reflect best practice when it comes to the dollar as the bottom line.

The hospital has had a further expansion in recent times by adding two extra wings to the existing structure and upgraded the chiller. The same problem exists because the new chiller is designed more to the pre expansion size and problems experienced earlier have been repeated with the additional new buildings.
Experience and handover knowledge is essential to the servicing of equipment within the hospital. An example of knowledge not being passed on and not known is the filtration system feeding the elevator shaft. The engineering staff had always assumed the filtration system feeding wards two and three also fed the elevator. This was not the case and it was only after doing a task in the vicinity I noticed a door at the far side. On opening it I found very dirty, slimy thick dirt caked row of filters that had not been changed in over a decade.

A systematic approach to regular maintenance is essential to the wellness of any building, more so being a caring environment to the sick. Although I never had an induction into the hospital there was certainly no training provided into the system and for the most part you were left to fathom it out.

The engineering department comprised the following people

- Head Engineer
- Assistant Engineer
- Two Electricians
- Fitter
- Carpenter
- Plumber

The following people developed cancer.

- One Electrician (lymphatic cancer)
- Fitter (thyroid cancer)
- Carpenter (stomach cancer)
- Plumber (blood disorder)

We all had different treatments and all were healthy prior to working at this hospital. The area I worked in was directly behind the main switch room for the entire hospital and I have often wondered if there were any effects from this that caused our cancers. Regardless of the cause, after my diagnosed of cancer (the 4th person in a department of 7 staff members to be diagnosed with cancer) this department was relocated to another area of the hospital well away from the switch room. There has been no further incidence of employees in this department developing cancer. (Laurie)

As well as describing ventilation and ventilation maintenance problems that affected the health of people who used the building this story identified that of the five non-management building maintenance workers four developed cancer. This is not a normal symptom of sick building syndrome, but the building maintenance worker who provided this story seemed to think that his, and his co-workers' cancer could have been caused by his workplace being located behind the hospital switchboard which may have been responsible for electromagnetic radiation from the communication equipment entering the maintenance workshop. Even low levels of electromagnetic radiation, when employees are exposed to these on an ongoing basis, have been known to cause cancer (The Property Council of Australia 2009). It is important to note that once the maintenance workshop was relocated away from behind the hospital switchboard there were no more cases of cancer that developed in these maintenance workers.

Another cause that has been considered as causing sick building syndrome symptoms in building occupants is office work.

2.10 Office Work

Office workers have been the most researched occupational group in relations to the occurrence of sick building syndrome symptoms. Office workers spend most of their working hours in an enclosed building so are very much affected by the indoor air quality and other factors inside their building. Office workers can be affected by the equipment and products that they use as part of their work. This section describes some of these factors that have been documented in research study findings to cause symptoms of sick building syndrome in office workers.

Godish (1995) identified that carbonless copy paper contains many chemical including hydrogen terphenyls, aliphatic hydrocarbons, diaryl ethanes, alkyl napthalenes, chlorinated parapffins and alkyl benzenes. Colour developers for photocopy paper contain phenolic resins, salts of aromatic carboxylic acids, phenolic resins and many other chemical compounds. In research studies, Godish (1995, p. 95) identified that office workers who handled a large number of papers reported the following symptoms of ill health that they perceived were related to their work. "Itchy rashes on the hands, swollen eyelids, headaches, burning throat and tongue, fatigue, excessive thirst, burning sensation on the face and forehead, backache, nausea, eye irritation, sore and dry burning lips, facial rash and dry throat." It was believed that the rupture of the capsules on the paper containing the colour forming chemicals and the solvents used in the paper were the causes of these health effects. The office employees reported that their ill health effects occurred 2–3 h after commencing work and resolved at night and over the weekends when they were not working in their office.

Hedge et al. (1995) in a research study that included the occupants of 27 buildings, identified employees who used their computers full time reported more symptoms of sick building syndrome than employees who used computers occasionally or not at all. These researchers theorised that this might be because the electrostatic field generated by the VDT screen attracted more particulate contaminants into employees' breathing zone.

Other office equipment that was identified as causing the symptoms of sick building syndrome in office workers by Godish (1995) included photocopy machines whose toner emits VOCs, electrostatic photocopy machines that omit ozone and laser printers that can produce elevated levels of Freon and Acetone in the breathing zone of the operator. Another cause that has been considered for sick building syndrome in office workers is psychosocial factors as traditionally office workers have had poor control over their work tasks and work environment.

2.11 Psychosocial Factors

Roy (2010), when investigating cases of sick building syndrome only found psychosocial factors present when there had been long standing indoor air quality issues and the people in the workplace had not had their incidences of ill health, usually due to the poor air quality in the building, dealt with effectively. Greer (2007) agrees with these findings stating that her review of published literature identified that psychosocial factors were a symptom of sick building syndrome, not the cause, with the effects of exposure to some toxins causing anxiety, changes in mood and in behaviour due to ill health being experienced by the building occupants.

The Property Council of Australia (2009) identified that work related stress can cause people to become sick, but, this is not something that is in the control of the building owner, unless the building owner is also the person's employer.

In the case study under "New and Refurbished Buildings" the Safety Professional wrote that *There was some allegation that the staff in the area did not want to move into the building and that the claims that were being made were exaggerated.* This would be a psychosocial factor that could increase complaints about the symptoms that these employees were experiencing as they were dissatisfied with their new accommodation. When people are dissatisfied, or angry, they are more likely to make complaints about factors that, if they were satisfied with their work and workplace, they would have ignored.

Workplace Services (2000) agrees with this and documents that poor management practices and other factors that cause employees to have low morale, while not causing sick building syndrome symptoms, do affect the way that the symptoms of sick building syndrome are perceived and affect the building occupants' level of tolerance of their ill health. Particularly important was the level of control that the person could exert over their work and over their work environment and the response of management staff to their ill health complaints.

Marmot et al. (2006) agreed with this as their research findings from the Whitehall 2 study, which analysed the questionnaire results from 4,052 participants from 44 buildings in which occupants of the building reported sick building syndrome symptoms, identified that respondents who had high work load demands, low work related support, low control over their work and low control over their work environment reported more symptoms of sick building syndrome than those with control. The research study by Hedge et al. (1995) identified that employees with low job satisfaction reported more symptoms of sick building syndrome than employees with high job satisfaction.

A research study was conducted by Mendelson et al. (2000) in 5 hospitals in Canada. Hospitals 2 and 5 were not defined by their Occupational Health and Safety

Committee as being sick building sites. Hospitals 1, 3 and 4 were and these hospitals all had employees on long term sick leave with symptoms of sick building syndrome. Hospital 3 had over 200 employees on extended sick leave with sick building syndrome symptoms. In hospital 3 there had been problems with the air quality in the hospital building in that sulphuric acid, hydrochloric acid and sodium hydroxide had entered the building through the air intakes causing adverse health effects in employees. Cleaning fluids used in this hospital contained phenol and formaldehyde. Exposure to these substances also affected employees' health.

At these 5 hospitals 1,853 union members were surveyed in relation to factors that affected their health when at work. It was found that symptoms of sick building syndrome were more likely to be reported by employees who worked in an area in which renovations had taken place in the last 2 years. There was also a positive relationship between employee work overload and reports of adverse health effects. This was similar to the findings of Marmot et al. (2006). It was identified by Mendelson et al. (2000) the less that the management staffs in the organisation were seen as supportive of employees' health concerns the more the employees were likely to perceive that their adverse health effects were caused by their place of work. This psychosocial effect was similar to that identified by Roy (2010).

Bachmann and Myers (1995) when analysing the results of an office workers' health survey completed by 624 respondents from three buildings were unsure if psychosocial factors caused the symptoms of sick building syndrome because employees were dissatisfied with their work or workplace, or if the symptoms of sick building syndrome, such as fatigue, caused psychosocial factors to occur. Both causes seemed to produce psychosocial symptoms in their research findings.

The chapter in this book written by Kinman and Clements (2011) titled "The role of demographic and psychosocial factors in predicting SBS symptoms in workplaces" provides a comprehensive description of psychosocial factors that have been considered to contribute to the occurrence of sick building syndrome symptoms. As well as psychosocial factors there are also personal factors that can cause sick building syndrome.

2.12 Conclusions

This chapter has identified that people are individuals and can react differently to different environmental conditions and airborne toxins, particularly if they have pre existing asthma or another medical condition or if they are just sensitive to an indoor pollutant. The most commonly reported symptoms of sick building syndrome are related to skin irritation, eye irritation, respiratory symptoms, cognitive complaints, nausea, lethargy and the symptoms of exposure to other environmental causes of ill health. There are a wide variety of symptoms of sick building syndrome as a result of there being a wide variety of causes for employees experiencing ill health when in a building.

Factors that have been identified to cause sick building syndrome symptoms include the environmental factors of temperature, humidity, adequate ventilation, acoustic comfort and lighting. The symptoms caused by these environmental factors are usually relieved when the occupant leaves the building. Symptoms caused by building related chemical and biological hazards can cause either short-term or long-term health effects that do not always resolve when the occupant leaves the building.

The major impact of sick building syndrome on employees are often hidden in increased incidences of sick leave and medical claims, lower productivity of employees and in increased employee turnover. Most people in the work force do not complain about their ill health. They just leave the company to find another organisation to work for where they can have better health.

The legal implications of sick building syndrome for product manufacturers, product distributors, employers, insurance companies, real estate agents, contractors, building architects and building owners have been considered. The following chapters in this book provide research based information about sick building syndrome that help to explain how to identify incidences of sick building syndrome, causes of sick building syndrome symptoms, the incidences of sick building syndrome symptoms, ways to prevent further incidences of sick building syndrome and ways to enhance people's well being when they are occupants of a building.

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Chapter 3
Indoor Air Quality

S. Müjdem Vural

3.1 Introduction

The most basic need of all humans is to lead a healthy life. Since people spent most of their time indoors, indoor air quality plays an important role in forming a healthy environment.

Natural and artificial agents pollute the indoor air. These pollutants are particles as well as gas and vapors. Gas and vapors include;

- combustion products (carbon monoxide, oxides of nitrogen, sulfur dioxide etc.),
- volatile organic compounds (benzene, toluene, formaldehyde etc.), and
- toxic natural gases (ozone, radon).

Particles include

- aerosols (asbestos, pollen, dust, ect.)
- organisms (bacteria, fungi, virus).

Sources of these pollutants include outside environment of the building, usage of the building (user and user's activities) and building products.

Pollutants from the sources given above may harm indoor air quality and this polluted air may cause biological and psychological health problems. Health problems may vary from headaches to cancer and from fatigue to high levels of stress.

All pollutants have different structures. Hence, adverse health effects they cause on humans and the necessary preventive measures also vary. Different pollutants cause different risks in different people (Spengler et al. 2000). The potential effects of a given pollutant on humans constitute the risk. Risks caused by different pollutants occur differently depending on the biological and psychological condition of

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the user. The dose of the pollutant in the air as well as exposure times is amongst other factors that determine the severity of the health effect. Acceptable exposure levels, sources and adverse health effects of indoor air pollutants must be known for determination and evaluation of risks. The human health risk assessment given by a NRC (U.S. National Research Council 1983) report is used in risk studies of indoor air quality. This human health risk assessment contains four steps; hazard identification, dose-response assessment, exposure assessment and risk characterization (Anderson and Albert 1999). To evaluate the indoor air quality of a building, these four steps are not sufficient. A more detailed risk analysis model must be constructed by architects. Such a model the purpose of which is to identify potential indoor air pollutants is deemed important because it can reduce the duration and cost during risk analyses.

In this chapter, first indoor air quality, indoor air pollutants, sources and health effects of indoor air pollutants, risk and risk analysis and then the relationship between indoor air quality and risk analysis will be discussed. The steps of indoor air quality risk assessment especially the pre-assessment step suggested in the study titled "Evaluation of an Indoor Air Quality Risk Analysis Model" (Vural 2004) will be given.

3.2 Indoor Air Pollution

Atmosphere contains nitrogen, oxygen, argon, carbon dioxide and trace amount of other gases. When the ratio of these components (Table 3.1) changes the air quality changes called as air pollution. Indoor air quality is also changes as the ratio of indoor atmosphere components changes.

The first indoor air pollution that mankind met was in Stone Age. For heating and cooking, people started fire in their caves. This activity of fire was the source of pollutants. They improved the indoor air quality by starting the fire at the mouth of the cave.

Table 3.1 Components of atmosphere (Tünay and Alp 1996)

Components	Volume (%)	Concentration, ppm
Nitrogen	78.084 ±0.004	780,900
Oxygen	20.946 ±0.00	209,400
Argon	0.934 ±0.001	9,300
Carbon dioxide	0.033 ±0.001	315
Neon		18
Helium		5.2
Metan		1.5
Krypton		0.5
Hydrogen		0.5
Xenon		0.08
Nitrogen dioxide		0.02
Ozone		0.01–0.04

In 1970s the first intense studies about indoor air quality began in the north European countries especially in Scandinavian countries. One of the main reasons for these intense studies was the oil shock in 1973. Air conditioning systems were decreased and new building details were designed for saving energy through out the oil shock. This new construction system caused the indoor air pollutants increase in buildings. Such increase in indoor air pollutants was observed in 100 preschool classes in Sweden (Lee 2000).

In the Unites States the first and large scale study was Harvard Six City Studies. The death rates due to the exposure to airborne particulates were increased on the days which levels of particle air pollution were high (EPA 2009).

Since then many more studies have been initiated and completed. For the renewal of indoor air quality standards PRD 62-R, ASHRAE, the American Society of Heating, Refrigerating and Air-Conditioning Engineers, initiated a study in 1996 and the results were published in 1999 (Kerrigan 1996; ASHRAE 1999).

Approximately with 300 researchers from 40 countries pilot studies of NATO, North Atlantic Treaty Organization, were concluded between 1989 and 1996. As a result of these studies, for decreasing the dose of pollutants, a product label of each product companies produce was proposed (Maroni and Lundgren 1998).

3.3 Indoor Air Pollutants, Sources and Health Effects

Indoor air pollutants can be classified in different ways. The classifications of indoor pollutants are given below (Wadden and Scheff 1982; Pearson 1989; Yocom and McCarthy 1991; Holdsworth and Sealey 1992; Patrick 1994; Griffin 1994; Godish 1995; Meckler 1996; Brennan and Turner 1999; Spengler et al. 2000).

- According to the physical properties
  - Gas and vapors
  - Particles
- According to the chemical properties
  - Organic
  - Inorganic
- According to the adverse health effects
  - Toxic pollutants
  - Harmful and irritant pollutants
  - Carcinogenic pollutants
  - Mutagenic pollutants
  - Allergens
- According to their sources
  - Outside environment of the building
  - Usage of the building (user and user's activities)
  - Building products

In this chapter, pollutants will be classified according to the physical properties. Each indoor air pollutant has a different structure coming from different sources. Single pollutant will have different health effects with in different levels on users. Many institutions in different countries set the acceptable levels (threshold values) of indoor air pollutants. Some of the main pollutants and their acceptable levels from different institutes are given in Table 3.2.

Table 3.2 Acceptable levels of indoor air pollutants

Pollutant	Acceptable level	Reference – standard
Carbon monoxide	60 mg/m^3 (50 ppm) for 30 min	Air quality guidelines for Europe-WHO (World Health Organization) 1987
	40 mg/m^3 (35 ppm) for 1 h	NAAQS (US National ambient air quality standards) 1990
	10 mg/m^3 (10 ppm) for 8 h	TS (Turkish standards) 12281
Carbon dioxide	500 ppm for 8 h	ASHRAE 1982
	<1,800 mg/m^3	WHO 1987
	<800 ppm	TS 12281
Nitrogen dioxide	150 μg/m^3 (0.08 ppm) for 1 h	Air quality guidelines for Europe-WHO-1987
	400 μg/m^3 (0.21 ppm) for 24 h	
	100 ppb for 1 h	NAAQS 1990
	<0.05 ppm	TS 12281
Sulfur dioxide	<0.5 mg/m^3 for short term exposure	WHO 1984
	75 ppb for 1 h	NAAQS 1990
	0.14 ppm for 24 h	
Benzene	No safe level	WHO 1987
	<0.01 mg/cm^3	TS 12281
Formaldehyde	0.1 mg/m^3 (0.08 ppm) for 30 min	WHO 1987
	120 μg/m^3 continuous	ASHRAE 62 – 1999
	0.75 ppm for 8 h	OSHA (U.S. Occupational Safety and Health Administration)
	0.016 ppm	NIOSH (National Institute for Occupational Safety and Health)
	<0.065 ppm	TS 12281
Ozone	150–200 μg/m^3 (0.076–0.1 ppm) for 1 h	WHO 1987
	100–120 μg/m^3 (0.05–0.06 ppm) for 8 h	
	0.05 ppm	ASHRAE 62 – 1999
	0.12 ppm for 1 h	NAAQS 1990
	0.075 ppm (2008 std) for 8 h	
	<0.12 mg/cm^3	TS 12281
Radon	100 Bq/m^3 for 1 year	WHO 1987
	2 pCi/L	ASHRAE 62 – 1999
	148 Bq/m^3	EPA (US Environmental protection agency)
	400 Bq/m^3	TAEK (Turkish atomic energy institution)

Table 3.2 (continued)

Pollutant	Acceptable level	Reference – standard
Asbestos	No safe level	WHO 1987
	0.6 fiber/cm^3/8 h chrysotile	TS 11597
	0.3 fiber/cm^3/8 h other than chrysotile	
	0.21 fiber/cc/8 h	OSHA
Particles	PM_{10} – 150 $\mu g/m^3$ for 24 h	NAAQS 1990
	$PM_{2.5}$ – 35 $\mu g/m^3$ for 24 h	
Bacteria & viruses	No reference	No reference

The health effect on users of each pollutant is forming a risk. As pollutants and acceptable levels change, as the risks also change. These variation is also differs with the users biological and medical background. For example radon has a severe adverse health effect on a smoker than a non-smoker. The nature of pollutants and their risks on users must be examined for indoor air quality assessment.

Table 3.3 Combustion gases, sources and health effects

Pollutant	Sources of pollutant	Health effects
Gas and vapors		
Carbon monoxide	Vehicle exhausts Chimney Incomplete combustion Tobacco smoke Household chemicals	Headache Fatigue Lack of coordination and performance Breathlessness Weakness Dizziness Dimness of vision Vomiting Changes in pulse rate Confusion Changes in personality Coma
Carbon dioxide	Biological activities of people Chimney Incomplete combustion Tobacco smoke	Drowsiness Dizziness Headache Nausea Breathlessness
Nitrogen oxides	Vehicle exhausts Chimney Incomplete combustion Tobacco smoke	Burning and stinging of eyes, nose and throat Coughing Respiratory complaints
Sulfur oxides	Fuel and coal combustion	Burning and stinging of eyes, nose and throat Suffocation Coughing Increasing of respiratory complaints

The pollutants according to their physical properties, sources of pollutant and health effects will be given in Tables 3.3, 3.4, 3.5 and 3.6 (Wagner 1991; Millette and Hays 1994; Patrick 1994; Fink 1998; Governo and Kavanagh 1999; Spengler et al. 2000; Provey 2001; Balanlı et al. 2004, 2005, 2006, 2008; EBN 1993, 1995a-b, 1996; EHC 1998a-k; EPA 1998, 2009; EPA; Shen and Schmidt 1993).

Table 3.4 VOCs, sources and health effects

Pollutant	Sources of pollutant	Health effects
Gas and vapors		
Benzene	Vehicle exhausts Incomplete combustion Tobacco smoke Processed composite wood products Finishing Paints	Burning of eyes and lacrimation Cancer Anemia
Toluene	Vehicle exhausts Incomplete combustion Adhesives Floor materials (carpet, vinyl) Tobacco smoke Processed composite wood products Finishing Paints Thinners Ink	Fatigue Lack of coordination Disturbed sleep Eye irritation
Formaldehyde	Processed composite wood products Adhesives Insulation products Carpets Textiles Wall papers Paints Thinners	Uncomfortable of odor Burning of eyes and lacrimation Upper respiratory irritation Sneeze Headache Nausea Vomit Diarrhea Asthma exacerbations Allergen trigger Coughing Increasing in the pulmonary function Water retention Fatigue Inquietude Disturbed sleep Death (50–100 ppm)

Table 3.5 Natural gases, sources and health effects

Pollutant	Sources of pollutant	Health effects
Gas and vapors		
Ozone	Electronic air cleaners Copying machines	Dimness of vision Chest pain Coughing Headache Eye, nose, throat and lung complaints Lack of concentration Symptomatic chest Asthma Upper respiratory effects
Radon	Rocks Soil Water Building products	In long term exposure lung cancer

Table 3.6 Particles, sources and health effects

Pollutant	Sources of pollutant	Health effects
Particles		
Asbestos	Soil Insulation products Finishing	Pleural neoplasm Asbestosis Lung cancer Mesothelioma
Pollen	Graminaceae family	Allergy
Dust	Ash Coal Cement dust Sawdust Soil	Allergy Eye diseases Upper respiratory effects Coughing
Bacteria & viruses	Ventilation systems Humidifiers Refrigerators Toilets Unhealthy areas	Ach Fever Sinus infection Legionnaire' s disease

3.4 Risk and Risk Analysis

Risk is generally defined as the potential for an unwanted negative consequence or event (Anderson and Albert 1999). Risk may be considered as the probability of an adverse effect, or an assessed threat to persons, the environment, and/or property, due to some hazardous situation (Asante-Duah 1993).

Risk or “expected loss” can also be defined quantitatively as the product of the consequences of a specific incident and the probability over a time period or frequency of its occurrence. Risk analysis refers to a systematic framework for understanding and managing diverse risks (Andrews and Moss 2002).

Risk analysis framework includes;

- Risk assessment
- Risk managemnet
- Risk communication (Williams 2000).

Risk assessment entails quantifying and characterizing risks to determine how risky a given situation is (Williams 2000; Duru and Besbelli 1997). This step relies on assumptions made by scientists based on results from scientific data (Graham 1995).

Risk management is the policy for use of science in risk assessment (Anderson and Albert 1999). Risk management involves decisions about risks considering regulatory, political, social, physical and economical points of view. In this step risk manager answers questions such as “what is acceptable?” and “what can be done about these risks?” (Duru and Besbelli 1997).

Risk communication involves conveying information about a risk or risk management decision to different groups of stakeholders (Spengler et al. 2000).

General risk analysis framework can be defined as above. Since the human health risk assessment given by NRC (U.S. National Research Council 1983) report is used in risk studies of indoor air quality, it must also be defined.

In NRC report that was published in 1983, risk assessment is defined as “the use of the factual base to define the health effects of exposure of individuals or populations to hazardous materials and substances” (Williams 2000). The risk assessment process is divided into four steps. These steps include:

- Hazard identification
- Exposure assessment
- Dose-response assessment
- Risk characterization

In NRC report that was published in 1983, risk management is defined as a “decision-making process that entails consideration of political, social, economic, and engineering information with risk-related information to develop, analyze, and compare regulatory options and to select an appropriate regulatory response” (Williams 2000).

Risk communication was defined in NRC 1983 report as any public or private communication that informs individuals about the existence, nature, severity, or acceptability of risks. One of the primary goals of risk communication is to better inform decision makers, in the context of either public debate or personal action (Williams 2000).

3.5 Indoor Air Quality Risk Analysis Model

There are many air pollutants that may adversely impact indoor air quality. Evaluation of every single pollutant for every single building may lead to loss of time, effort and money. Therefore, during the assessment phase of the indoor air quality risk process, initially a pre-assessment was deemed necessary in order to provide data for other steps and prevent the losses listed above.

In the study titled "Evaluation of an Indoor Air Quality Risk Process Model" (Vural 2004), an enhanced risk process model was suggested by making the following changes to the risk process:

- A pre-assessment step was added as the initial step
- An application step was added after the risk management step
- The risk communication step, in addition to providing information to the public, also provides feedback to architects during the design stage.

The five main steps of this new suggested model for indoor air quality risk analysis (Fig. 3.1) are; pre-assessment, risk assessment, risk management, application and risk communication.

3.5.1 *Pre-assessment Step*

The building itself and the occupants are defined in the *pre-assessment step* of indoor air quality risk analysis.

Possible indoor air pollutants from the building itself or from the occupants are also listed in this step.

In the pre-assessment step (Fig. 3.2) pollutants can be classified through;

- Building identification
- End user interviews
- Potential threat analysis

3.5.1.1 Potential Threat Analysis

Collected information such as tables of building products and the pollutants they contain, similar to those detailed in the study titled "Indoor Air Pollution Caused By Building Product and Risk Assessment in Preliminary Research Step" by Vural and Balanlı (2005) will be helpful in this step. While analyzing the risks of a building, researchers can determine what pollutants there are by relying on their experience, utilizing their senses or simply by using checklists.

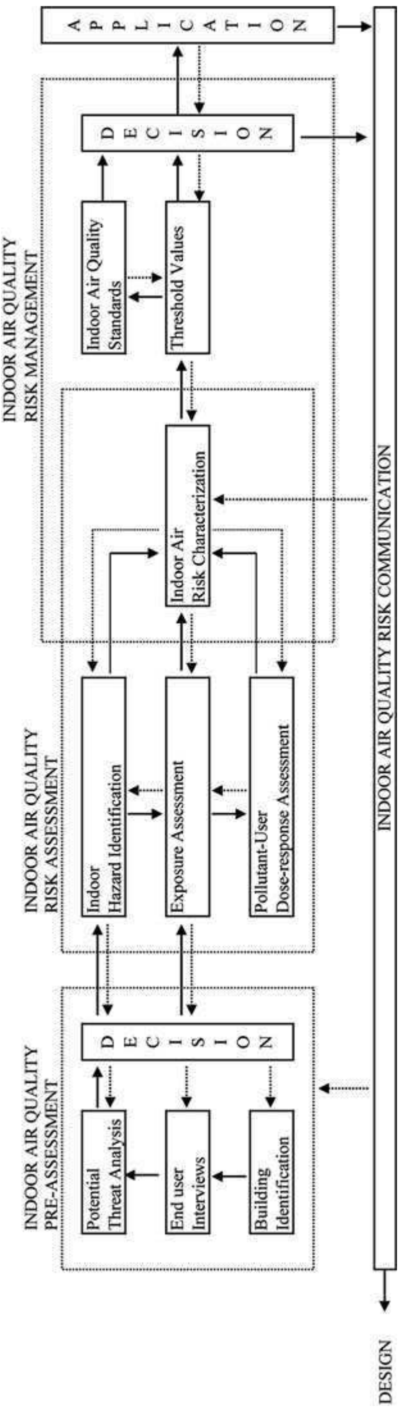

Fig. 3.1 Indoor air quality risk analysis

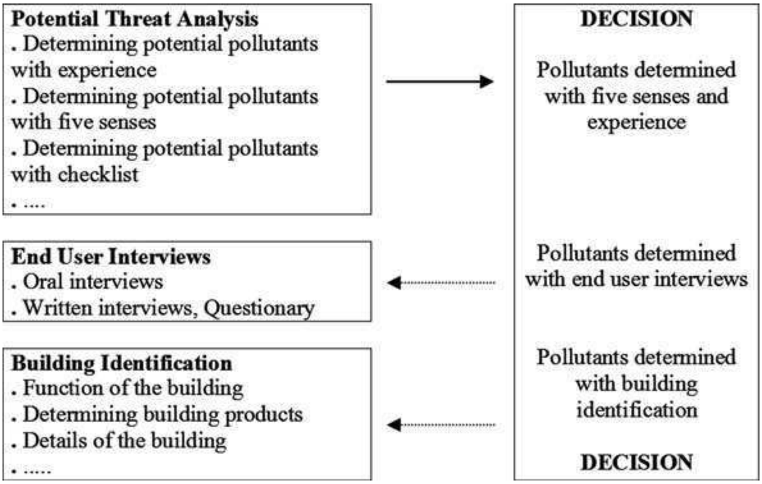

Fig. 3.2 Pre-assessment step of indoor air quality risk analysis model

3.5.1.2 End User Interviews

A single pollutant may cause different adverse effects for different users based on a number of parameters such as gender, age, previous medical history, personal habits such as smoking, intensity and frequency of building usage or other similar parameters that can only be identified after conducting thorough interviews with building users. Such feedback from users will make it easier for the architect to determine probable pollutants and their adverse effects. Oral and written interviews with users can be used to determine correlations between health of users and indoor air pollutants within the building.

3.5.1.3 Building Identification

Buildings are designed to meet different needs of users. The function of a building varies according to the users' needs. Buildings of different functions such as residential (apartment building), commercial (office building, shopping mall) or industrial (factory) display different characteristics in terms of;

- Users and user activities,
- Equipment,
- Building products,
- Details,
- Environment.

This variation is the main reason why indoor air pollutants are different in every building.

In risk assessment studies building identification is crucial for determining potential existence of pollutants.

As a result in this pre-assessment step; information provided by the building identification, user interviews and potential threat analysis will be useful in determining the existence and intensity of pollutants.

3.5.2 Risk Assessment Step

In the risk assessment step, NRC report is used (U.S. National Research Council 1983). This human health risk assessment contains four steps; hazard identification, dose-response assessment, exposure assessment and risk characterization (Anderson and Albert 1999). The steps of this report were not changed but redefined. As a result in the risk assessment step, adverse health effects of indoor air pollutants regardless of pollutant concentration or severity of effect, are determined. Existences of indoor air pollutants are then investigated by measuring. Risk factors are calculated by taking into consideration predetermined health effects and the relevant cause-effect relationships. According to the total risk, risk of the building is determined (Fig. 3.3).

3.5.3 Risk Management Step

In the risk management step, level of risk previously determined is designated as acceptable or unacceptable in the light of indoor air quality standards and threshold values (acceptable levels).

3.5.4 Application Step

According to the decision, the next step, application, is put into practice (Fig. 3.4). If risks are decided to be at an unacceptable level, either the building is improved,

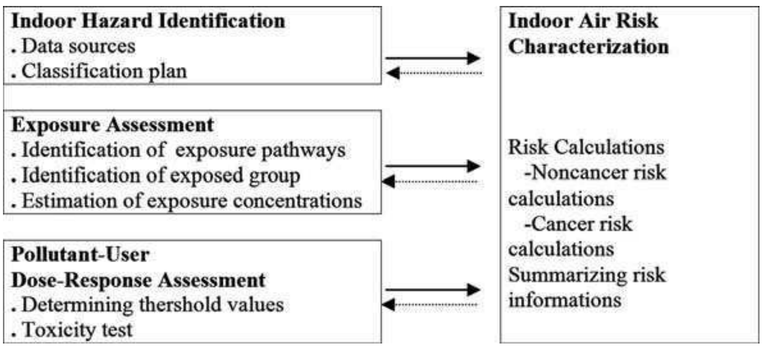

Fig. 3.3 Risk assessment step of indoor air quality risk analysis model

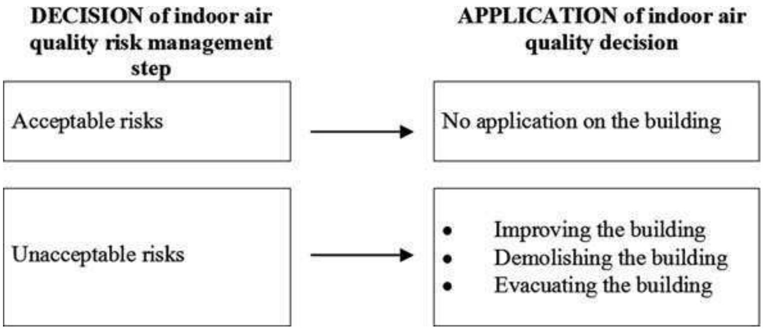

Fig. 3.4 Application step of indoor air quality risk analysis model

or evacuated or demolished. If risks are deemed to be at an acceptable level, no application is done on the building.

3.5.5 Risk Communication Step

The risk communication step provides feedback to every step of the model and to the design stage (Vural 2004).

3.6 Conclusion

A risk process model can be developed by adding a pre-assessment step to the risk assessment, risk management and risk communication step of the risk analysis framework used to prevent indoor air quality risks.

If this model is utilized;

- The pre-assessment step will eliminate the need to conduct a wide range analysis by revealing only those building products that are present in the building and pose a risk. This will save time, effort and money.
- The architect will play a necessary lead role in the risk assessment.
- Indoor air quality of existing buildings can be improved while indoor air quality of new buildings can be taken into consideration during the design stage, eliminating the need to make corrections or improvements at a later time, which again saves time, effort and money.

Indoor air quality risk analysis is conducted by architects and experts from other disciplines. The intended outcome of this interdisciplinary study is to determine if a building is indeed a healthy building or not.

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Chapter 4
Perceived IEQ Conditions: Why the Actual Percentage of Dissatisfied Persons is Higher than Standards Indicate?

Risto Kosonen, Mervi Ahola, Kirsi Villberg, and Tarja Takki

4.1 The Meaning and Targets of IEQ

4.1.1 Profitable Investment

The indoor environment is where people spend 90% of their time. It is well known that the indoor environment is an important factor not only for occupants' comfort as a whole, but also for their health and productivity. This is incorporated in the human right to a healthy indoor environment as formulated in the WHO Constitution (WHO 1985). Indoor environment comprises several factors (acoustics, lighting, thermal environment, air quality). The individual performance is significantly affected by the conditions of the working environment.

The latest studies have proved that the investment on improved IEQ (thermal comfort, IAQ, acoustics and lighting) is very cost-effective (Fisk and Seppänen 2007; Wargocki and Wyon 2006; Wargocki et al. 2002; Hongisto 2005; Juslen 2007). Wood (1989) has indicated that the salaries of workers in the US office buildings have exceeded the costs of building energy, maintenance, annualized construction and rental by a factor of 100.

In offices all these factors have an impact on workers, but the most significant two are thermal environment and air quality.

According to a study of BOMA (BOMA 1999) 90% or more of the respondents give the following six features a rating of very important: comfortable temperature, indoor air quality, quality of building maintenance work, building management's responsiveness, building management's ability to meet the tenant's needs and acoustics.

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4.1.2 Standards Specify Targets

There are several international and local standards and guidelines that give recommendations and propose design criteria for achieving good indoor environment (ISO 2005; EN 2007; ASHRAE 2004; CEN CR 1999). Recommended values for the mean air velocity, air temperature, relative humidity, vertical temperature gradient and mean radiant temperature both for winter and summer conditions are listed in these documents.

Also the minimum outdoor air flow rates to be supplied into the space by the ventilation system in order to assure good air quality for the occupants in the room are defined (EN 15251 (2007)). Outdoor air flow rate of 7–10 l/s per person is namely required in office buildings.

The thermal sensation of the body as a whole (general thermal comfort) can be predicted by calculating the predicted mean vote (PMV) index introduced in ISO (2005). The predicted percentage dissatisfied (PPD) index, obtained from the PMV index, provides information on thermal discomfort (thermal dissatisfaction) by predicting the percentage of people likely to feel too hot or too cool in the given thermal environment.

The criteria for the excellent level of PPD – index is 6% (EN 15251 2007). Criteria for the good and basic levels are set to 10 and 15%, respectively. A model for local discomfort that predicts the percentage of dissatisfied due to draught was introduced by Fanger et al. (1988). An index called draught rating (DR) index was derived as a function of mean air velocity, air temperature and turbulence intensity.

A draught rating (DR) lower than 15% is recommended in the standards. CEN CR (1999) specifies different limits on DR for three categories of thermal environment in rooms. The set categories for the predicted thermal state of the whole body (EN 2007) and local discomfort (CEN CR 1999) are shown in Table 4.1.

The above mentioned overall thermal sensation levels are confirmed as guidelines in recently approved standard EN 15251, which highlights the importance of

Table 4.1 Recommended criteria and categories for the thermal environment

	Thermal state of the body as a whole		Local discomfort	Perceived air quality	
Category	Predicted percentage of dissatisfied PPD [%]	Predicted mean vote PMV	Percentage of dissatisfied due to draught DR [%]	Percentage of dissatisfied PD [%]	Required ventilation rate for occupants[a] [l/s/person]
I	<6	–0.2<PMV<+0.2	<15	<15	10
II	<10	–0.5<PMV<+0.5	<20	<20	7
III	<15	–0.7<PMV<+0.7	<25	<30	4

[a]Total ventilation for a room is calculated based on diluting emissions from people and the building emissions (Category II: 0.35–1.4 l/s per m^2)

maintenance of good thermal conditions, when energy performance of building is designed to fulfill the Energy Performance of Buildings Directive (EPBD).

During the design process, the desired thermal conditions for a space may be selected based on the defined international or national indoor climate classifications (e.g. CEN CR 1999; FISIAQ 2001). In the selected indoor climate class the target values are set for both maximum percentage of dissatisfied for the body as a whole (PPD) and for the local discomfort (DR). In addition, the relevant targets for indoor air quality, outdoor air flow rates and acoustics conditions are set during the design process.

4.1.3 What About the Actual Perception?

Even though numerical physical measures define accurately different factors of the indoor environment, only the perceived quality determines the total performance of the building from user's point of view. The occupant IEQ survey is a tool that helps to assess how well a building is performing from the viewpoint of its occupants (Zagreus et al. 2004).

Further, a holistic approach of IEQ development and maintenance is required for an effective process to improve the perception of indoor climate conditions. A systematic method for the assessment and improvement of IEQ has been proposed by Takki and Virta (2007).

The subjective response is a useful too to analyze the occupant perception on indoor environment quality.

4.2 Occupants Underutilized Source of Information

Historically, building occupants have been underutilized as a source of information on building performance. However, an occupant satisfaction survey is a powerful tool to analyze the perception for the actual indoor environment quality.

4.2.1 Assessment Process

The questions assess satisfaction with the following IEQ areas: office layout, office furnishing, thermal comfort, indoor air quality, lighting, acoustics, safety and security, and building cleanliness and maintenance. Basic demographics are also collected from respondents and information about their workplace.

The survey questions elicit whether the workspace is in the internal or perimeter zone, near a window, and also the orientation and the layout type of the office are linked with the collected information.

A web-based survey has been utilized as a diagnosis tool to identify specific problems and their sources in a cost-effective manner. Whatever a respondent indicates dissatisfaction with an aspect of building performance, a branching page follows with more detailed questions about the nature of the specific problem.

The approach of the Web – based survey gives two main benefits: (1) it can inexpensively be administered to many buildings and (2) its interactive branching questions allow it to “drill down “into areas that occupants rate poorly.

Thus in many cases, the survey diagnoses the root of the problems. The approximate time required to complete the survey is 5–12 min.

4.2.2 Rating of Satisfaction

Upon starting the survey, participants click through a series of questions asking them to evaluate their satisfaction with different aspects of their working environment. In Fig. 4.1, there is shown a thermal comfort sample of the survey.

Satisfaction is rated ranging from “very satisfied” to “very dissatisfied”, with a neutral midpoint. The question related to whole body and local thermal sensation in 7-point scale, acceptability of thermal environment, air movement, lighting, air quality and acoustics.

The respondents who indicate dissatisfaction (the lowest three points on the scale) are branched to a follow-up screen probing them for more information about the nature of their dissatisfaction.

Respondents who indicate neutrality or satisfaction move directly to the next survey topic. As a rule of thumb is that a 50% response rate is required to reduce non-response bias to an acceptable rate (Hill et al. 1999). In the conducted surveys, the response rate have ranged from 45 to 97%, with the majority of response rates between 50 and 75% and the mean at just over 68% (Kosonen et al. 2008).

4.3 How Well We Can Reach the Set Targets?

The occupant satisfaction survey has been used to evaluate the performance of 29 office buildings in Finland (Kosonen et al. 2008). Survey clients include both government and private organizations locating in Helsinki metropolis area. All

THERMAL COMFORT

	Very Dissatisfied	Dissatisfied	Partially dissatisfied	Not Dissatisfied or	Partially Satisfied	Satisfied	Very Satisfied
How satisfied are you with the temperature in your workspace?	−3	−2	−1	0	+1	+2	+3

Fig. 4.1 A thermal comfort sample of the occupant IEQ survey scale

buildings are mechanically ventilated and equipped (except one building) with air-conditioning system.

The studied buildings fulfill the requirements of either indoor class excellent or good in Finnish classification (FISIAQ (2001)). Thus, the buildings represent the state-of-the art technology in Finland. The used mechanical systems are either all-air systems with centralized air-conditioning or active chilled beam systems with room or zone based control.

4.3.1 Results of an Individual Building

Occupants were asked to vote on their overall perceptions of IEQ to see the most critical factors for improvement. Figure 4.2 presents a survey result demonstration where satisfaction ratings are tabulated for each point on the scale.

This executive summary is particularly useful to managers to see a top-level overview of the most critical environment factors. As in this case, the lowest general satisfaction levels are rated on air quality, thermal comfort and acoustics. In this specific case, average value of thermal comfort is rated "negative" in the thermal sensation 7-point scale. However, the average value can not fully depict the breakdown between satisfied and unsatisfied occupants.

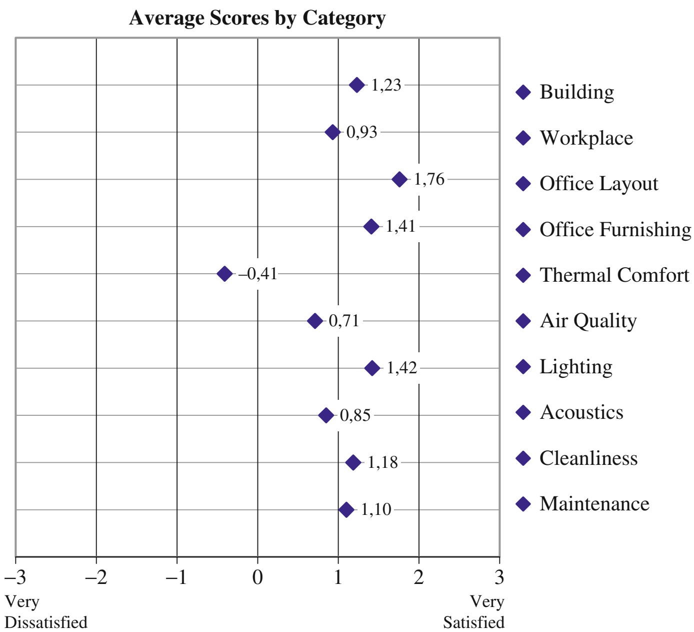

Fig. 4.2 An example of average occupant satisfaction survey results in a case-study building

However, even if average satisfaction rating is quite often used to categorize buildings (Zagreus et al. 2004; Euleb 2007), it cannot define the actual number of persons who are dissatisfied with the conditions

It should be noted that the average satisfaction score could be reasonably good but eventually there might be zones where the percentage of the dissatisfied could be even 30–60%.

An occupation perception map is a tool for analyzing more closely the location and actual number of dissatisfied persons. In the map in question, the percentage of the dissatisfied with environmental factors are exhibited in different zones. Afterwards this information can also be exploited for focus field audits on the problem areas and workplaces.

For example in a case-study building, there are one problem area for air quality and four for thermal comfort (Table 4.2). In this case, acoustic privacy is rated very low in all zones, respectively.

The breakdown of the sensation ratings (7-point scale) give a generic view how serious the problem is. As an example, the breakdown of thermal sensation rating is shown in Fig. 4.3. In this case-building, altogether 36% of occupants are voted either cool or cold. This result indicates that thermal comfort has been perceived a serious problem.

Cold sensation could be results of the whole body thermal sensation (too low air temperature) or local thermal problem (draught caused by air movement). That possible to further analyze by asking questions on preference for more, less or unchanged air movement and air temperature.

In Fig. 4.4, there is an example where major part of occupants are preferred higher air temperature and no change in air movement. This confirms that in this case the thermal sensation problem is too low air temperature.

Sometimes, the dissatisfaction on thermal sensation varies in summer and winter times and at different floor level. To find-out the reason for cold sensation, thermal sensation on air temperature and draught should analyzed at the same time.

Table 4.2 An example of occupation perception map in a case-study building

	All (%)	2nd floor (%)	3rd floor (%)	4th floor (%)	5th floor (%)	6th floor (%)	7th floor (%)	8th floor (%)
Building	3	3	0	0	13	7	1	0
Workplace	5	3	6	0	23	0	0	5
Furniture (comfort)	10	15	12	8	6	6	7	7
Furniture (adjustment)	10	9	15	9	0	13	10	14
Thermal comfort	53	80	35	63	54	53	32	55
Air quality	22	10	11	27	22	42	33	9
Lighting (quantity)	9	15	6	25	0	0	3	15
Lighting (quality)	12	12	12	17	13	12	16	0
Sound level	16	15	21	33	13	6	10	15
Acoustic privacy	32	21	36	58	25	35	16	29

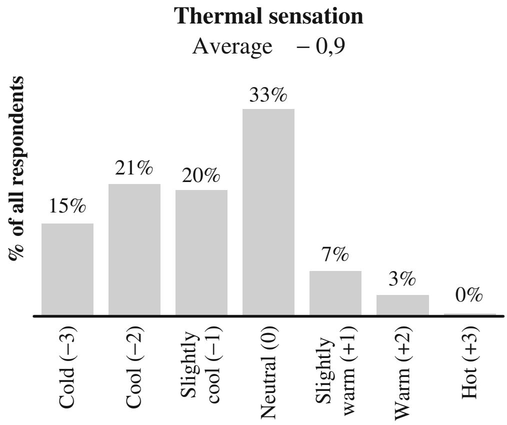

Fig. 4.3 The breakdown of thermal sensation ratings in a case-study building

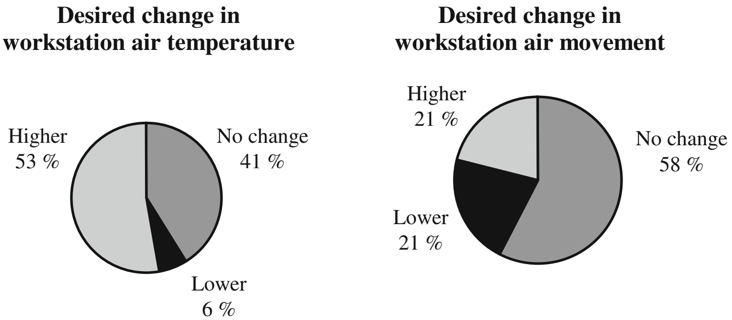

Fig. 4.4 Desired changes in workstation air temperature and air movement in a case-study building

As an example in Fig. 4.5, occupant can generally perceive draught problem during summer and too cold air temperature during winter.

4.3.2 Results in Building Stock

Occupants' overall perceptions on the studied 29 buildings are shown in Fig. 4.6 (Kosonen et al. 2008). From the point view of the occupants, thermal comfort, IAQ and acoustics (noise level and acoustic privacy) have got the lowest average ratings. Almost in all buildings, those factors are the main concern for improvements.

4.3.2.1 Average Dissatisfaction Rating

In this survey, there are buildings where the average ratings on thermal comfort, air quality and acoustics are negative (average all dissatisfied). Still, in most of the cases average ratings on survey categories are positive indicating at least partial satisfaction on the system performance.

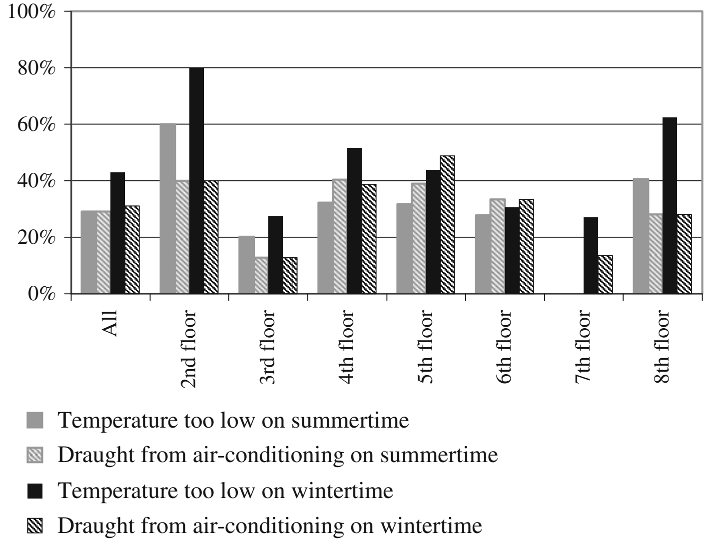

Fig. 4.5 Comparison of perceived air temperatures and draught during summer and winter conditions at different floors in a case-study building

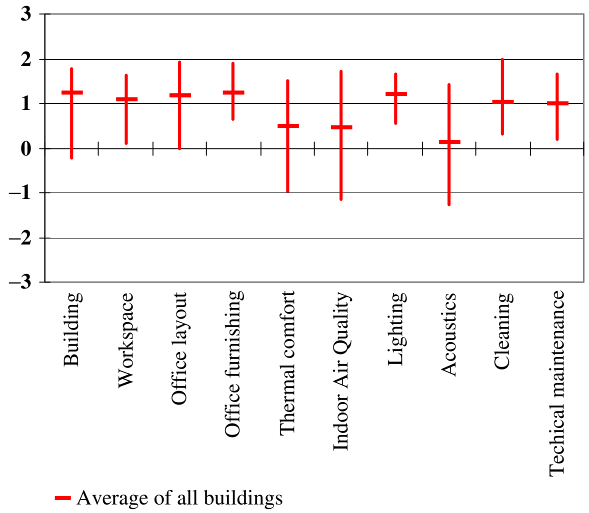

Fig. 4.6 Benchmark comparison of average satisfaction ratings and their variations by survey category ($n = 3{,}796$ persons in 29 buildings)

4.3.2.2 Number of Dissatisfied Persons

When the total numbers of the dissatisfied are computed (negative rates of –1, –2 and –3 together), the number of the dissatisfied persons is very high (Fig. 4.7). The percentage of dissatisfied on thermal comfort and air quality is over 20% in many buildings. To further confirm that the level of dissatisfied is indeed anomalously high, only 6 buildings of 29 cover ASHRAE's demand of less than

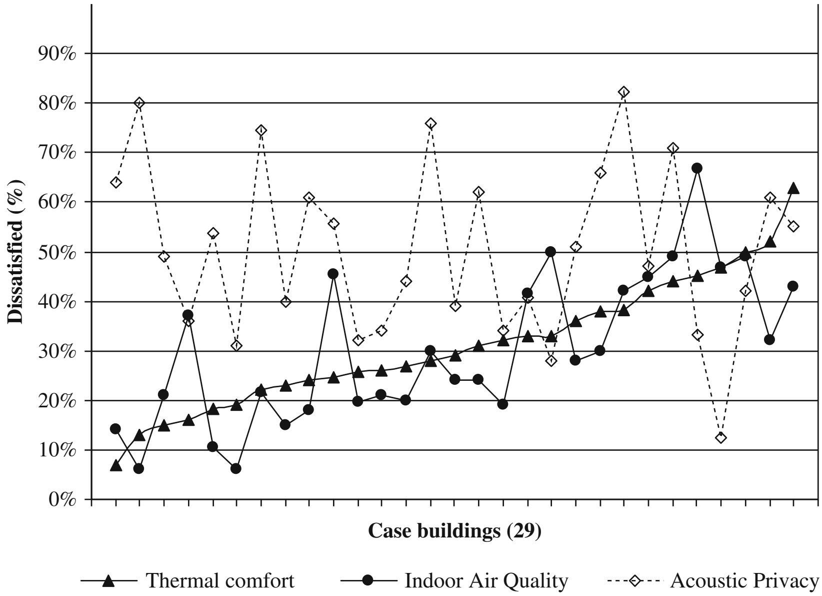

Fig. 4.7 The percentage of the dissatisfied on thermal comfort, air quality and acoustic privacy in 29 buildings. Case buildings are binned in the ascending order of dissatisfied on thermal comfort

20% dissatisfied on general thermal comfort (ASHRAE 2004). The results are even worse in acoustics privacy: the percentage of dissatisfied is typically 30–60%.

All this depicts that actual perception on IEQ is much lower than during the design phase set requirement level. In practice, it seems that even the requirements of the lowest indoor class (15–25% of dissatisfied) is difficult to be met when the metric is satisfaction rating on IEQ.

To recast respondents on thermal comfort, indoor and acoustics who indicate dissatisfaction, the breakdown of the lowest three points on the scale is shown in Figs. 4.8, 4.9, and 4.10. This indicates that in many building the number of dissatisfied (–2) and very dissatisfied (–3) occupants is high. Perception on indoor air quality is rated better than on thermal comfort and acoustics and the number of just partial dissatisfied (–1) on indoor air quality is higher than on thermal comfort and acoustics. Respectively, the number of very dissatisfied (–3) on acoustics is the highest.

4.4 Set Targets and Perception on IEQ: Not Really Match

4.4.1 Acceptability as a Starting Point

Parameters to characterize ventilation may include ventilation rates, contaminant levels and physical characterization of the indoor environment. These factors affect human responses through each other but also independently.

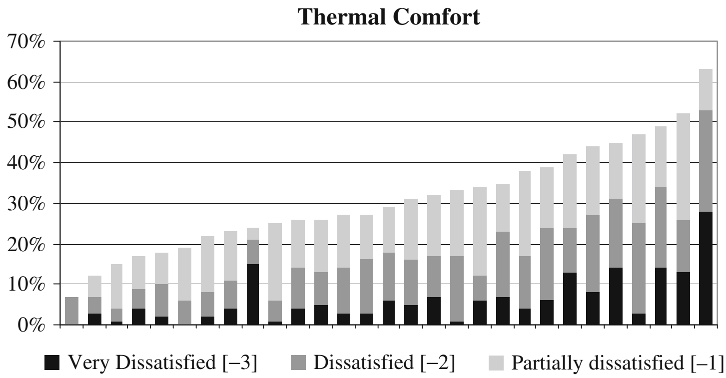

Fig. 4.8 The breakdown of the respondents on thermal comfort who indicate dissatisfaction (the lowest three points on the scale)

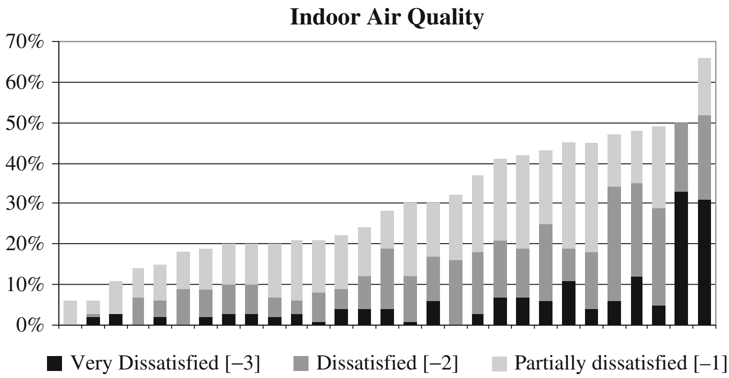

Fig. 4.9 The breakdown of the respondents on indoor air quality who indicate dissatisfaction (the lowest three points on the scale)

Outdoor air flow rate of 7–10 l/s per person is namely requested in international standards. However, the latest studies have proved that the air flow rate of 20–30 l/s per person is required to enhance perceived air quality (Fisk and Seppänen 2007).

Criteria for an acceptable thermal climate can be specified as requirements for general (the overall sensation of the body) or local thermal discomfort. Such requirements can be found in existing standards and guidelines.

Despite the excellent control over environmental conditions in climate chambers, it has not been possible to assess how dissatisfaction due to multiple sources is defined. For example, people may be dissatisfied due to general thermal comfort and/or dissatisfied due to local discomfort parameters, but at the present there is no method for combining the total number of people finding environment unacceptable.

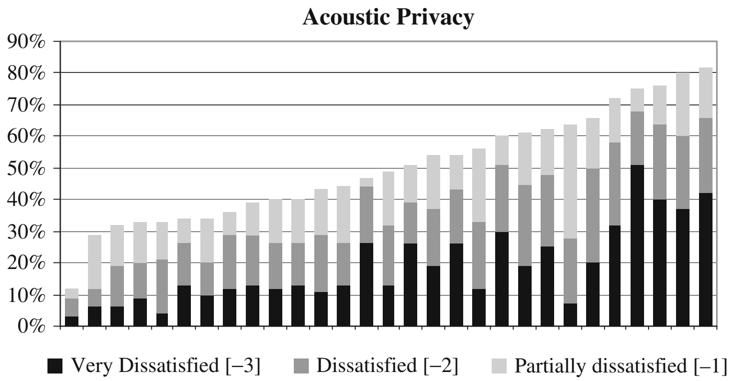

Fig. 4.10 The breakdown of the respondents on acoustic privacy who indicate dissatisfaction (the lowest three points on the scale)

4.4.2 Not Easy to Meet the Set Targets

In many commercial buildings, thermal conditions are not well-controlled due to insufficient of cooling or heating capacity, high internal or external loads, large thermal zones, improper control system design or operation, and other factors.

For example, in a large US study, 50% of the subjects preferred a change in their thermal state, 38% of subjects in winter were dissatisfied with thermal conditions, and almost 50% of the thermal conditions during summer were outside of the thermal comfort zone (Schiller et al. 1988). Thermal conditions inside buildings vary considerably with time, e.g., as outdoor conditions change, and spatially within buildings.

The percentages of the dissatisfied on thermal comfort and air quality are (separately or together) often over 30% (Kosonen et al. 2008). To further confirm that the levels of dissatisfied are indeed anomalously high, only 6 of the 29 buildings cover ASHRAE's requirement of less than 20% dissatisfied on general thermal comfort (ASHRAE 2004). The results are even worse in acoustics privacy: the percentage of dissatisfied is typically 30–60%. In other field studies, the actual percentage of the dissatisfied is also much higher than in standards e.g. 12% (Hwang and Cheng 2007), 12% (Schiller 1990) and 48% (Melikov et al. 2005).

The quality of the indoor climate in schools has been found to be poor in a number of surveys (Daisey et al. 2003; Mendell and Heath 2005). Together with the high internal and external load variations, it makes challenging to fulfill the requirements for sufficiently low local discomfort level predicting the percentage of dissatisfied due to draft (ISO 2005).

Poor indoor air quality causes an increase in symptoms and illness, and it shortens attention span, whereas good air quality can enhance children's concentration and also teachers' productivity (Wargocki et al. 2005).

The commonest indoor climate problems are inadequate ventilation and thermal comfort. To achieve a good indoor climate, an adequate airflow should be used and the functionality of air distribution should be analyzed to guarantee the performance.

All this confirms that in practice, it is not easy to meet targets for occupant perceptions on IEQ.

4.4.3 Why the Actual Percentage is So High?

In investigating perceived IEQ, it is essential to note that existing standards are based on laboratory research on college-aged subjects and not people working in the office environment.

This study of office buildings shows that the percentage of dissatisfied according to the surveys is much higher than the set target values in the international standards.

It is essential to note that subjects are asked what the thermal conditions usually are like in the occupied building. In this kind of retrospective approach, subjects may exaggerate how often and to which extent they are dissatisfied on IEQ, in order to ensure that something will be done about it.

Another source of variation in surveys is that in the survey it is not possible to know how bad the conditions have been in the past in all the places the subjects have been occupied. There could be only limited time period that the occupants are referring to when they complain.

In the office occupation satisfaction survey, systematic physical field measurements were not carried out to explain the difference. However, the executed audits demonstrated that different technical problems might exist.

Generally, the main reasons for the high number of the dissatisfied persons are the faults in commissioning and maintenance process. Also nowadays, the design process is mainly focusing on the peak load conditions and the performance of the system is not sufficiently analyzed during mid-season.

In addition, organizational changes are continuous and require changes not only in the workplace layouts but also in the mechanical systems. Without adjustments, layout changes might create e.g. draught, lighting and air quality problems.

4.5 Conclusions

The results depict that even if the average satisfaction in IEQ survey shows high scores major problem areas may exist in some parts of buildings. Also in many buildings, the actual percentage of dissatisfied persons is higher than 30% especially with thermal comfort, indoor air quality and acoustics.

In the building stock, commissioning and maintenance process are often neglected. Also, the required system adjustments are not executed after layout changes of workplaces. Using the perception map as a tool to find out the problems areas, it is possible to focus improvements cost-effectively to critical workplaces and simultaneously improve significantly perception on IEQ operation with building designers.

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Chapter 5
Sick Building Syndrome from the Perspective of Occupational and Public Health

Hülya Gül

5.1 Introduction

Sick building syndrome (SBS) is a term used for a constellation of findings caused due to indoor air quality (Burge 2004; Joshi 2008). In developed countries, indoor air quality attracts attention as a public problem of importance for a long time. Considering the fact that too many people are potentially under risk, SBS is among the issues of first priority to be dealt with. Indoor air is regarded as more reliable than the outdoor environment for a long time due to the air contamination of outdoor environment and unsuitable climatic conditions. Yet indoor concentration of contaminants could be more than those of outdoor environment. Especially, operating building ventilation and air conditioning systems at half capacity due to energy conservation after the energy crisis occurred in 1970s facilitated the health problems caused by on ambient air to emerge. During this period, deviation from natural products started and slat, synthetic fibbers and plastics replaced wood, marble and natural fibbers. These new products are the end products of petroleum and most of these could disperse in the indoor air and accumulate. Only through the studies conducted in 1980s, the negative effects of indoor air on human health due to construction and cleaning materials, paint materials and residues appearing by heating were noticed (WHO 1984; WHO 1989). WHO indicated in published reports that people today spent most of their time in indoor environments and sick building syndrome was recorded in 30% of the newly constructed or restored buildings in average (Bruce et al., 2002). In 1990s, the problem became more complex due to the increase in prefabricated house construction and construction material usage and the fact that computers became widespread. Applying energy conservation for various reasons caused that infrastructure and frame of the buildings became cold. Thus, a series of dependent factors affect the quality of inhaled indoor air. Today, both employed and non-employed persons spend almost two thirds of their lifetime

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indoors such as workplaces, schools, official buildings, shopping centres and vehicles. One of the important environments where artificial atmospheric conditions are provided is the workplace.

Ramazzini known as the founder of occupational diseases had defined the factors affecting the quality of air in the workplace inhaled by the employees and the findings regarding contaminants and dangerous dusts in eighteenth century for the first time (Gochfeld 2005). Constantly changing living conditions allowed building technologies to improve. While the needs remained limited in the past such as having shelter, being protected and ensuring privacy, it gained importance today to construct indoor buildings to meet the demands of physical and psychological comfort increasing in parallel with the opportunities provided by technological developments. One exposes to various biological and chemical contaminants in all these environments due to the structure of the buildings, production or living habits and similar reasons. While people spend 16–24 h/day in advance in indoor environments, they spend approximately 2 h/day in outside environments. Thus, most of the exposure with dangerous gases and particles occur in indoor environment. In numerous studies carried out, it has been recorded that the level of the indoor contaminants are higher than the contaminants found in outside environment. The measurements accomplished by the American Environmental Protection Agency (EPA) show that the poor indoor air quality in modern buildings isolated from the outside environment is more dangerous when compared with outside air quality, which is thought to be contaminated. However, the reason for this effect not being cared sufficiently is that the effects regarding indoor air contamination take time to emerge and do not endanger life directly or in short term.

Problems regarding indoor air quality are met ever-increasingly in parallel with the increase of the environmental pollution caused by the developing industrialization (Özyaral et al., 2006, Gül et al., 2009). Indoor air is regarded as the air found in housing, unindustrialized workplaces and public buildings (school, hospital, etc). According to ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) standard, acceptable indoor air quality is explained as follows: Air where no known contaminants in dangerous concentration levels specified by public authorities are found and 80% or more of the people living within this air feel not dissatisfied with the air quality (ASHRAE 1989; 2001). Indoor environments should meet the primary needs of the people regarding the health care, protect the people within from excessive cold and heat and receive adequate sunlight. The indoor air should be always clean. If the quantity/amount and diversity of tools, devices and other equipments found in office work environment are not in a certain condition, the indoor atmosphere could be contaminated easily. More application of synthetic materials when constructing a building, the increase in the number of people working in the offices and presence of more competition and stress in the work environment contribute to the increase of SBS. Indoor air in buildings used continuously or in deterministic periods, which we define as indoor atmosphere, could be contaminated by very variable cross effecting independent factors. As well as these atmosphere contaminants could be originated from atmosphere of the outside environment, they could also be originated directly in the building itself.

To observe dangerous biological, physical and chemical factors affecting the human life negatively in housings and other indoor buildings such as carbon monoxide, sulphur dioxide, nitrogen oxides, formaldehyde, cigarette smoke, radon, asbestos, lead, volatile organic molecules, various microorganisms and allergens is defined as indoor contamination (Chao et al., 2003; Akpınar-Elci 2008). The prevalence of these contaminants in indoor air depends on the building properties, material used when constructing the building, heating system, ventilation condition, work carried out inside the building and the ways of behaviour of the people living inside. Though it has been asserted that being exposed to low-level chemical agents generates a strong neurological inflammatory response, it has been put emphasis on particles and physical factors as well. Considering all of these factors, insufficient ventilation seems to be the most important factor.

Public buildings in which the people live or use as a school with the purpose of sport, cultural and social activities and most of the offices at which the people work are exposed to mould invasion causing severe risk for the human health as a result of mould contamination emerged depending on environmental moisture and relative humidity (Gelincik et al., 2005; İşsever et al. 2002). The relationship between buildings with moisture and developing symptoms is indefinite. Bacteria, viruses, fungi and fungal spores, insects and insect faces, animal wastes and pollens originating from the plants, which are found in indoor environment, may have pathogenic, toxicogenic and allergic effects. The building getting sick affecting rapidly by humidity/heat/pressure/ventilation factors provides a basis for any microorganisms to settle carried from the outside environment inside the building. Microorganism (s) getting a chance to live in a suitable environment grow at the places, where they are localized. Especially ground floors, dark and airless storerooms, places under the stairs, roof and attic; water, electricity and other sanitary fitting canals; places with high humidity such as bathrooms, showers and kitchens, moist or wet floors and rooms are very suitable environments for microorganisms to grow, especially mould, yeast and some other bacteria.

Depending on inadequacy of indoor air quality due to aforementioned and similar factors, sick building syndrome with unknown cause may emerge, which could develop in more than one person sharing the same environment. As the result of many studies conducted, it has been reported that the indoor air quality has accelerated diseases observed, even if not the only cause, and aggravated these (Gül et al., 2007). This disease especially affects upper respiratory tract and develops with symptoms resembling those of seen in some allergies and flu such as eye redness, burning or itchy eyes, nasal congestion or rhinorhea, sore throat, headache, concentration difficulty, fatigue and dry skin. Another disease emerged depending on exposure to indoor contaminants is Building-Related Illness (BRI), of which cause is known (Fischman 2007). The most important difference separating the BRI from SBS is that their symptoms could be identified clinically and their causes are explicit. Complaints included in the group of BRI, in contrast to SBS diseases do also continue after the person has left the building. It is like the clinically diagnosable, identifiable diseases with known causes that could be treated (infection, immunological or allergic) such as Asbestosis, Legionnaires'disease, Pontiac Fever and chemical allergies. One could complain from both SBS and BRI at the same time. Multiple chemical sensitivity (MCS) is another syndrome, which is similar to SBS (Arnold et al. 2006). The people with MCS are allergic people showing high sensitivity against the chemicals in the environment. Scent sensitivity is one of the precise causes of the condition associated with MCS.

Considering that employees working in modern office buildings make up 50% of the total labour force in industrialized countries and that 20–30% of this group have reported symptoms similar to SBS, it could not be denied that SBS should be evaluated as an important issue of occupational medicine. Regarding public health, SBS is of importance due to the fact that it has effects on labour productivity as well as causing health problems. Epidemiologic studies, though asserting some factors related to SBS, it is generally evaluated as a multi-factored health problem and a medical, psychological and social case.

5.2 Etiology of SBS

No single environmental factor or a group of factors is defined for the cause of SBS; however there are numerous theories presented regarding this issue. It is the best to consider SBS as multifactorial in the absence of any basic theory. Studies conducted put emphasis on the fact that combination of the contaminants in inhaled air of indoor atmosphere has effects on symptoms or on combination of symptoms (Ezzati 2005). Indoor air contamination may depend on the internal condition of the building and also occur due to the effect of outdoor conditions (Myers and Maynard 2005). Possible reasons for SBS are physical (for ex. ventilation rate, illumination, sound, noise), chemical (for ex. smoking, hanging or stable dust, carbon dioxide, carbon monoxide, nitrogen oxides, sulphur dioxide, volatile organic compounds, pesticides), biological (e.g., bacteria, mould), personal and psychosocial factors (e.g., gender, age, allergies, stress, dissatisfaction with work, place lived in, genetic predisposition, environmental smoking) (ASHRAE 2003c, Kubo et al., 2006; Mahmoudi and Gershwin 2003). Mostly, volatile organic compounds, radioactive elements, non-persistent gases and formaldehyde found in many environments affect the air quality inhaled. Apart from that some factors are related to the symptoms emerging, for instance, being exposed to activities such as constantly photocopying with copy paper including carbon in an unchanging environment (Jaakkola et al., 2007). The effect of psychological factors on building related illnesses could not be disregarded (Magnavita et al., 2007). There are researchers reporting that SBS emerges as a result of a reaction against the workplace rather than being simply a disease (Marmot et al., 2006; Mendell and Fisk 2007). Psychosocial atmosphere in the workplace partially affects the prevalence of SBS and resolution of related problems (Gomzi et al., 2007, Hansen et al., 2008).

One of the psychosocial factors that are thought to be effective in the development of Sick Building Syndrome is monotonous work environment. Monotonous work means being overloaded psychologically due to constantly repeating activities or tasks. Employees could not be satisfied also mentally due to psychological monotony. At present day, more than 700,000 chemical agents are in daily use. Chemical contaminants in indoor air could be originated from the outdoor or indoor environment. Moderate amount, even very low amount, of these contaminants may cause health problems in some people having certain sensitivities. Dust is associated with SBS as well. Dust irritates mucous membranes. Biological contaminants such as pollens, bacteria, viruses and moulds may pass through ventilation systems (Straus 2009).

5.2.1 Air Quality Parameters

It is of great importance that the employees work in healthy standards in their workplaces, where they spend at least 8 h/day. Accordingly, some factors that have been held responsible for the development of SBS are as follows (ASHRAE 2003a, Soysal and Demiral 2007).

Formaldehyde (HCHO): Formaldehyde is an organic compound found in most indoor environments. Usually urea-formaldehyde adhesives are used in floor covering and in pressed wood products for walls and ceilings. In low concentrations, it causes lacrimation and upper respiratory tract irritation, whereas in high concentrations, it leads to lower respiratory tract irritation and pulmonary edema. It may trigger asthma attack in people with asthma. Another effect of formaldehyde is on the central nervous system. It may cause short-term memory loss and anxiety. Indoor environment value for formaldehyde should not exceed 0.065 ppm. When reached 0.1–0.5 ppm, it leads to earache, nasal mucosa irritation, difficulty in breathing, complaints of cough and asthma, cardiac complaints, dizziness and difficulty in memorizing. International Agency for Research on Cancer (IARC) classified formaldehyde as group 2A carcinogen.

Carbon monoxide (CO): For carbon monoxide, air standard of outdoor environment should guide indoor environment. Maximum carbon monoxide dose to be received in outdoor environment in 1 h should not exceed 25 ppm. Main source of carbon monoxide inside the building is the exhaust smoke diffusing through into the building and smoke spreading from the ovens with poor ventilation system. WHO and EPA recommend 9 ppm as the highest value for carbon monoxide to be allowed in indoor air.

Carbon dioxide (CO_2): Usually, indoor carbon dioxide levels are higher than outside due to the fact that every living thing give off carbon dioxide into the air by respiration. Carbon dioxide concentration above 1,000 ppm is indicative of insufficient ventilation and this causes complaints of headache, nausea, eye and throat irritations in the employees. WHO and EPA recommend 1,000 ppm as the highest value for carbon dioxide to be allowed in indoor air.

Ozone (O_3): Devices in the office are the most important factor for ozone gas to spread into the environment and when the amount of ozone is above this standard limit, symptoms of sick building syndrome such as eye and throat pain, headache, etc. are observed in the employees. British Allergy Foundation (BAF) has demonstrated that the prevalence of diseases such as fatigue, insomnia, eye and throat pain, allergy and asthma is 94% due to the spread of ozone through photocopiers, fax machines and printers. Standard value for ozone should not exceed 0.06 ppm (0.12 mg/m).

Oxygen (O_2): All living things regularly require oxygen to survive. Living things meet their need for oxygen through atmospheric air. Human beings must inhale 4.76 m^3 atmospheric air for 1 m^3 oxygen due to the fact that oxygen is found in approximately 21% of atmosphere. If the oxygen level falls below 21% in the inhaled air, respiration and blood circulation accelerates, blood pressure increases and symptoms regarding headache and fatigue begin to emerge in a short time period in people working in such places.

Nitrogen dioxide (NO_2): It includes gases such as nitrogen monoxide and nitrogen dioxide emerging due to the combustion. If nitrogen dioxide is present in any place, probably, other nitrogen oxides (such as NO, N_2O_3) are available as well. It causes irritation in mucous membranes, chronic pulmonary disease, asthma and leads to death in the concentrations above 150 ppm.

Volatile Organic Compounds (VOCs): These chemical agents are commonly used in numerous construction materials such as paint, polish, carpeting, artificial wooden panels, some insulating materials, and various decoration materials, in home products industry, furniture and in some cosmetic cleaning products as well. Volatile organic compounds being colourless but odorous spread out into the environment during the application of the products and could accumulate in the environment in certain amounts. Therefore, it is reported that, especially in small and not sufficiently ventilated places, the level of volatile organic compounds is high. In the studies conducted by Environmental Protection Agency (EPA), it has been determined that people could face very high levels of contamination when using these kind of products with organic content and this contamination could last for a very long period. Yet as the result of studies of similar characteristics, it has been reported that in some cases, such kinds of organic compounds could be found 2.5 times more in indoor environments than in outdoor environments. Discharge of volatile organic compounds (VOCs) is high especially due to the new material, high indoor temperature and humidity; however it could be possible to reduce concentration by sufficient ventilation. Volatile organic compounds (VOCs) have effects on human health depending on their level in indoor environment (Glas et al., 2008). In persons coming into contact with 2–3 ppm or less amount of volatile organic compounds, allergic reactions such as irritation in eye, nose and throat may develop. When exposed to 4–5 ppm, more severe reactions may emerge and loss of memory, sneeze and rushes may also develop. When exposed to 10–20 ppm, breathing difficulties and burning in eyes, nose and throat could develop. Especially people suffering diseases like asthma are more sensitive to these compounds and such compounds could initiate asthma attacks in these kinds of patients. Because they also have carcinogenic effects, it should be laid further emphasis on these compounds.

Particulate Matter ($PM_{2.5}$): Particulate matters could be in particulates and also in liquid droplets. Usually, they emerge as combustion products. They trigger asthma attack in people suffering asthma and may cause nasal and upper respiratory tract irritation. Though no internationally accepted standards for $PM_{2.5}$ have been specified by WHO and EPA yet, the recommended value is 35 $\mu g/m^3$ and 50% more for indoor air.

Humidity: In compliance with ASHRAE standards, it is estimated that the relative humidity in indoor air should be between 30 and 60%, and better around 45% regarding the health. Humidity level that is below 35% in work environment causes dry eye, problems related to respiratory system and an increase in tendency to infections. Moreover, low humidity levels leads to a higher prevalence of nasal symptoms. In the studies conducted, it has been determined that dermal symptoms are increased more in low humidity levels. People are not very sensitive to the humidity level between 40 and 70%. This level of humidity could be tolerated by people. On the other hand, high levels of humidity provide a basis for the development of pathogenic and allergic organisms like fungi. Furthermore, as the humidity level increases, the felt temperature increases as well. According to ASHRAE, when at least 80% of the building employees complain about thermal discomfort, a problem regarding indoor environment should come to mind. It is known that this fact causes some severe symptoms considering the health. In the environments with a relative humidity more than 65%, it gets harder to control the human body temperature and this high level of humidity encourages the reproduction of bacteria, fungi and production of allergenic dusts in the home (mites). As for low level of relative humidity, it causes mucous membranes to dry and an increase in dermal diseases.

Temperature: When other indoor conditions are suitable, the indoor temperature should be between 18 and 24°C for healthy people. If employees present in the room feel that air temperature, humidity, air velocity and the temperature of the surfaces surrounding the room are most suitable, then, the thermal comfort is established. Though studies on Sick Building Syndrome could not present a precise result, the best performance from the employees is acquired between 19 and 20°C (ASHRAE 2003b). National Institute for Occupational Safety and Health (NIOSH) recommends that the temperature should not exceed 26°C for men and 24°C for women. In some sources, the suitable temperatures recommended are 20–24°C for winter and 22–26°C for summer. In the report of European Commission, it is indicated that the temperature between 20 and 26°C provides a suitable work environment. Again in the same source, it is implied that in a study carried out, the prevalence of SBS symptoms increases significantly above 22°C. Besides, evidence supporting this fact is the increase of gas discharge from building materials in high temperatures.

5.3 Symptoms of SBS

To diagnose SBS is more difficult when compared with other diseases (Niemelä et al., 2006, Norbäck 2009). Though their health worsen, the people having SBS symptoms continue to work due to the fact that no definitive diagnosis for this disease is established; however their efficiency in private and business life falls down. This creates an important public health problem. When a patient applies to a physician due to typical SBS symptoms (headache, fatigue, dizziness, nausea, nasal congestion or flow, dry cough, dry skin, itchy skin, itchy eyes, lacrimation and concentration difficulty, etc.), it is of critical importance to take a complete and proper anamnesis (Rios et al., 2009, Runeson et al., 2006). If no medical diagnosis is available to define these emerging symptoms, the physician should ask the proper questions to establish a SBS diagnosis. The most important question is the relationship between the time spent in the workplace and these symptoms. For instance, if an office employee has not suffered this syndrome until changing his/her place in the building or office, than the new office place is to blame. To define Sick Building Syndrome, we do not have any diagnostic or clinical tests and analysis methods at our disposal regarding the issue. Medical authorities still discuss the issue whether SBS is a genuine diagnoses of a medical case. That is because most of the symptoms are subjective reports and could not be measured easily. Even in some cases reported, some professionals deny its existence due to the fact that results of measurements of suspicious chemical agents and others in sick buildings are below the limits.

Additionally, as no symptoms are recorded for other people in the building, only people excessively sensitive to very low level of VOCs report disease. For this and similar reasons, SBS usually could not be defined and a false diagnosis is established. Diagnosis is established depending on patients' history, physical and clinical findings at first. Rarely, laboratory and imaging methods confirm the complaints. Later, the building should be examined completely with the personal complaints of its inhabitants. A person suspecting he/she has had SBS may ask whether the building has been investigated regarding possible contaminants. Occupational health specialists specially trained in this subject should perform a walkthrough by examining the existence of common SBS symptoms and problematic areas among the people living in the building with an intention to check the buildings suspicion for being sick. If some of the inhabitants of the building complain about symptoms similar to SBS and the building has problems such as overpopulation, contamination, insufficient ventilation or humidity, the researcher should make suggestions to improve the indoor air quality of the building. To determine the level of exposure to the factors dangerous for health in indoor environment is a hard job to do (Halios and Helmis 2007). The possible interaction between these compounds makes this task more difficult. If the individual affected could not leave the building or the originating cause for the disease could not be eliminated, to treat SBS symptoms individually may help to overcome this disease.

Similar tests conducted to determine the origins of allergic sensitivity of some patients with MCS may also help patients with SBS symptoms, of which exact source is not known. Attempting to reduce stress may also help to decrease and cope with SBS symptoms. If the environmental problems could not be amended, the individual should decide how to prevent SBS in its main source at best. When got suspicious of SBS once, the building should be assessed as a possible source of problem and necessary improvements should be accomplished. In the reported prevalence of SBS, there may be gender differences because women tend to report symptoms much more than men (Brasche et al., 2001).

Besides, there are studies concerning that women have a more sensitive immune system, that they are much more concerned about their health and are more prone to develop dry mucosa and facial erythema. At the same time, it could be claimed that women are exposed to indoor environmental factors much more due to the fact that they are more inclined to work at office jobs, where office equipments and materials much intensely used. When risks causing diseases in developing countries are listed as a result of the studies conducted, it is recorded that indoor air contaminants take the 8th place in the list. In the case that indoor air quality exceeds the specified limits, it affects especially the sensitive people negatively. It is estimated that indoor air contaminants cause globally 1.6 million death and 2.7% DALYs (Disability – Adjusted Life Years) (WHO 2005, Smith and Mehta 2000).

Not everyone working in a sick building has to develop a disease. This case affects especially the people more negatively, who are under risk regarding cardiac and respiratory tract diseases. Physical conditions of people in the place where they live are extremely important for sick building syndrome to emerge. This syndrome is a clinical case characterized with multiple symptoms. Though everybody is affected by the factors effective in the same conditions, the emerging symptoms will not be same. Among reported symptoms, there are headache, eye irritation, nasal bleeding, nasal and sinus congestion, cough, cold and flu-like symptoms, several diseases including gastrointestinal complaints and generally developing complaints regarding respiratory system. Course of disease occurs depending on a series of extremely complex factors. Quality of workplace makes sense when occupational characteristics, environmental conditions, stress and sensitivity of the individual come together. If the symptoms disappear when the person, in whom the syndrome develops, leaves the building, this fact is a direct indication of the relationship between the person and building (Takigawa et al., 2009). It is very useful to keep a daily symptom log in every 2 h for every day spent at work in a table divided into 7 days, including the weekends, the time period when it is not worked. Multiple symptoms could be observed in this syndrome (Bobic et al., 2009, Eriksson and Stenberg 2006). Symptoms can be divided into the following categories:

- Mucous membrane irritation: Eye irritation, throat irritation, cough, dry skin, dry eyes, dry nose and/or dry throat.
- Neurotoxic effects: Headache, fatigue, loss of concentration, feeling constantly tired, headache or general appearance/condition proposing ailment/malaise.
- Respiratory symptoms: Allergic symptoms such as difficulty in breathing, cough, wheezing, lacrimation or nasal flow, symptoms like feelings of chest constriction, chest congestion and chest compression.
- Dermal symptoms: Rash, itchiness, dryness.
- Chemical-sensory changes: Increased or abnormal scent perception, visual disorders.

From the viewpoint of healthy life and life quality, opinions about the building and the emerging problem could be divided into two main sections.

- Building Related Symptoms (SBS)
- Building Related Illnesses (BRIs)

Building related symptoms are some non-specific annoying/discomforting problems mostly effecting eyes, nose and throat (Allermann et al., 2007, Murphy 2006). Clinical diagnosis of symptoms established by physicians is to define building related illnesses (BRIs) (Muhic and Butala 2004). A very long hidden or asymptomatic period is required to last until BRIs emerge. For instance, like the latent period of time passing for the lung cancer to emerge in a person exposed to radon, which is found in indoor atmosphere. Legionnaires' disease – one of the BRIs – appears among building inhabitants as the result of the contamination of cooling towers with legionella bacteria. *Legionella* is responsible for Pontiac Fever as well. The disease is not contagious in nature. Patients show flu-like symptoms. Apart from all of these, building related illnesses could be grouped only after the symptoms related to the disease has revealed. The treatment of BRIs and the recovery period cover a long time period. Usually, emerging problems become chronic in the person living in sick building exposed to these kinds of diseases. Even if the building is left or the environmental conditions are organized or bettered, symptoms depending on problems do/could not immediately vanish (Brightman et al., 2008). Accordingly, BRIs could be divided into three main groups.

- Toxic diseases (Ex.: Carbon monoxide poisoning)
- Infectious diseases (Ex.: Legionnaires' disease)
- Allergic diseases (Ex.: Asthma, hay fever or delayed type hypersensitivity pneumonitis)

5.4 Precautions of SBS

There is no effective and specific proven treatment to eliminate SBS. Many specialists come to agreement about the fact that the best treatment for SBS is to avoid it by abolishing contaminants asserted to be the cause of SBS and other identified sources (Edvardsson et al., 2008, Lahtinen et al., 2009). The people with SBS should be encouraged about protecting themselves from the building related factors that make them sick. However, this is not always possible because it could lead to insulation and job loss. It is difficult to investigate and evaluate the aforementioned problems observed in indoor air quality due to the issue is comprised of many aspects. Mostly reported symptoms and health complaints are different and they are not that much characteristic so as to be attributed to any specific medical diagnosis or causal factor easily. Considering these factors and their results, air quality of the workplace environment should be maintained as high as possible to ensure the sustainability of psychological and physiological health of the employees as well as to provide job satisfaction and efficiency. Existing problems should be resolved by determining possible sources of contamination. Due to the fact that high prevalence is indicative of potential building related problems, to calculate the prevalence of building related symptoms with an intention of characterizing indoor air quality in the offices is a frequently applied method. Sick building syndrome questionnaire frequently used when resolving problems related to indoor environment that require a systematic study is the most important element of the detailed process carried out by occupational health specialists to explain and evaluate risks (Lahtinen et al., 2004, Reijula and Sundman-Digert 2004).

The questionnaire to be applied is a convenient tool for the investigation of air quality problems inside the building to be carried out by occupational health personnel and quality of data acquired from the investigation could be taken as a reference when analyzing the health problems emerging at work. To be able to attain a result performing a successful treatment in this case, which is quite complex to understand, it is reported in the studies conducted that analysis for determining the environmental air quality and that the living spaces being asked in detail besides taking anamnesis when examining the underlying reason of emerging diseases, are a must. Preventing SBS starts with an appropriate design and building maintenance. Special attention must be given to heating, ventilation and air conditioning (HVAC) systems (Fisk et al., 2009, Mendell et al., 2008). WHO has specified rules regarding regular inspection and maintenance for proper management of building ventilation systems as well as rules preventing the penetration of biological contaminants inside the building. Moreover, to design the buildings appropriately for minimizing the access of the contaminants, to inspect older buildings for possible VOCs and to better potential problems may prevent SBS observed among the inhabitants of the building. Education and communication are basic for effective air quality management of any building.

Questions concerning hygiene and maintenance principles that should be answered to prevent the buildings from being sick could be listed as follows: Is the building being cleaned sufficiently? Are the properties, materials and shelves being constructed in compliance with humid/wet hygienic principles to minimize the dust in living spaces? Are there personnel responsible for the cleaning and maintenance of ventilation systems of the building? Is a regular method being applied for maintenance? Are all necessary sections such as cooling towers, evaporation based cooling systems, drop collection tables/sections, air canals, filters, humidifiers, etc. being cleaned regularly and are leaking, cracked, burst, hollow parts checked? If we could answer yes to the questions asked above, problems are minimized. If our answers include no, some problems await us regarding building sickness. We require making adjustments in shortest time so as to correct our answers as yes. To provide the necessary ventilation in indoor environments is determined as the task of the employer. For this, it will be to the point to perform following suggestions.

An effective protection method that could be used especially in multi-storey buildings is cleaning central system devices and indoor air, which is an expensive protection method compared to other methods. Air intakes of the building should be constructed far away from the road and other sources of contamination. Filters with high effectiveness should be used in ventilation systems. Behavioural education is an important protection method as well. Ergonomic precautions should be taken.

Noise is also perceived to be an important problem by the employees. It should be paid attention to the insulation problem. More importance should be attached to the hygiene of general environment. Ventilation is the leading precaution to be taken in order to prevent indoor air contamination. The easiest way to maintain the oxygen level in enclosed volumes in natural conditions at the required level regarding the health aspect is to perform natural ventilation. The air, which is contaminated (carpet pile and clothing fluff, smell of perfume and sweat, etc.) and of which oxygen level is reduced due to the usage, is expelled out into the atmosphere and fresh uncontaminated (passing through the necessary filter systems) air with high oxygen level is taken in. This is one of the most important conditions of human health and efficiency. To ensure the necessary ventilation in indoor environments of the workplaces and to set up a warning system to become activated in the case that the ventilation system does not operate are defined in the laws as the task of the employer.

Furthermore, it should be considered that following and similar risk factors related to SBS could pose problems:

1. That the employees use computer more than 5 h daily, up to 8–10 h. Common usage of computers increases heating and electromagnetic radiation load of the buildings. At the same time, this temperature causes the relative humidity inside the building to decrease. Hence, precautions such as arranging shift hours of the personnel that are constantly working on computers may be effective. It is recommended that the cleaning of the computers is carried out at frequent intervals.
2. Too much employees working together at the same department create a problem as well. There are at least 10–15 people in 100 m^2 in advance working together at the same department in the buildings in generally. In fact, at most seven people should be present in an area of 100 m^2.
3. Presence of problems regarding building maintenance (air conditioning devices and fans should be cleaned once every 3 months or more frequently, general maintenance should be performed and air circulation capacities should be checked constantly).
4. Insufficient ventilation (in a non-smoking environment, ventilation should be between 7 and 12 Litter per individual in an hour).
5. Use of materials made up of compounds with high evaporation and toxicity (new carpets and soft floor coverings should be cleaned off volatile substances before installed in the building).
6. Presence of open shelves in voluminous areas or leaving papers exposed (Materials such as files, books, papers, newspaper, etc. found in office environments should be kept in enclosed cabinets).
7. To prevent dust, solvent and ozone discharge from devices such as printers or photocopiers, all operating stages of these devices should be completed within the device itself. If possible, building a separate enclosed room, it should be ensured that photocopying and similar procedures are carried out in that room.

5.5 Conclusions

Today numbers of people living in big cities are increasing every day and majority of these people spend most of their time working in indoor environments. Occupational health includes studies to maintain and improve well-being of people working in all kinds of professions in terms of physical, mental and social aspects. It is possible to talk about mainly two groups of factors determining the health status of a working individual. These are avoidable environmental factors found in workplace environment and personal characteristics of an individual.

We are confronted with indoor air contamination and its effects on human health as a problem threatening public health more and more. Though the sick building syndrome does not threaten life, it is uncomfortable. It causes loss of labour force and efficiency and may cause serious health concerns. In the whole world, the importance attached to the indoor air quality is increasing day by day. Indoor air quality has gradually become the basic criterion for healthy comfort and standards have been developed regarding this issue. Especially in this period of time, when residences like skyscraper have increased, it should be given priority to instructional programs such as aiming at maintaining indoor air quality, applying smoking prohibition in indoor environments without making any concessions and ensuring the proper choice of heating systems, ventilation systems and construction materials and legal regulations should be made. To ensure the sustainability of the health of the employees and at the same time job satisfaction and efficiency of them, it should be tried to keep the air quality of the workplace environment as high as possible.

Indoor air problems in the workplaces are among the issues that should be considered frequently by occupational health specialists when evaluating the health risks in a work environment. A good quality of indoor air has an important effect on the health of the employees and on ensuring positive social atmosphere in the workplace and an increase in production in the offices. Education and communication are important elements in therapeutic and preventive management programs regarding indoor air quality. If the people present in the building, workplace physicians, managers and engineers completely know and understand the causes and importance of indoor air quality problems, they could collaborate more effectively in resolving and preventing the problem at source. If the sources are known and possible to control, then eliminating or changing the source of contamination is an effective approach to be taken in indoor air quality problems.

Because there are no special methods available yet implying a relationship between SBS and possible risks, the precautions to be taken are not known in the same way. Standard epidemiology and industrial hygiene evaluation techniques sometimes could not help as well. It is also an important public health concern requiring the collaboration of the people from the various fields of study such as physicians, epidemiology specialists and engineers. This awareness is also of importance regarding its influence on the effectiveness at work in the workplaces besides attaching importance to the human health, comfort and satisfaction of the individual with the building he/she is present. As well as higher efficiency and less job loss could be provided by the improvement of the indoor air quality, economic losses emerging due to medical treatments could be also prevented. New living conditions and new environmental conditions created will continue to cause the development of this problem and other similar problems. However, it is possible to avoid this disease by means of good adjustment and proper planning and by taking our environment under control on a regular basis.

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Chapter 6
Psychosocial Factors that Aggravate the Symptoms of Sick Building Syndrome and a Cure for Them

Nami Imai and Yoshiharu Imai

6.1 A Lack of Recognition of Sick Building Syndrome

Human beings breathe unconsciously. This means that people take oxygen into their body and expel carbon dioxide continuously. Therefore, they hardly recognize the existence of air and are unconcerned about air pollution in their daily life, even though they may worry about water or food pollution. In fact, the mass of air that a person takes in each day is larger than the mass of food or water that they consume, and so poor air quality can cause many health problems. However, people do not recognize this fact. Moreover, people do not consider that they may have sick building syndrome, even though they know of its existence, so they do not bother to make themselves aware of its symptoms. This is due to the fact that sick building syndrome was only recently defined.

Many people have no sense how danger when they smell a toxic chemical, even if they recognize it. People may forget that the air in their living environment is not always safe and do not think that it may harm their health if it smells a little strange. For example, many kinds of antibacterial, anti-flammable, etc, chemicals are used on the carpets in public buildings such as hotels or city halls, and some of these chemicals may volatilize and harm human health. The smells of these chemicals are peculiar but people just associate them with public buildings and so accept them as normal. Therefore, the first and most fundamental problem of sick building syndrome is that people do not consider that the air surrounding them could harm them.

Sick building syndrome patients get worse when they enter a building containing toxic air and get better or become free from symptoms when they leave the building. Thus, patients begin to think that they have a problem with their constitution or a chronic disease. For example, if a patient gets a headache every time they enter

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a building, they think that it is because they have a chronic headache. This phase confuses patients. In this phase, patients wish to be cured spontaneously without going to hospital or to be cured by taking over-the-counter medicine because they do not know that toxic chemicals in the air of their house or office or public buildings that they visit such as libraries or city halls harm their health and assume that the origins of their symptoms are internal. As they suspect that their condition results from a hereditary disease or virus or is due to their lifestyle such as a lack of sleep or fatigue, they search for solutions in the wrong places and continue to breathe in toxic air and aggravate their symptoms. In other words, wrong self-diagnosis prolongs the length of time that they take in toxic chemicals from the air.

The fact that such patients already have sick building syndrome and continue to consume toxic chemicals from the air makes them at high risk of developing chemical sensitivity (Imai et al., 2008). Some researchers have argued that after consuming a high density of toxic air in a short period or low density of toxic air over a long period, people develop chemical sensitivity when they encounter the small amount of toxic chemicals again (Cullen 1987). In addition, if sick building syndrome patients aggravate their symptoms, they can escalate to multiple chemical sensitivity. Different from chemical sensitivity in which the patients show symptoms only when they encounter a particular chemical, multiple chemical sensitivity patients react to many kinds of chemicals without any relation to their past exposure history. Patients with this condition cannot live in the community because they may react against the smell of cosmetics or synthetic detergents or volatilized air from mothballs. In conclusion, misdiagnosing sick building syndrome increases the risk of multiple chemical sensitivity developing.

6.2 Difficulty of Establishing Diagnosis

The content of this section is based on Imai et al. (2004). Sick building syndrome aggravation is not only caused by patients' lack of recognition of sick building syndrome but also a lack of knowledge about the condition within the medical profession. Many medical staffs are unconcerned about the use of chemicals because they are commonly used in hospitals. Sick building syndrome and chemical sensitivity are new concepts, and they are not treated as priorities in medical and nursing education. Therefore, many medical staffs do not know that toxic chemicals in the air can be a cause of significant health problems, and so they often make wrong diagnoses when sick building syndrome patients complain about their condition.

The author has found that sick building syndrome patients usually visit at least one hospital where they do not get medical treatment for sick building syndrome but rather receive treatment for their symptoms, such as headache, nasal catarrh, dermatitis, etc. In this situation, their symptoms temporarily disappear, but then recur when the patient returns to the place filled with toxic air. Therefore, the patient has to visit hospital again. After a few visits, some patients start doubting their doctor's diagnosis and visit other hospitals. Consequently, sick building syndrome patients often have to visit many hospitals to obtain a correct diagnosis and treatment. This phenomenon is known as “doctor shopping”.

While sick building syndrome patients and medical staff treat the patient’s symptoms, the patients are continuously consuming the toxic air and aggravating their symptoms. The ignorance of medical staff’ about sick building syndrome is therefore doubly bad because they not only make a wrong diagnosis but also aggravate the patient’s symptoms.

On the other hand, patients who have jobs in society or are busy caring for family members do not go to hospital even though they have sick building syndrome or multiple chemical sensitivity symptoms. Some of them may just forget to care about themselves or forget how important their health is because they are too busy to think about such matters. However, many sick building syndrome patients who do not go to hospital expect to be healed spontaneously because they think that their symptoms are due to fatigue.

In addition, even when patients realize that their symptoms are caused by sick building syndrome, they often cannot find appropriate medical institutions because in many countries there are only a few medical institutions that are able to diagnose and treat sick building syndrome. Even if they find a medical institution for sick building syndrome, many patients hesitate to visit it because they feel that the medical institution is too far from their home, they cannot make time to go there, or transportation expenses are too high. For example, in Japan, the only suitable medical institutions are in Tokyo. Therefore, sick building syndrome patients who live in rural areas must use the bullet train or fly to reach to these institutions and so have to spend large amounts of money on transportation and accommodation on top of their medical fees. As many patients suffering from sick building syndrome are unemployed, such costs are too high. On the other hand, even if they can afford the expenses, some patients choose not to visit such institutions because they have to wait more than 3 months. Patients who decide to have a medical examination at a special medical institution for sick building syndrome are eager to obtain a correct diagnosis and to alleviate their symptoms quickly (Fig. 6.1).

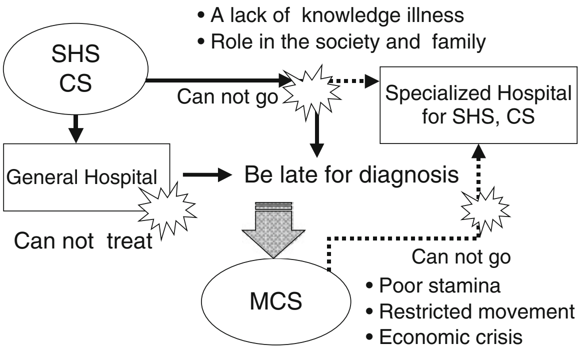

Fig. 6.1 Psychosocial aggravating factors of MCS in Japan (Imai and Imai 2009)

6.3 Difficulty of Taking Radical Measures to Improve the Environment

When patients' symptoms are correctly diagnosed as sick building syndrome and there is little difficulty in visiting appropriate medical facilities, will patients' treatment progress smoothly? Unfortunately, probably not because they must find the exact origin of the toxic chemicals in order for the treatment to succeed. Specifying the origin of toxic chemical volatilization is a really difficult task because toxic chemicals can be volatilized from building materials, furniture, electrical appliances, or other personal belongings, all of which may be in the same space.

Let's explain about a case from the author's research. The patient had no chronic illness but, 1 day, he suddenly became to develop a headache and feel dizzy when he smelt the air volatilized from copying machines.

He complained that he felt bad, especially when copying machines were working and producing a strange smell. Thus, he thought that a copying machine in his office was the cause of his sickness. He asked his boss to move the copying machine to another room, and his boss arranged to do so. However, his symptoms did not recover because, according to him, something remained in the office after the copying machine had been removed and had stuck to other item such as papers or wallpaper. The author does not know whether his complaint is true or not. No one can accurately determine what harmed his health because lots of things were used in his office, and there were many staff and visitors.

On the other hand, if patients and medical staff can specify the origin, can the problem be solved easily? Unfortunately, countermeasures to reduce the levels of toxic chemicals in the air of an office often take a long time or cannot be implemented. For example, if the glue used on wallpaper is the origin of sick building syndrome, can you imagine how much it would cost to remove the glue? Some people do not show any symptoms even though they spend long periods in toxic air. Of course, breathing in toxic air harms everyone but people who do not show any symptoms are happy to remain there in the short term. Would those people agree to remove the wallpaper if the cost of doing so would reduce their income? In particular, if the head of the office does not show any symptoms, does he/she want to incur such a high cost?

Let's move on to another example, a teacher of a nursing school visited the author and underwent a consultation in the Nursing Counseling Room. At that time, many students and staff working in the newly built schoolhouse had developed sick building syndrome. After an investigation, we found that the cause of their sickness was formaldehyde volatilized from building materials used on the walls and floors. However, the schoolmistress of the school did not want to take any countermeasures because she did not have any symptoms and could not understand what toxic chemicals in the air were causing the health problems of the students and staff. She considered the removal of building materials to be unnecessary and that opening windows and changing the air would solve the problem. She also thought that the quantity of formaldehyde would decrease over time. This is wrong. The density of formaldehyde in the air of a building made of building materials containing formaldehyde does not decrease. It decreases during winter and increases again in summer. This cycle is repeated every year until the materials are broken down by wear and tear.

Accordingly, the only effective measures are radical measures; i.e., removing all toxic materials from the interior of the building. Attempting to reduce the density of toxic chemicals in indoor air by ventilation, using adsorbents, or covering them with sealing paint is not sufficient in many cases. The reduction in the density of toxic chemicals achieved by opening windows is lost about 1 h after they had been closed. If we want to achieve a sufficient reduction in toxic chemical density from an adsorbent, we need to use a huge quantity and continuously replace it to maintain the effect. Toxic chemicals that are covered by sealing paint will leak from points that are not painted (Imai and Imai 2006). Therefore, we cannot prevent the effects of toxic chemicals using these methods. Please note that radical measures are the only way to solve problems associated with toxic chemicals (Imai et al. 2007).

Let's move back to the nursing school example, the schoolmistress did not want the fact that her nursing school had a health problem to be known publicly as she was afraid that if it became public, the number of students would decrease, and it might cause the school financial difficulties. This is not a simple problem. From a manager's point of view, trying to run their organization successfully is one of their main tasks, and therefore, they cannot consider action that is detrimental to their organization's existence even if they also want to respect human health. In this case, even though she was the schoolmistress of a nursing school that educates medical staff, she put her organization's profit before caring for human health. In other companies, we can assume that the situation is just as bad.

We can find a clear example in the food industry. Many foods that are sold in shops contain chemicals such as preservatives, coloring agents, and artificial coloring agents. Of course, most of these are not good for human health. Indicating the quantity of these chemicals is required by law because a person's health will be harmed if they consume a large amount of such chemicals. However, from a food company's point of view, they need to keep their product fresh as long as possible and also need to decorate their product to suit consumers' tastes. Therefore, company profit is considered more important than customers' health. As a result, the lack of understanding by management about sick building syndrome and their concerns about financial problems or bad publicity caused by the exposure of a health problem are obstacles to radical measures being taken against sick building syndrome (Fig. 6.2).

As mentioned above, the lack of knowledge about sick building syndrome; difficulty in finding the origin of toxic chemicals; and the obstacles to taking radical measures to improve the environment such as economic, physical and psychological barriers aggravate sick building syndrome. These factors prolong patients' exposure to toxic chemicals, which may cause sick building syndrome to escalate to multiple chemical sensitivity. Therefore, we must remove these factors in order to solve the problems of sick building syndrome.

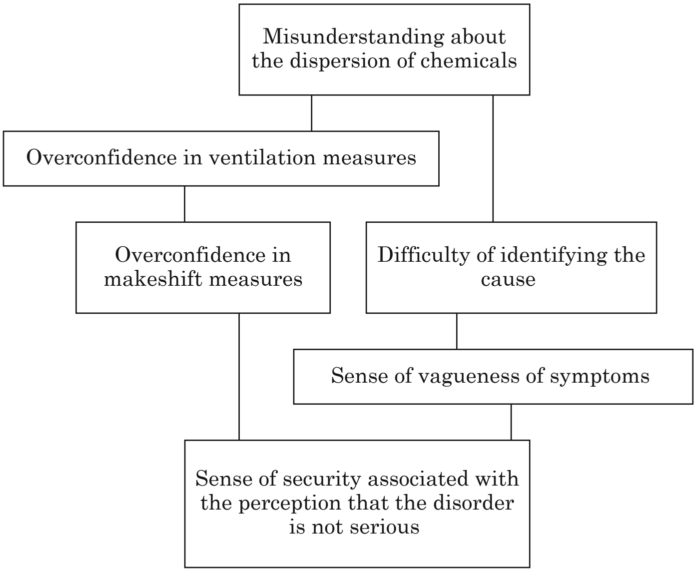

Fig. 6.2 Psychological barriers against taking measures to improve the living environment (Imai et al., 2008)

To solve such problems, all of us must be concerned about sick building syndrome. People need opportunities to learn about sick building syndrome and must understand what measures to take against the problems it causes; i.e., there is no effective measure except removing all toxic materials from the environment. Sick

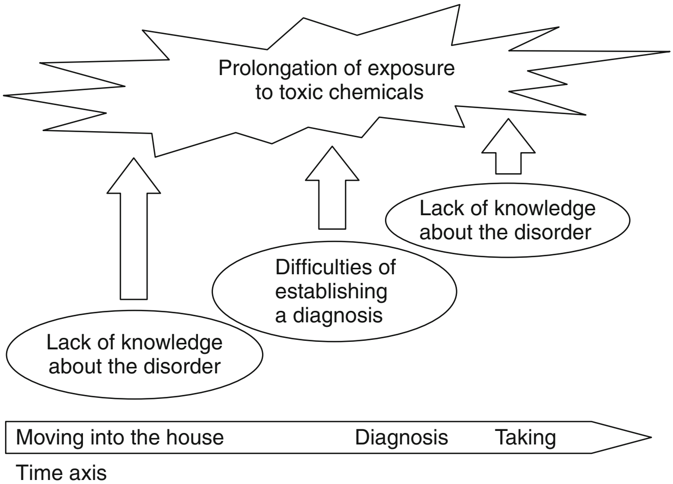

Fig. 6.3 A Flow of symptoms' aggravation by prolongation of getting right diagnosis (Imai et al., 2008)

building syndrome can be categorized as a pollution-related illness. Therefore, national governments must also attempt to solve these problems by making laws that prevent the use of toxic materials in living environments with strict penal regulations and/or provide financial support for sick building syndrome patients to take radical measures to solve their problems.

Moreover, we, as individuals, must understand that these tragedies are happening on a global scale and how difficult solving such problems is.

We must also understand that we will suffer from large-scale economic, physical, and psychological problems if sick building syndrome is left untreated. We must realize that the symptoms will develop into intractable disease if we do not take radical measures. In other words, we must recognize the importance of safe air to our existence (Fig. 6.3).

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Chapter 7
Building Biology and Examination Models for Buildings

Ayşe Balanlı

7.1 Introduction

People have attempted to fulfill their needs, which they couldn't satisfy within their natural environment, by constructing shelters called "buildings"; so building is a "man-made" environment designed and constructed in the natural environment that contributes positively to users' life in order to fulfill the user's biological, psychological and sociological needs. In other words, the function of a building is to meet the users' needs at the most basic level: to survive in healthy conditions (Öztürk and Balanlı 1995).

Previously, buildings were constructed in the natural environment, using natural materials and methods in accordance with the limited functions that the users expected. But today, the environment, people and buildings are exposed to fundamental changes due to the evolution in living conditions, society, science and technology.

Today's building is constructed in a polluted outdoor environment with materials produced as a result of an artificial process with multi-faceted and complex relationships, involving many users with diverse expectations of new functionalities. This complex relationship between the human, the building and the environment has disrupted the most basic function of the building: to present a healthy environment to its users for a healthy life (Balanlı and Öztürk 2006).

The need of constructing healthy buildings necessitates a scientific study that covers the building, its environment and its users and identifying the relations between them. The studies about this discipline called "building biology" started in some Western European Countries many years ago (Balanlı and Öztürk 2006).

In this chapter, building biology will be defined as a subject of environment; the relations between the building and its user will be established; and "Building Biology Examination Methods" developed for helping researchers will be explained.

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7.2 Building Biology

7.2.1 Definition of Building Biology

The buildings that gain negative features as a result of different factors derived from its indoor and outdoor environment will fail to fulfill its users' needs and accordingly will be responsible for the psychological and biological heath problems of its users.

"Building biology", which works on the relationship between the building, its environment, and its users' health, aims to help construct healthier man-made environments.

Building biology is defined as "a scientific field which attempts to prevent the negative effects on people's lives by identifying the relationships between the building, its environment and its users, while setting and controlling the rules to direct the design, construction and usage of building in terms of its users' health" (Öztürk and Balanlı 1995). This scientific field is not only interested in benefiting its user, but also examines the living and non-living environments as a whole. As it is clear in the description, it benefits from all sciences and academic branches related to building, human and environment. Besides from the architecture and engineering fields that relate to the building, it also interacts with medicine, biology, sociology, psychology, ergonomics, ecology, physical sciences, chemistry, geology and meteorology among others.

7.2.2 Building Biology as a Subject of Environment

While the building and its user compose an environment together, they also maintain their survival in other environments on their own.

Environment can be described as "a surrounding which enclose an entity while having a correlative relationship and interaction with it and can be variable, complex and multidimensional in some situations" (Balanlı and Öztürk 2006).

Environment can also be classified according to the structures of the entities, the relationships and the surrounding.

"Living environment" is the surrounding that includes all relationships of all the organisms in their lives. Organisms include plants, humans, animals and microorganisms.

Surroundings composed of non-living entities but that host living things can be identified as "non-living environments".

"Natural environment" is the entire environment of all living and non-living entities that exist by itself (Hançerlioğlu 2000) moving and changing continuously (Ozankaya 1995).

"Man-made environment" is a new and artificial surrounding of nature or a part of nature that is selected and created specifically for the actual conditions, in order to fulfill the desired functions (İzgi 1999). This artificial environment is a living area for the organisms.

"Social environment" is a cluster of people that live together on a common land, have a common culture and interact with each other in order to survive and work towards common interests (Ozankaya 1995).

"Physical environment" is a natural or a man-made surrounding made of non-living elements that include the living beings or social environment (Balanlı and Öztürk 2006).

The space inside a shell, which separates a part of the natural environment apart and surrounds it, is called "indoor environment". The rest of the space with all it's surrounding is called "outdoor environment" (Balanlı and Öztürk 1995a).

So, both building biology and all the relationships between the building and human can be explained as the relationship between living and non-living areas throughout the environment (Balanlı and Öztürk 1995b).

7.2.2.1 Living Environment: Human

Humans carry biological characteristics due to their physical existence and psychological characteristics due to their own unique behaviors. As a necessity of these biological and psychological characteristics, they interact with other humans in their environment. These relationships shape their sociological characteristics. The sociological, biological and psychological characteristics of humans cannot be entirely independent from each other and every human being can be described by these three characteristics (Öztürk and Balanlı 1995). Buildings are designed and constructed to satisfy specific needs of humans evaluated by these characteristics.

- Social needs of human

  Sociology deals with the structure of society, its powers and social processes while determining its objective rules. People cannot survive by themselves. Survival forces people to live as a group. Group defines more than one person coexisting and interacting with each other, and it is one of the basic concepts of sociology (Ozankaya 1995).

  The behavior standards called "norms" are the common values and rules sanctified by the people in the group. People feel the need to make up these norms and obey them. For the integrity and the continuity of the groups, norms should be set in religion; ethics, customs and traditions, law and fashion and they should be obeyed. This is a social need of the people.

  People learn to obey these norms as a result of the socialization process. The socialization process is effective in forming the personality and ego and it teaches the role of the individual in society. Therefore, related to his/her sociological features, the individual can be said to have the following needs:

  - Living in a group (social environment),
  - Obeying to norms (social rules),
  - Passing through the socialization process (Öztürk and Balanlı 1995).

The mission of the designer is to create environments that satisfy these defined needs. So the designer should produce man-made environments

- That integrate the groups,
- That gather the compatible groups together,
- That organize the relationships between the groups,
- Where the needs are fulfilled according to the social norms and culture,
- Where the people's interests and attitudes are considered,
- That contributes to the socialization process.

When the social needs of the people are not met, negative conditions, attitudes and behaviors will arise such as: loneliness, alienation, incoherence, assimilation, isolation, immature personality, incompatibility and degeneration, which may result in psychological and biological problems over time.

- Psychological needs of human

  Psychology is the science of behavior. Motivation is the factors that cause the individual to behave in a certain way at a certain time (Plotnik 1999). Behaviors arise as a result of motivations and it is directed to a purpose. The purpose is generally to fulfill a need and get satisfaction. The needs of the individual related to his/her psychological features are oriented to the purpose of being happy. During his/her lifetime the individual, at first trying to satisfy his/her biological and afterwards sociological needs, represents an interdependently changing biological and psychological development. This development modifies the needs as well.

  Psychological needs are at different levels in terms of intensity and importance at each stage of life (childhood, puberty, middle ages, and late ages).

  Behaviors change according to hereditary and environmental factors. The psychological event always happen related to the environment that they exist in. That is why the environment is always an element of the psychological reality (Kağıtçıbaşı 1998).

  All environments, living, non-living, physical, social, and natural or man-made, affect the psychological events in positive or negative ways.

  Buildings are non-living, physical, social, and man-made environments where the people spend most of their time. These environments that are capable of changing the entire life in all aspects should be designed and created to fulfill its users' needs. Winston Churchill says "First we shape our buildings, then the buildings shape us" (İmamoğlu 1992). Referring to this approach, the designer creating the building will also be shaping the people living inside (Balanlı and Öztürk 2006).

  There are research findings that architectural design may affect the social relationships, human behavior and productivity. Nice and scrupulous environments may lead people to think and feel better, and also provide the growth of life force and pleasure. It is considerably difficult for attentive, elegant, sensitive and peaceful people to be brought up in careless, messy, ugly and noisy environments (İmamoğlu 1992).

  The designer, in a position to create places consistent with people's psychological needs and development, has an important duty. If this duty is not performed properly, the behaviors will be obstructed while stress is created.

As a response to this stress in people, a series of psychological and physiological defense mechanisms appear. When the stress is too strong or the defense is insufficient, people can face psychosomatic diseases. "Psychosomatic disease" term can be defined as functional and structural defects of the organs due to the inappropriate stimulation of the autonomous nervous system and the endocrine system (Cumhur 2001). The Psychosomatic diseases, described as the physical manifestations that originate from psychological impacts such as anxiety, emotional conflict and stress, appears almost in all parts of the body but mostly in the systems which are not possible to control consciously. The following are the psychosomatic diseases that are most frequently seen:

- Cardiovascular problems
- Respiratory system diseases
- Digestive system disorders
- Skeleton and muscle problems
- Reproduction problems
- Urinary system diseases
- Dermatological problems
- Hormone disorders
- Nervous system diseases (Fox 1999).

Also, stress can cause some diseases to worsen and some to accelerate.

- Biological needs of the human

  Biology is a science that researches the structures, activities and the life processes of an organism or a fossil from all facets (Starr 2000).

  The biological structure of the human is studied by anatomy which is one of the special research areas of human biology. Anatomy is one of the main branches of medicine that studies the organs of the body in terms of form, structure, position and function and the relationships between them.

  Systematic anatomy studies the systems composed of the organs that function for the same goal. These are:

  - Skeletal system
  - Muscular system
  - Nervous system
  - Sense organs (sight, hearing, taste, smell, touch)
  - Respiratory system
  - Circulation system
  - Digestive system
  - Excretory system
  - Reproductive system
  - Hormones
  - Immune system
  - Protective outer covering (skin, nail, hair) (Fox 1999).

The foremost task of the designer is to provide the necessary conditions for the people -the users- to lead healthy lives. For each system that makes up the biology of the human, the corresponding function that is expected of the building is listed in Table 7.1.

7.2.2.2 Non-living Environment: Building

Building can be described as:

- An object, since it is a result of a production process.
- A non-living, physical and man-made environment that is built by preparing a part of the nature which is selected to fulfill the aimed functions, in order to its function.
- A system, because it includes conceptual and physical elements that affect and are related to each other and thus forms a functional and an identified whole.
- Building as an object

Selecting and separating a part of nature, thus creating a separate space and transforming this space into a different environment can only be achieved by designing and constructing a shell and its compartments. This shell enables us to define the building as an object.

The construction of the building as an object starts with producing the necessary materials that will make the designed models into an object. The basic purpose of materials is to form the shape. However in the nature, materials convenient for all purposes are not to be found and mostly, these materials cannot be incorporated into a building as it is found in nature. Natural resources, which are put through artificial processes, are turned into relatively finished "building products". These products are ranked as material, piece, component, element and unit, according to their function, production process and finishing (Balanlı 1997).

Building materials are basic mass products and its compounds, alloys and composites, having no identifiable geometric shape; that are formed as a result of both natural and artificial processes. For example natural stone, concrete, paint etc.

Building pieces are each one of the objects produced as a result of shaping the materials for a specific function and that form a whole when put together. For example bricks, cables, pipes, panels etc.

Building components are custom products that are obtained by joining the materials and pieces together, or giving them special forms; and that have a specific place and function within the building. For example window, flooring, sink, column etc.

Building elements are whole products made-up of materials, pieces and components put together using several methods, in order to meet one or more of the physical functions of the building. For example foundation, floor, roof, wall etc.

A unit is a part of a building, formed by combination of building elements that serve a specific function by themselves. For example room, kitchen, bathroom, classroom etc. (Balanlı 1997; Özkan 1976).

Table 7.1 Required functions that correspond to the biology of the user (Balanlı and Öztürk 2006)

Biological systems	Needs
Skeletal system	Ergonomic conditions necessary for movement Providing security of movement Protecting the system from negative conditions (strike, break etc.) Providing necessary oxygen
Muscular system	Ergonomic conditions necessary for movement Providing security for movement Protecting the system from negative conditions (fatigue, stress etc.) Providing necessary oxygen
Nervous system	Preventing the existence of conditions causing stress Providing relaxation and necessary sleep
Sense organs (sight, hearing, taste, smell, touch)	Preventing surfaces and air to affect the protective outer covering negatively Providing sufficient hearing and sight Protecting from unpleasant vision, noise, pollution and smell
Respiratory system	Providing necessary oxygen Having no pollutants in the indoor air
Circulation system	Providing necessary oxygen Getting away carbon dioxide in the air Having the indoor dimensions not obstructing the blood circulation
Digestive system	Making up appropriate conditions for alimentation Providing necessary oxygen for digestion
Excretory system	Providing the proper conditions to perform the excretion activity Providing hygiene
Reproductive system	Preventing the existence of conditions affecting the hormones negatively Providing the proper conditions to perform the reproduction activity
Hormones	Preventing the existence of conditions obstructing the hormone production
Immune system	Preventing the existence of antigen and allergen Not having conditions triggering the allergic reactions
Protective outer covering (skin, nail, hair)	Preventing to have surfaces affecting the skin, nail and hair negatively Providing to perceive the stimulus accurately

- Building as an environment
  The space, which surrounds the building and in which the building exists, is described as "outdoor environment" and the space surrounded and bounded by the shell of the building is described as "indoor environment". The common feature of the indoor and outdoor environments is the existence of the physical and social characteristics. Depending on these characteristics, a building can be considered to have physical and social environments as well.

  The "physical outdoor environment" of the building includes

  - Natural (air, water, soil, organisms),
  - Man-made (buildings, roads, parks etc) environments.

  The "social outdoor environment" of the building is identified with

  - Forming of the groups outside of the building,
  - Obeying the norms,
  - Effects on the socializing process.

  The "indoor environment" also shows "physical and social indoor environment" characteristics like the "outdoor environment".

  The characteristics of the "Physical indoor environment" of the building are;

  - Dimensional and spatial features,
  - Visual features,
  - Auditory features,
  - Tactile features,
  - Atmospheric features.

  The "social indoor environment" of the building is identified with the

  - Group forming,
  - Obeying to norms of religion, ethics, fashion, customs and traditions,
  - Effects on the socializing process

  The indoor and outdoor features of the building are shown in Fig. 7.1 (Balanlı and Öztürk 2006).

  The physical and social features of both indoor and outdoor environments of the building affect the building users totally in both negative and positive ways (Fig. 7.2).

- Building as a system
  System is a gathering of the conceptual and physical elements that affect and related to each other, in order to form a functional and identified whole (Balanlı and Öztürk 1995b).

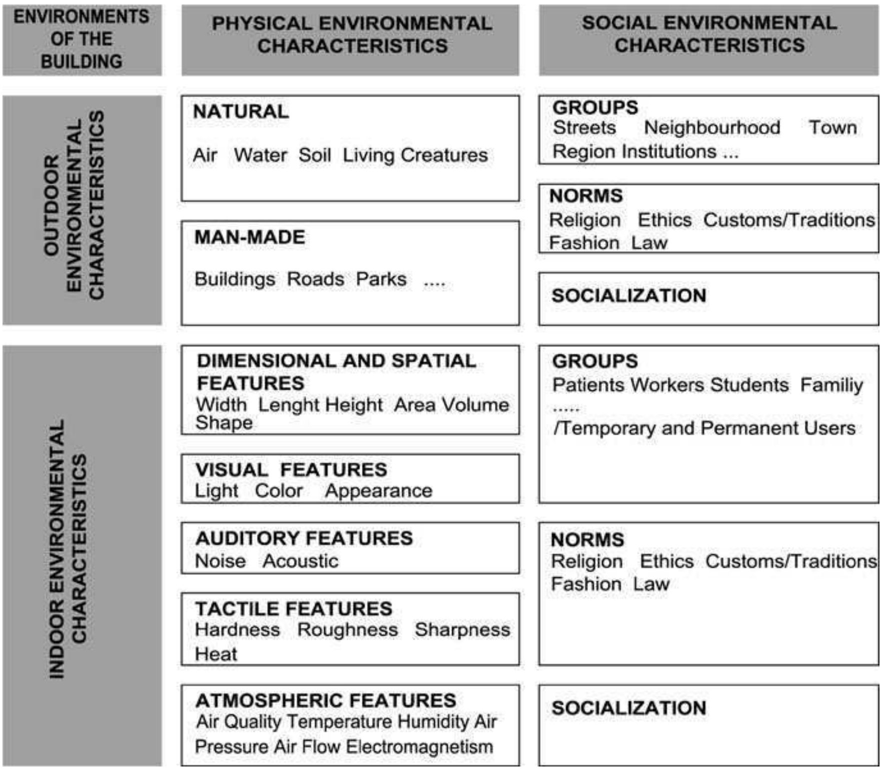

Fig. 7.1 The physical and social indoor and outdoor environmental features of the building

Considering the building as a system, the components of the "building system" are

- The purpose of the building system: The reason for the production of the building,
- The objectives of the building system: The measurable features of a building desired to be achieved as an object and an environment,
- The sources of the building system: All the necessary physical and conceptual elements for the design and construction of the building,
- The activities of the building system: Any activity performed during the design, construction and utilization of the building,
- The output of the building system: The output as an object which is a result of the design and production processes; the output as an environment which is all the indoor and outdoor features of the building that make it an environment (Balanlı and Öztürk 1997).

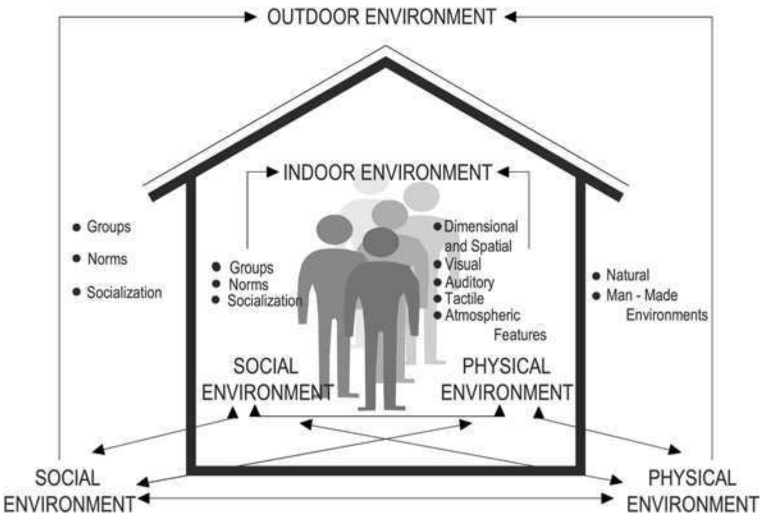

Fig. 7.2 The interaction of the user with the indoor and outdoor environment of the building (Balanlı and Öztürk 1995a)

7.3 Health Relationship Between Building and Human

According to WHO (World Health Organization), health is not only the disease to be absent or not being sick; but also totally being well physically, psychologically and socially. Referring to this description, the effects of the environment and also the effects of the building, as an artificial environment, on the conservation and the continuity of this well being status are subjects to researches and discussions while trying to find the solutions.

Several different groups of people involves in the design, construction and utilization processes of a building, such as the users, designers, producers, building product producers, controllers etc. These people have effects on the buildings, while the buildings also affect its users in negative or positive ways through their lifetime. Each negative effect leads the people or the building to loose their health. The negative effects on the building cause its features to fail and results in developing an unhealthy environment. So, an unhealthy building will have negative effect on the people's health (Fig. 7.3).

7.3.1 The Negative Effect of People on the Building – The Unhealthy Building

The designers, producers, controllers and the users are the factors of a building to be healthy or unhealthy.

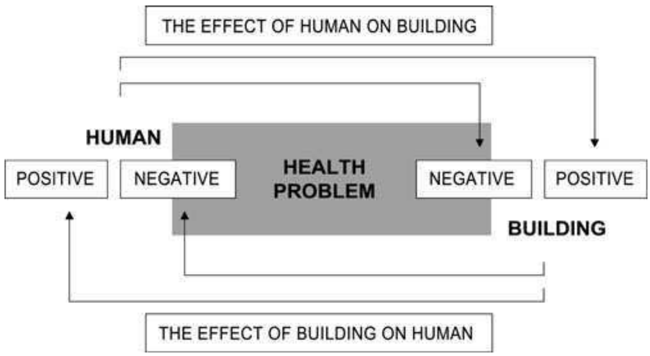

Fig. 7.3 The health relationship between building and human

An unhealthy building is designed when the designers (architects, engineers, product designers etc)

- Do not determine the construction and utilization requirements properly and completely, in regard with the environmental factors,
- Do not reflect these factors and requirements to the design,
- Take inaccurate design decisions.

An unhealthy building and unhealthy building products are produced when the building and building product producers

- Do not evaluate the production sources sufficiently,
- Do not reflect the design to the construction properly,
- Take inaccurate construction decisions.

The building turns to be an unhealthy environment when its users

- Do not use the building suitable for its function or make changes in the functions,
- Change the physical and social features of the building due to some factors and necessities,
- Do not apply a regular and a satisfactory maintenance to the building.

The controllers may not inspect the design, construction and the utilization of the building properly due to

- Having no or inadequate necessities as the laws, codes, regulations, technical specifications, standards, instructions or special contracts,
- Not applying these necessities or having difficulty in application,
- Having no sanctions about the requirements of these applications.

As a result of negative or inadequate acts of these people, an unhealthy building is designed (Balanlı and Öztürk 2006).

7.3.2 The Negative Effect of Building on the People – The Unhealthy People

People spend most of their time inside the buildings. The function of the buildings is to meet the users' needs. The unhealthy building users, whose needs are not met, the biological and psychological health of the users are affected. So the primary requirement for each building should be to associate a correct relationship between the building and the health of its user.

7.4 Building Biology Examination Models

In order to examine the relationship between the building and the users' health in terms of building biology, these models can be followed; since the building is described as

- An object and the environments of that object forms,
- A system.

Risk assessment can be followed as an examination model as well (see Chap. 3).

7.4.1 The Examination Model for the Health Problems Due to Indoor and Outdoor Environment of the Building

Regarding the existence of a negative factor at the indoor and outdoor environment of building; it should be considered that this factor may cause a problem; in relation with this problem another negative condition risking the health may arouse and finally a health problem can be seen. This chain of relationships can help to determine the health problems originated from the indoor and outdoor environments of the building and to examine which negative environmental feature of the building causes a certain health problem (Fig. 7.4).

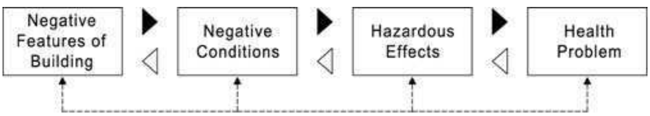

Fig. 7.4 The relationship between building and health problems

The steps of the model developed to specify the health problems caused by the building are to determine

- The negative features within the indoor and outdoor environments of the building,
- The negative conditions due to those negative features,
- Hazardous impacts of those negative conditions on health,
- The health problems which might be caused by those hazardous impacts.

The formation of a health problem can be examined from the opposite way as well:

- The health problem arouses,
- The hazardous impact risking the health,
- The negative conditions occurring as a result of negative features,
- Negative features of the indoor and outdoor environment.

So, using this model;

- The existing buildings can be examined in terms of building biology,
- The user can be lead according to the information gathered and the existing buildings can be rehabilitated,
- The evaluations may guide the designs of new buildings (Balanlı and Öztürk 1995a).

Table 7.2 shows the health problems, caused by the negative features in the indoor environment of the building; while Table 7.3 shows the examples for the steps to specify the indoor and outdoor environmental factors of building causing a health problem.

In studying the health relationship between the human and the building both the users and the environmental features of the following are needed to be defined:

- a building type with a specified function (education or tourism buildings),
- a designed or a certain existing building (Yildiz Technical University or Hilton Hotel).

In another words, during the examination of some specific buildings in terms of building biology, the identification of the user and the environment should be added to the model suggested in Fig. 7.5, along with the detailed features of the indoor and outdoor environments.

7.4.1.1 The Identification of the User

Users' sociological, psychological and biological needs, purposes, activities, interactions with the building and its environment and utilization time of the building are not the same of each other. Because of this reason the negative features of the building which affect the users' health may not cause the same health problems in every condition.

Table 7.2 The health problems caused by the negative features in the indoor environment of the building

Negative features	Negative conditions	Hazardous effects	Health problem
Radon going into the building through soil, water, natural gas, and building products (Balanlı et al. 2004)	Having radon over the limit value in the indoor air of the building	Breathing radon	Lung cancer
Products containing asbestos (Balanlı and Tuna Taygun 2005)	Flitting of asbestos fibers in air	Breathing fibers of Chrysotile Crocidolite Amosite Anthophyllite Tremolite Actinolite	Asbestosis Lung cancer Mesothelioma Pleura tumor
Insufficient sound isolation outside the building and of the external walls of bedroom (Balanlı and Öztürk 2004)	Indoor noise level in bedroom; 62–65 dBA (Çevre ve Orman Bakanlığı 2002)	Increase in heartbeat during sleep	Cardiovascular problems (Berglund and Lindvall 1995)

Table 7.3 The indoor and outdoor environmental features of building causing a health problem

Health problem	Hazardous effects	Negative conditions	Negative features
Allergy (Balanlı and Öztürk 2004)	Contact with Allergens Breathing Bee bites	Allergens; Dust mites Domestic animals Pollen Bee Fungus	Not preventing the development of allergens and triggering of the allergic reactions through design, application and usage
Legionnaires disease (Balanlı and Öztürk 2005)	Breathing *Legionella* bacterium	Development of living environments for *Legionella* bacterium in water, air and human	The negative design, construction and utilization of hot and cold water system heating, ventilation and air conditioning systems, cooling towers, pools and spa

According to this, to have accurate results in the examination, it is important that users'

- Features related to the utilization time of the building (permanent or temporary users),
- Features related to their characteristics (sociological, psychological and biological)

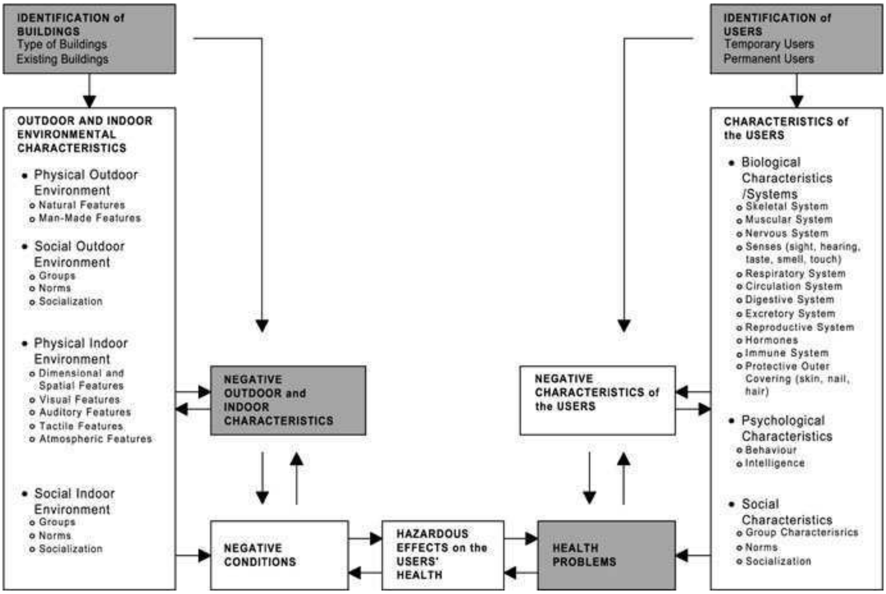

Fig. 7.5 The conceptual model to examine outdoor and indoor characteristics of building in terms of building biology (Balanlı and Öztürk 2004)

are needed to be defined.

- The sociological features of the user:
  - The characteristics of the group (the race, country, region; the relations, dependence and the aims of the groups etc.)
  - Social norms (religion, ethics, common customs, law etc.)
  - Socialization processes (the structure of the family; educational background; the field of practice and position; cultural features etc.)
- The psychological features of the user:
  - Behavior (physiologic, the learned and unlearned motivations etc.)
  - Mental processes (baby, child, teenager, adult and old; the perception of the building; mental disability etc.)
- The biological features of the user:
  - The age group (baby, child, teenager, adult or old); gender, height, weight etc.
  - The risk group (baby, child, adult or old; pregnant; sick; disabled; recovered from an illness; addict etc.)
  - Biological systems (respiratory system, circulation system; skeleton and muscles systems etc.)

The influence of building on its user is also depends on the duration of this affection. The users may use the buildings temporarily for a short period of time; or permanently for a long period of time.

The tourism buildings, schools, hospitals and libraries contain people staying both permanently and temporarily. For example, within the university libraries where the educational and research activities are held and any kind of document and information is provided; the library building is used by the two separate groups – the service receivers and the service providers (Balanlı et al. 2006).

- The service receivers within the university libraries:
  The students (vocational studies, undergraduate and postgraduate), faculty (lecturers, assistance), personnel and the researchers are the temporary users receiving a service. These users form a group of people who
  - Use the building for certain time periods,
  - Can be young (student, research assistant etc); adult and aged (lecturers, researchers etc),
  - Mostly form a large group or groups within the university,
  - Might be from different races, regions or countries and have different social norms,
  - Might have a permanent or a temporary disability,
  - Intend to get a document or information (Balanlı et al. 2006).
- The service providers within the university libraries:
  The librarian, manager and clerical staff are the permanent users of a library. These users form a group of people who
  - Use the building through the working hours,
  - Include young people and adults,
  - Generally have similar social norms,
  - Are mostly from the same race, region and country,
  - Have no physiologic disability to work,
  - Have the purpose to give the identified services and educated accordingly,
  - Work dependently to each other (Balanlı and Küçükcan 1998).

7.4.1.2 The Identification of the Features of Building and Environment

The indoor and outdoor, the physical and social environmental features present discrepancies according to the type of the building. So, during the examination of the characteristics of buildings, the type of the building or the specifications of building should be identified. The identification is related with the function and general features of the building type (office building, tourism buildings, library etc). For the specific buildings (for example Hilton Hotel), the identification should contain the information such as the location, the position, structural features, number of floors, the size and the features of the plan etc.

For a university library, the outdoor environment is mostly the university campus. The buildings, roads, gardens etc. exist within this environment. The social outdoor environment consists of the students, lecturers, university staff and the visitors. If the library is located outside the university campus, then the local community or the institutions at the neighborhood constitute the social outdoor environment.

The physical indoor environment of a library can be identified with its dimensional and spatial, formal, visual, auditory, tactile and atmospheric features. The social indoor environment covers the social relations of physical indoor environment users. The physical and social indoor environmental features can possess negative qualifications; due to being affected by the design, the construction, the use of the building or the outdoor environmental conditions.

To be able to associate a relation between the indoor environment and the health of its user; the values related with the characteristics of specified building should be compared with values defined by the laws, codes, regulations, technical specifications or standards. Any fact exceeding the limit values is a problem risking the user health. But the results of a scientific research may help for the undefined negative features.

7.4.1.3 The Steps of the Examination Model

The building biology examination model (Fig. 7.5) is produced for a special building or a building with a certain function. After the determination of the building and its users, the steps of this model are as follows:

- The identification of the indoor and outdoor environmental characteristics of the building
- Determination of the negative features of indoor and outdoor environments of the building
- Identification of the negative conditions due to those negative environmental features
- Identification of the negative characteristics of the user
- Determination of the health problem

To determine the reasons of the health problem, the steps to be followed are:

- Identification of the health problem
- Identification of the negative characteristics of the user
- Determination of the hazardous effects on health
- Determination of the negative conditions which result in those hazardous effects
- Determination of the negative characteristics of indoor and outdoor environments of the building which cause those negative conditions (Balanlı and Öztürk 2004).

7.4.2 Examining the Building Biology Problems Using the System Approach

The building related problems and their effects on people are complicated and need to be examined using a specific system. That is why the problems related with the building biology should be considered with the system approach which improves the conception, determines a system, solves the problem and has a role in decision making.

7.4.2.1 The Conceptual Model of Building Biology System

The main objectives in producing healthy buildings should be first identifying the factors causing the building biology problems and then preventing the occurrence of negative conditions causing these negative factors. In a building biology system, these objectives not only lead the resources and activities, but also determine the quality of the outputs. The resources of the building biology system affect the activities of the system, the building itself and its environment. A building and its environment of a required quality can be achieved by associating the system activities with the purposes, objectives, targets and resources as the inputs of the system (Balanlı and Öztürk 1997). The conceptual model of the objectives, activities, resources and outputs of the building biology system is shown in Fig. 7.6. A building related problem that can result in a negative way in terms of people's health can be considered better; a system can be determined in solving the problem; decisions can be generated and these decisions can be examined by using the "Building Biology System Conceptual Model".

7.4.2.2 The Components of the Building Biology System

When considered as a system, the components of the building biology system are:

- The purposes and objectives
- The resources
- The activities
- The outputs

- The purposes and objectives of the building biology system
  The main purpose of the building biology is to prevent health problems caused by building. The specified objectives of this purpose are trying to prevent the occurrence of these negative conditions affecting the people's lives; generating decisions accordingly and inspecting these given decisions.
- The resources of the building biology system
  The resources of the building biology system are:

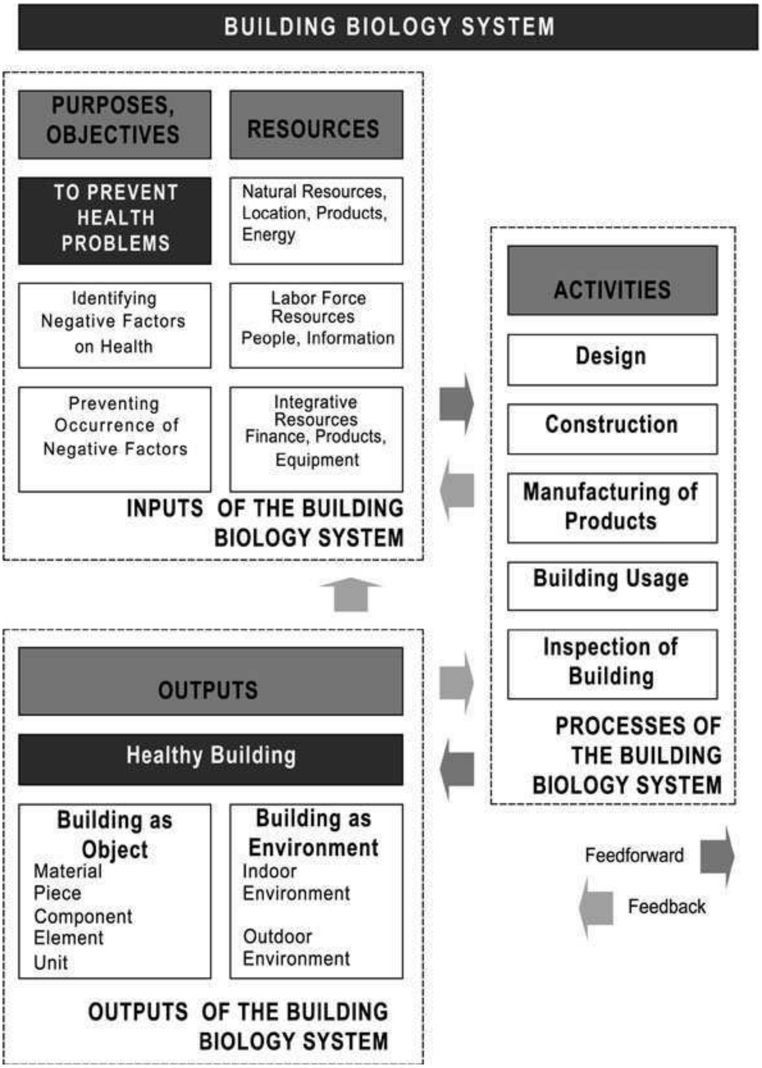

Fig. 7.6 The conceptual model of building biology system

- Natural resources (the building site, building products, energy etc.)
- Labor force resources (users, designers, contractors, product producers, controllers etc.)
- Integrative resources (finance, equipment, etc.)

- The activities of the building biology system
  The activities of the building biology system are:

  - Design activities (the management architectural, engineering and product design)
  - Production activities (the management, site preparation, the construction of the building and the manufacturing of the building products)
  - Usage activities (the management, temporary and permanent usage)
  - Control activities (the management, the inspection of the design, construction and the usage)

- The outputs of the building biology system
  The building biology system leads to two types of output:

  - Building as a healthy object (not having any negative factors in terms of people's health)
  - Building as a healthy environment (a healthy physical indoor and outdoor environment and social indoor and outdoor environment)

Applicable examination methods are required to define the problems and develop solutions for the relationship between building and health which is the subject of building biology. In this Chapter "The Examination Model for the Health Problems Due to Indoor and Outdoor Environment of the Buildings" and "Examining the Building Biology Problems Using the System Approach" methods, which can be beneficial for these examinations, are presented.

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Chapter 8
The Influence of School Environment on the SBS Symptoms and the Development of Asthma and Allergy

Motoko Takaoka and Dan Norbäck

8.1 Introduction

Human reactions to the indoor environment can be divided into three main categories. The most common effects are complaint reactions due to poor subjective indoor air quality, e.g. thermal discomfort, complaints of stuffy air, dry air or malodours. Secondly, there are some diseases with known aetiology that may be caused by factors in the indoor environment, e.g. building related asthma. Finally, subjects may report certain medical symptoms with unclear aetiology, but with a possible relation to the indoor environment. The term "sick building syndrome" (SBS) or "sick house syndrome" (SHS) has been used to describe such symptoms. They include symptoms from eyes, skin and upper airways as well as headache and fatigue (Norbäck 2009).

In the last few decades, the prevalence of asthma has increased in the industrial country, especially among children and young persons (Sennhauser et al. 2005). Nowadays, there are indications that the increase of asthma is highest in middle-income countries Indoor environment appear to play a substantial role in the development asthma. Poor indoor environment has been suggested to be related to the increase in the prevalence of asthma, especially among young persons and children.

Apart from the home, school is the most important indoor environment for children. Classrooms are densely populated, which can lead to both thermal discomfort and perception of poor indoor air quality. Children spend a large part of their total time in schools. Moreover, elementary school-aged children spend a large portion of their time in a fixed single classroom. Children's patterns of exposure to environmental pollutions are very different from those of adults. Children have greater susceptibility to some environmental pollutants than adults, because they breathe

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higher volumes of air relative to their body weights and their tissue and organs are actively growing, developing and differentiating (Faustman et al. 2000; Landrigan 1998).

In one review article on school environment it was concluded that formaldehyde, total volatile organic component and bioaerosol exposure in schools were sufficiently high to influence the students and has been found to be associated with allergy, asthma, and other respiratory symptoms (Daisey et al. 2003).

Mendell and Heath assessed whether school environments can adversely affect academic performance. They concluded in their review that poor indoor environmental quality (IEQ) in schools may have different negative effects on the students. Microbial and chemical exposures related to indoor sources and building characteristics found in schools, excessive dampness and poor ventilation, have been linked to reduced school attendance, respiratory infections, asthma and allergy in children and adults (Mendell and Heath 2005).

When comparing the some data from similar exposure measurements in dwellings and schools in mid-Sweden, the exposure to formaldehyde, VOCs, and house dust mite allergens were found to be lower in schools. In contrast, room temperature and CO_2 levels were higher in schools than in dwellings, and the air concentration of moulds, bacteria and respirable dust were similar (Norbäck 1997). Measurements in schools have shown that the air exchange rate often is low, resulting in high concentration of CO_2 (Mi et al. 2006; Smedje and Norbäck 2000; Kim et al. 2007b; Zhao et al. 2006; Simoni et al. 2010) and particle exposure (Smedje et al. 1997a; Simoni et al. 2010).

Moreover the school environment may contain indoor pollutants such as mold, bacteria, air born dust, volatile organic compounds (VOC), VOC of microbial origin (MVOC) and formaldehyde (Meyer et al. 2004; Kim et al. 2007a). Other problem in schools in Scandinavia is high room temperature (Smedje et al. 1997b). In China, room temperature in classrooms is very low in winter because of lack of a heating system (Mi et al. 2006; Zhao et al. 2006).

There is a widespread contamination of cat, dog allergens in school in many countries (Salo et al. 2009; Tranter 2005). Although pets are not present at school, pet owners carry the pet allergens in their hair and clothes to the classrooms. Some studies also reported contamination of allergens from horse (Kim et al. 2005) and house dust mite (*der f* 1/*p* 1) cockroach (*bla g*1/*g*2), mouse (Mus ml) in schools (Amr et al. 2003; Sheehan et al. 2009). Sheehan et al. (2009) compared allergen level in home versus schools for children with asthma and founded that higher level of mouse allergen in the schools than that of home. Allergen exposure in school may be important trigger for asthma in school children.

Health studies in schools have mainly focused on asthma and asthmatic symptoms in students, or sick building syndrome (SBS) (Norbäck and Torgen 1989; Norbäck et al. 1990) or nasal symptom or nasal inflammation school staff (Wålinder et al. 1998; 1999). There are few experimental or longitudinal studies on health effects of the school environment. In one 4 year longitudinal study it was found that the school environment had an influence on the development of doctors diagnosed asthma (Smedje and Norbäck 2001b). Two intervention studies in schools have shown beneficial effect of increasing the ventilation in schools (Smedje and Norbäck 2000; Norbäck and Nordstrom 2008).

8.2 Exposure Conditions in Schools

8.2.1 Room Temperature

Thermal climate in building may influence environmental perceptions, symptoms, physiological signs, as well as the emission of chemicals from building materials. Room temperature in office environment have been shown to be related to SBS and temperature above 22°C increased mucosal irritation and general symptoms such as headache and tiredness may occur in temperature climate (Jaakkola et al. 1989). Moreover, a review article has concluded that high room temperature may lead to reduced productivity, a higher risk of accidents, and decreased mental performance (Wyon 1993). Classrooms are densely populated, which can lead increased temperature due to heat produced by the pupils, in combination with solar radiation, and low air exchange rates. Moreover large glass window can increase the thermal problems on the warmer regions or during warmer parts of the year. It has been reported from Sweden that high room temperature in schools is common and could be a possible cause of sick building syndrome (Norbäck et al. 1990; Norbäck and Smedje 1997). In some parts of the world, e.g. in China, where there is no heating system in the classrooms, room temperature is low in the classrooms (Mi et al. 2006; Zhao et al. 2006). In tropical countries, room temperature is similarly high both inside and outside the schools.

Available school studies have shown that room temperature often exceeds the recommended maximum value of 22°C in schools (Table 8.1). The mean room temperature was 23.2°C in May and 21.4°C in December in Swedish Schools (Kim et al. 2005). In contrast it was 13–21 in schools in Shanghai, China (Mi et al. 2006), and similarly low in schools in north China in winter time (Zhao et al. 2006).

Norbäck and Nordstom (2008) studied the effect of temperature change in computer classroom in a university and reported that ocular (OR1.52 per 1°C), nasal (OR1.6 per 1°C) and throat symptom (OR1.53 per 1°C), headache (OR1.51 per 1°C) and tiredness (OR1.54 per 1°C) were significantly associated with temperature. Mi et al. (2006) showed that indoor temperature in schools in Shanghai was associated with daytime breathlessness (OR 1.18 for 1°C; $p < 0.001$).

In summary, room temperature is one of the most important factors for the environment of classrooms. It is important to control room temperature in classrooms through air conditioning, sun shield and sufficiently high ventilation flow.

8.2.2 Relative Air Humidity

Low relative humidity (<20–30%) is related to ocular and upper respiratory symptoms and dermal symptoms in some indoor environments, with low population

Table 8.1 Indoor climate and exposure levels measured in Sweden and China schools

	Sweden[a]	Sweden[b]	Sweden[c]	China[d]
	1993	2000	2000	2000
Exposure factor	Mean (max)	Mean (max)	Mean (max)	Mean (max)
Room temperature (°C)	24(27.5)	23.2(26.6)	23.2(26.6)	17.4(20.7)
Relative air humidity (%)	37(61)	41(51)	41(51)	56(82)
Carbon dioxide (CO_2) (ppm)	550(1,725)	815(1,275)	815(1,275)	1,060(1,910)
Air change rate (per hour)	NA	4.5(8.1)	4.5(8.1)	9.1(29.4)
Respirable dust ($\mu g/m^3$)	14(29)	94(544)	94(544)	NA
Total dust ($\mu g/m^3$)	66(107)	NA	NA	NA
Formaldehide ($\mu g/m^3$)	<5	7.1(16)	7.1(16)	9.4(20)
VOC ($\mu g/m^3$) sample by pump	23(93)	NA	NA	NA
NO_2 ($\mu g/m^3$)	5(9)	NA	NA	55(86)
Viable bacteria ($10^3/m^3$)	0.3(11)	NA	1.77	NA
Total bacteria ($10^3/m^3$)	38(110)	NA	17.0	NA
Viable molds ($10^3/m^3$)	0.4(4.5)	NA	0.36	NA
Total molds ($10^3/m^3$)	33(170)	NA	14.8	NA

NA = not analyze.
[a]Thirty nine schools (28 in the primary schools and 11 in the secondary schools) (Smedje et al. 1997a).
[b]Nine schools (six in the primary schools and three in the junior high schools, Kim et al. 2005).
[c]Eight primary schools (Kim et al. 2007a).
[d]Ten junior high schools (Mi et al. 2006).

density and high ventilation flow, but too low air humidity is rarely a problem in schools. High relative air humidity (>70%) may contribute to water condensation and microbial growth on indoor surfaces, and indirectly cause both SBS and asthmatic symptoms. Moreover, high relative humidity indoors can be an indicator of poor ventilation. Too high relative air humidity, however, can be a problem in schools in some parts of the world. Mean relative air humidity in Swedish schools was 41% in May and 31% in December (Kim et al. 2005). Mi et al. (2006) reported that the mean relative air humidity was 36–82% in 30 classrooms in Shanghai, China. Moreover, current asthma was positively associated with indoor relative humidity.

In the home environment, there is the relationship between high humidity and levels of house dust mite allergens. House dust mites grow in the mattress of the bed. Humidity levels in the ambient and indoor micro- environment play an important role in the levels of dust mites. Dust mites require indoor absolute humidity levels above 7 g/kg which corresponds to 45% relative humidity in the room (Dybendal and Elsayed 1994). Since schools do not contain beds, house dust mites cannot grow in the school environment, but mite allergens can be transferred from the home environment by contamination of clothes. In Swedish schools, levels of house dust in settled dust is low (Smedje et al. 1997a). In Korea, somewhat higher levels of house dust mites have been detected in school dust (Kim et al. 2007b).

In summary, high levels of air humidity can lead to microbial growth in schools, and the relative air humidity can be lowered by increasing the ventilation. Problems with too low air humidity are less common in schools because they are densely populated and humans emit water vapor.

8.2.3 Ventilation

Sufficient ventilation is crucial to remove indoor-generated pollutants from indoor air or to dilute their concentration to acceptable levels. Moreover, ventilation can reduce the prevalence of airborne infectious diseases (Lee and Chang 2000). Since humans emit CO_2, and the outdoor concentration of CO_2 is relatively constant, measurement of CO_2 is commonly used as convenient indicator of the building ventilation (Fromme et al. 2008). The closing of windows and doors during lecture hours caused high levels of CO_2. As early as 1858, the German pioneer of modern hygiene Pettenkofer (1858) showed that subjective air quality is related to the indoor concentration of CO_2. As a rule of thumb, the air is perceived as unacceptable by non adapted visitors when the CO_2-concentration exceeds 1,000 ppm. At the end of the nineteenth century, Heyman (1880) noted that CO_2 levels in Swedish schools often exceeded the 1,000 ppm limit, and a maximum concentration of 5,000 ppm CO_2 was detected. Most of the current ventilation standards, but nationally and internationally, are based on the old recommendation by Pettenkofer (1858) that the CO_2 concentration should be below 1,000 ppm (ASHRAE 1999). In some cases 800 ppm have been suggested as a limit value (Seppanen and Fisk 2004), which corresponds to a personal outdoor air flow of about 10 l/s.

There have been a number of review articles on the health impact of building ventilation. Godish and Spengler (1996) reported that there is limited evidence to suggest that ventilation rate increase up to 10 l/s per person may be effective in reducing symptoms, but higher ventilation rates may not be so. Seppanen and Fisk (2004) reported in their review article that beneficial health effects could be achieve by reducing CO_2 concentration down to 800 ppm. The importance of classroom ventilation to achieve a healthy indoor environment for students was pointed out in the review article on school environment by Daisey et al. (2003).

School environment studies have shown that CO_2 concentration often exceeds the recommended maximum value of 1,000 ppm in schools (Table 8.1). Measurements in Swedish schools have shown that as much as 80% of the classrooms had inadequate ventilation (Smedje et al. 1997a), defined as either a CO_2 concentration above current Swedish standard of 1,000 ppm, or a personal outdoor air supply rate less than seven liters per second. These values are used as ventilation standards in Sweden (National Swedish Board of Occupational Safety and Health 1993). The American Society of Heating, Refrigerating and Air–Conditioning Engineers (ASHRAE 1999) gives guidelines for CO_2 as <1,000 ppm and a minimum personal outdoor air flow of 8 l/s (ASHRAE 1999). Another study showed the mean CO_2 exceeded 1,000 ppm in 45% of the classroom in Shanghai, China

(Mi et al. 2006). In a recent study from USA, Michigan school the peak levels of CO_2 reached 2,700 ppm (Godwin and Batterman 2007). Fromme et al. (2008) noted that the median indoor CO_2 concentration in the classroom in German schools was range 598–4,172 ppm in winter and 480–1,875 ppm in summer and in 92% of the classroom the CO_2 daily median was above 1,000 ppm.

There are some studies showing health effects of low ventilation flow in schools. School children exposed to CO_2 levels >1,000 ppm showed a significant higher risk for dry cough (OR 2.99, 95% Cl 1.65–5.44) and rhinitis (OR 2.07, 95% Cl 1.14–3.73) (Simoni et al. 2010). Indoor CO_2 in schools in Shanhai was associated with current asthma (OR 1.18 for 100 ppm; $p < 0.01$) and asthma medication (OR 1.15 for 100 ppm; $p < 0.05$) (Mi et al. 2006). Increased indoor CO_2 in computer classrooms was associated with headache (OR 1.19 for 100 ppm CO_2) (Norbäck and Nordstrom 2008). Increasing the personal outdoor air flow rate from 1.3 to 11.5 l/s, through installation in schools of new ventilation systems with displacement ventilations, decreased the risk for asthmatic symptoms in pupils (Smedje and Norbäck 2000). Moreover, a relation between low air exchange rate in schools and nasal obstruction and nasal inflammation has been demonstrated (Wålinder et al. 1998).

In many countries, schools have no mechanical ventilation system. The number of pupils per room volume is high, and the natural ventilation of the building is not enough to reduce CO_2 level to normal level. Since window opening has a limited capacity to reduce indoor CO_2 installation of mechanical ventilation system in schools is needed if the ventilation standards should be fulfilled. Supply-exhaust ventilation is the most efficient ventilation system to control ventilation and achieve good air quality. Moreover, this type of ventilation system can be combined with a heat exchanger to recover heat from the supply air ducts.

In schools, the new type of displacement ventilation system has been shown to have beneficial health effects, e.g. less nasal obstruction and inflammation (Wålinder et al. 1998).

In summary, it is important to keep CO_2 levels below current standard (1,000 ppm), which can be achieved either by reducing the number of students and increasing the ventilation flow. Use of an efficient ventilation system, e.g. displacement ventilation or other types of efficient ventilation, is needed except in very warm climate where window ventilation can be used to keep CO_2 level below 1,000 ppm. Inadequate ventilation with high CO_2 levels is still a problem in schools in many parts of the world.

8.2.4 Chemical Indoor Exposure

It has been shown in many studies that the indoor concentration of various volatile organic compounds (VOC) is higher indoors as compared to outdoor levels. Indoor sources of volatile organic compounds (VOCs) include building materials, consumer products and human emissions. The chemical compounds found indoors have very different biological properties, and formaldehyde is one of the more irritative compounds. Formaldehyde, acetone, xylene, limonene, and TVOC have been shown to be significantly related to SBS symptoms in dwellings (Takeda et al. 2009). Another author concludes that exposure to VOCs and formaldehyde can be a major cause of SBS (Jones 1999).

The term volatile organic compounds (VOC), is used to describe the sum of organic chemicals within a defined boiling range, usually 50–260°C. The term very volatile organic compounds (VVOC) has sometimes been used for organic compounds of lower boiling range (<0–100°C), and the term semivolatile organic compounds (SVOC) has been used to describe compounds of a higher boiling range (240–400°C). The concentration of VOC can be different in different parts of the school. Schools with swimming pool, computer rooms, science and art rooms, can have higher concentration of certain VOCs.

A wide variety of chemical derived from plastic products, electric apparatus, interior construction materials, and fabrics can be found in classrooms. One study found that the most prevalent VOCs in schools were benzene, ethylbenzene, toluene, xylene, α-pinene and limonene and indoor concentration were usually higher than outdoor levels (Godwin and Batterman 2007). Shendell et al. (2004) reported higher concentrations of benzene, toluene, and xylene in classrooms but lower levels of α-pinene and limonene. On the other hand, Norbäck (1995) reported higher toluene and limonene concentrations. Godwin and Batterman (2007) measured the air VOCs concentration in 64 elementary and middle school classrooms in Michigan and reported the most VOCs had low concentration (mean <4.5 $\mu g/m^3$). Fromme et al. (2008) reported the level of TVOC in German classrooms ranged between 110–1,000 ($\mu g/m^3$) and formaldehyde concentration was 3.1–46.1 ($\mu g/m^3$). Science rooms showed the highest concentration of naphthalene (10 $\mu g/m^3$) and another science room had high levels of alpha-pinene (35 $\mu g/m^3$), a component used in many cleaning products (Godwin and Batterman 2007).

In some parts of world, for example, in Asia, formaldehyde emission is major indoor problem in different indoor environments, including schools. Sources include chip board containing phenol formaldehyde resin and paints and lacquers. In the 96 classroom of school in Saga Prefecture, in Japan, 40% of classrooms, formaldehyde level were higher than that of the standard of Japanese Ministry of Education (100 $\mu g/m^3$) and relatively high levels of formaldehyde were found in some music classrooms (40–70 ppb) (Ichiba et al. 2009). In a new computer classroom in Japan more formaldehyde (50 ppb) was detected 1 month after the completion of construction work, when computers and furniture were carried in, as compared to concentrations immediately after completion of the building (Yura et al. 2005). The origins of formaldehyde were through to be computer, musical instruments and furniture.

When remodeling old schools without mechanical ventilation, it is crucial to use low emitting materials. Current asthma was more frequent among pupils exposed to higher levels of formaldehyde or total level of VOC in schools (Smedje et al. 1997b). In another Swedish study of primary school personnel, a relation between SBS and indoor exposure to VOCs was demonstrated (Norbäck et al. 1990). Among semivolatile compounds, phthalates in door dust in homes have been related to asthma and allergy in children (Bornehag et al. 2004). We found no study on health effects of phthalates or other semi-volatile compounds in schools.

In summary, VOCs from different sources are detected in schools, and the concentrations can be different in different parts of the school. There are few studies on health associations for specific VOC in schools.

8.2.5 Aerosols

Particle levels are often higher in schools than in hospitals or offices, because of low air exchange rate, inadequate cleaning, and the physical activity of the children. The WHO air quality guideline for PM10 is 50 μg/m^3 (24-h mean). Significant short-term exposures to particles (350–1,320 μg/m^3) have been measured when chalk is applied to the blackboard, or when the board is cleaned (Neuberger et al. 1991). Norbäck and Nordstrom (2008) reported that the mean PM10 was 15 μg/m^3 (range 6–24) at higher air exchange and 20 μg/m^3 (range 16–23) at lower air exchange rate in university computer classrooms. This is well below the WHO air quality guideline, but in ordinary classrooms higher levels of <PM10 have been reported. In one study on European primary schools on five countries, PM10 values in classrooms were in the range of 50–150 μg/m^3 (Simoni et al. 2010). Kim et al. (2007a) reported that there were considerable variations of indoor PM10 (12–544 μg/m^3), with a mean value of 94 μg/m^3 in Swedish classrooms. In five classrooms in Hong Kong (HK), the average of PM10 concentration were higher than the HK standards and maximum indoor level PM10 level exceeded 1,000 μg/m^3 (Lee and Chang 2000). Stranger et al. (2008) measured that the indoor air quality of 27 primary schools in Belgium and reported on indoor concentration of particles <2.5 microns diameter (PM2.5) and elemental composition. They detected K, Ca, Ti, V, Cr, Mn, Fe, Ni, Cu, Zn, Br, Pb, Al, Si, S and Cl, and black smoke and analysis of the elemental composition of PM2.5s (particle less than 2.5 μm) indicated a considerable contribution of soil dust to indoor PM2.5 mass.

In the study by Kim et al. (2007a) there were no association between PM10 concentration and asthmatic symptoms. In two other Swedish school studies, a relation between respirable dust and eye irritation in school personnel has been demonstrated (Norbäck et al. 1990), as well as relation between respirable particles and asthmatic symptoms in pupils (Smedje et al. 1997a). Simoni et al. (2010) reported an association between PM10 and nasal obstruction.

In summary, PM10 is often above the recommended limit value of 50 μg/m^3 in ordinary classrooms, and some studies have found health effects of PM10 schools.

8.2.6 Bioaerosols and Building Dampness

There is evidence from many studies that exposure to damp buildings is related to an increase of asthma bronchiale, and SBS symptoms (Bornehag et al. 2001; WHO

2009). Most of these studies have been dealing with health effects of dampness in the home environment, there are fewer studies on building dampness in school buildings.

There are various exposures related to building dampness, including house dust mite allergens, moulds and bacteria. In addition, building dampness may cause degradation of phthalate esters in PVC materials or water based floor glue, causing an emission of 2-ethyl-1-hexanol (Wieslander et al. 1999). There are various sources of indoor moulds and bacteria, including contaminated building materials, contaminated air filters, humidifiers, settled dust stirred up when the students are moving, and the outdoor environment.

Bacteria and moulds may grow in building material when the moisture content is high. Microbial growth within the building structure seems to be more common in colder climates, while microbial growth at exposed surfaces is more common in hotter climates. In some cases, negative pressure in buildings may cause vents from below the floor void or sump to become air intakes. This is a known cause of radon ingress from the sub foundation soil, but it may also lead to microbial contamination of incoming air (Thorne 1993). In schools with sign of dampness, the levels of dust and dust mite allergens were slightly higher than in school without sign (Zock and Brunekreef 1995).

Godwin and Batterman (2007) reported that the variability of bioaerosol concentrations within schools exceeded the variability between schools and five mold genera were detected in schools, of which *Aspergillus/Penicillium* was most common and was found in all classrooms and outdoor samples. Kim et al. (2007a) identified viable microbial species in indoor and outdoor air. Most common was *Cladosporium* sp. (indoor prevalence; 87%, outdoor prevalence; 100%), *Sterile mycelia* (indoor prevalence; 48%, outdoor prevalence; 100%) and the gram-negative bacteria *Pseudomonas* sp. (indoor prevalence 57%, outdoor prevalence; 75%). In another Swedish school stud, the most common micro-organisms were *Cladosporium*, and *penicillium* which were found 68 and 54% of the classrooms.

Usually, microbiological investigators of indoor air measure only viable organisms, and mainly microfungi. This may, however, lead to falsely low levels, since normally only about 1% of airborne microorganisms are viable (Table 8.1). Because of this, we recommended that non viable organisms, both bacteria and moulds, should be included in the measurements. There are various methods to assess total levels of moulds and total bacteria, e.g. the CAMNEA method (Palmgren et al. 1986). This method determine total number of airborne fungi and bacteria collected on Nucleopore filter by acridine orange staining and epifluorescence microscopy. Other methods include measurement of fungal DNA (Cai et al. 2009), ergosterol and beta-1-3 glucan as indicators of fungi, and chemical markers such as muramic acid, endotoxin, and 3-hydroxy fatty acids from endotoxin (Zhao et al. 2008). At higher concentrations of viable bacteria or molds in school where more pupils reported current asthma (Smedje et al. 1997b). In a Danish school study, the concentration of colony forming units of molds in floor dust was positively associated with eye irritation throat irritation headache, concentration problem, and dizziness in pupils (Meyer et al. 2004).

Moulds and bacteria emit specific VOC, microbial VOC (MVOC) (Wessen and Schoeps 1996). One Swedish school study reported that the concentration of most of the MVOC were 3–5 times higher indoors as compared to outdoor levels. Moreover at higher indoor concentrations of total MVOC, nocturnal breathlessness and doctor-diagnosed asthma were significantly more common (Kim et al. 2007b). Moreover, it was reported from another school study that there are positive associations between indoor MVOC and asthma in school personnel (Smedje et al. 1996). In summary, there can be a significant exposure to bacteria and moulds in some school environments, and mould exposure in schools can be related to both SBS and asthmatic symptoms.

8.2.7 Settle Dust

Aerosols may rapidly be removed from the air by sedimentation and impaction. Settled dust might be released again to the air due to certain activities especially from fleecy material. The tracking in of dust, in combination with poor cleaning, has resulted in widespread contamination of schools by cat and dog allergens (Munir et al. 1993; Smedje et al. 1997a; Tranter 2005). Settled dust may also contain various other types of pollutants, including microorganisms, pesticides, polychlorinated biphenyls, lead, and polycyclic aromatic hydrocarbons (PAH). In a large Danish Town Hall study, settled macromolecular organic dust (MOD) was shown to be one important exposure indicator related to sick building syndrome in office workers (Skov and Valbjorn 1990). The average exposure to MOD in Danish schools was found to be 2.3 mg/g of dust (Thorstensen et al. 1990), somewhat higher levels than the average of 1.5 mg/g of MOD measured in the Town Hall Study. The total amount of dust, vacuumed from 12 m^2 of floor surface, was also somewhat higher in schools than in offices (4.5 and 3.7 g, respectively). New floors (= less than 10 years old) contained less dust than old floors (Zock and Brunekreef 1995).

8.2.8 Allergens in Settle Dust

While the majority of exposure to indoor allergens occurs in home, children spend a large portion time of their day at school. The school environment can be an important site of exposure to cat and dog allergens, house dust mite allergens and cockroach allergens. Despite the lack of direct animal contact, schools in the temperate climate zones are frequently contaminated by cat and dog allergens, and in some countries even horse allergen. Although pets are not supposed to be present at school, pet owners carry the pet allergens in their hair and clothes. Pet allergens are easily transported to school environment. Tranter showed in the review, research has paid special attention to school environment as a second source, besides the home environment for exposure to allergens (Tranter 2005). Allergens are frequently found in settle dust in the classrooms. Allergen measurements in settled dust

Table 8.2 Cat, Dog, Horse, Cockroach, house dust mite and mouse allergen concentrations in settled schools dust

	Sweden[a]	Sweden[b]	China[c]	Korea[d]
	Median min–max	Median min–max	Median min–max	Median min–max
Cat allergen:	860	131	<100	<200
Fel d 1 (ng/g dust)	<200–4,700	<16–391	<100–177	<200–1,360
Dog allergen:	750	921	<200	670
Can f 1 (ng/g dust)	<200–6,200	<60–3,990	<200–527	<200–4,685
Horse allergen:	945	NA	<200	<200
Equ cx (U/g dust)	<200–31,000		<200–<200	<200–650
Cockroach allergen:	NA	NA	NA	<200
Bla g 1 (U/g dust)				<200
House dust mite allergen:	NA	NA	NA	250
Der f 1 (ng/g dust)				<200–850

NA = not analyze.
[a]Nine schools (six in the primary schools and three in the junior high schools) (Kim et al. 2005).
[b]Thirty nine schools (28 in the primary schools and 11 in the secondary schools) (Smedje et al. 1997a).
[c]Ten junior high school (39 classroom) (Zhao et al. 2006).
[d]Twenteen elementary schools (Kim et al. 2007b).

in classrooms are commonly used as a proxy-variable for indoor allergen exposure in school (Tranter 2005).

Several European countries have reported wide spread contamination of cat and dog allergens in schools (Almqvist et al. 2001). The reported concentrations were shown in Table 8.2. Cat allergens (*Fel d* 1) median values range from < 100 ng/g dust in Chinese schools (Zhao et al. 2006) to 860 ng/g dust in Sweden schools (Kim et al. 2005). Dog allergen (*Can f* 1) median values range from <200 ng/g dust in Chinese schools (Zhao et al. 2006) to 920 ng/g dust in Swedish schools (Smedje et al. 1997a). Most median values of dog allergens were higher than the values of cat allergens. The number of pet owners correlated strongly the concentration of pets allrgens ($r^2 = 0.93$) (Patchett et al. 1997). The levels of dust mite allergen (*Der f* 1, *Der p* 1) were relatively low in schools of USA (Amr et al. 2003; Sheehan et al. 2009) and Sweden (Kim et al. 2005). Cockroach allergens (*Bla* 1 or 2) were the least frequently measured allergen. The higher cockroach and mouse allergen levels were detected in areas of school where food is present (Amr et al. 2003). Table 8.3 shows the geometric means of each of six allergens in school compared to home and there were significant higher levels of mouse allergen in schools versus homes but the relative absence of dust mite allergens in schools (Sheehan et al. 2009).

Among building factors influencing allergen levels, dust mite concentration differences between ground and upper floor attributed to dampness in the ground floors (Einarsson et al. 1995; Munir et al. 1993). Higher exchange rates were weakly associated with lower cat allergens (r = –0.316), but continuous operation

Table 8.3 The comparison of the geometric means of six allergen levels in samples (School vs. Home)

	School	Home
Bla g 2 (Cockroach)	0.02	0.02
Fel d 1 (Cat)	1.38	0.56
Can f 1 (Dog)	0.47	0.2
Der f 1 (Dust mite)	0.05	0.66*
Der p 1 (Dust mite)	0.08	0.04
MUP (Mouse)	1.66*	0.41

Geometric means of allergen levels in all samples (School vs. Home, Sheehan et al. 2009).
The samples were collected from 4 schools and 58 bedrooms.
*$p < 0.001$; Wilcoxan single-ank test.

of ventilation was associated with lower dog allergens but cat allergens (Munir et al. 1993).

Some studies have demonstrated a relationship between allergen exposure, especially dust mite allergen exposure, and risk of sensitization (Charpin and Dutau 1999). It is believed that higher allergen levels are required to cause symptoms (Ingram et al. 1995) and the home exposure to common indoor allergens such as cats, dogs, mice, dust mite and cockroaches contributes to asthma in children (Matsui et al. 2006). On the other hand, Bollinger et al. (1996) suggested that lower allergen levels capable of causing symptoms if the exposure times prolonged.

In the school environment, some cross-sectional studies have showed a positive association between asthma prevalence and horse allergen levels in dust (Kim et al. 2005), cockroach allergens in school dust (Amr et al. 2003), and cat allergen levels (Smedje and Norbäck 2001a) in settled dust in classrooms. In a longitudinal school study, it was found that cat allergen levels in school dust was related to an increased incidence of doctors diagnosed asthma among atopic children (Smedje and Norbäck 2001b). In another study it was concluded that pet allergen in schools is high enough to cause symptoms in children with asthma (Munir et al. 1993). Finally, pet allergen exposure at school can cause acute asthma attacks in sensitized children. The significance of exposure to mouse allergens in schools and asthma morbidity are unclear (Sheehan et al. 2009).

The level of house dust mite allergen in schools is usually low. The source of house dust mites in homes is mites living in the bed, and since there are no beds in schools, the source is the transfer of allergens from the homes to the school by clothes and hair. The dust mite allergy is a common allergy in many countries, and sensitized children may react to even low levels at schools. The dust mite allergen (*Der f* 1) was detectable in the 62% of the classrooms in Korean schools (Kim et al. 2007a).

In summary, various types of allergens are found in settled dust in schools, and some studies have shown associations between allergen levels and asthma or asthmatic symptoms.

8.3 Other Factores

8.3.1 Carpeting and Textile Surface

If the classrooms contain carpets, e.g. wall-to-wall carpets, dust may be accumulated in the school. Wall-to-wall carpeting in schools has been shown to be related to SBS, and symptoms are reduced if the carpets are removed (Ibsen et al. 1981; Norbäck and Torgen 1989). Moreover, it has been demonstrated that dust from carpeted schools is more prone to induce basophilic reactions in cell cultures (Dybendal and Elsayed 1994), and that school carpets are more contaminated with moulds and bacteria than hard floors, or office carpets (Gravesen et al. 1986). Schools with carpeting was found to have higher concentrations of cat, dog and dust mite allergens in settled dust than schools with hard floors (Amr et al. 2003; Zock and Brunekreef 1995). Carpet and/or rugs are the effective reservoirs for collecting dust. Bioaerosol levels in the air have been shown to be positively associated with the presence of carpeting, suggesting that carpeting may be a source of bioaerosols in the in schools (Godwin and Batterman 2007).

There is a decrease in the use of wall-to-wall carpeting in schools, but in central Europe and USA, carpeting in schools may still be a problem. In schools without carpeting, major reservoirs of cat and dog allergens are chairs, school desks, and textiles. Typically, the allergen content is 100 times greater in dust from school desks, as compared to dust from hard floors. Amr et al. (2003) reported the highest level of *Der f* 1/*p* 1 was found in school, where most of the classrooms were carpeted and in some case even had additional rugs on top of carpeting. The presence of carpeting was associated with *Aspergillus* concentrations and total bioaerosol concentrations (Godwin and Batterman 2007).

In summary, carpeting and other textile surfaces in schools may accumulate various particle pollutants, such as allergens and microbial compounds, and the increased exposure may lead to higher risk for SBS and other health problems.

8.3.2 Illumination

Adequate illumination is important in schools, and natural daylight seems to have beneficial health effects. There are few studies on the health significance of illumination in schools. In one study, health and behavior of children in classrooms with and without windows were compared. The results indicated that children in windowless classrooms had impaired levels of stress hormones, which influenced both body growth and ability to concentrate and co-operate (Kuller and Lindsten 1992).

8.3.3 Noise

The mains source of noise in schools is human voice and human activities, but in some schools traffic from nearby roads may contribute to the noise level in the classroom. One Swedish study has demonstrated an association between cortisol in saliva, a marker of stress in the pupils, and the pupil's exposure to noise at school (Wålinder et al. 2007).

8.4 Conclusion and Recommendation

Concerning the physical environment, there is evidence that the schools environment can affect the prevalence of asthma, sick building syndrome, and subjective air quality. Since there is a large increase of asthma and allergic disorders in the population, exposure to allergens, microorganisms, and volatile organic compounds should be minimized. This is particularly important for young subjects with known hereditary disposition for allergy. Complaints on poor air quality in schools, should be considered as an early indication of disturbances in the indoor environment. If measures are taken to reduce the complaint rate at an early stage, the development of more severe conditions like SBS or asthma and allergy can be prevented. Moreover, there are indications that impaired indoor environment in school may impair learning and mental ability.

Control of room temperature and effective cleaning routines are simple means to reduce the prevalence of SBS-symptoms. Cleaning should be applied, not only to the floors but also to other horizontal surfaces. Exposure to microorganisms, which may grow in damp buildings, or be spread by air-conditioning systems, should also be minimized. Chemical emissions from building materials should be reduced, by selection of low emitting materials and products. This is particularly important when old schools, with natural ventilation only, are remodeled. Moreover, carpeting and other textile materials should be removed, unless it can be clearly demonstrated that they are properly cleaned.

Adequate maintenance of the school building is an important issue. The rooms in school should be monitored for the signs of dampness and moisture damages. Immediate action are warranted in schools to prevent dampness problem, higher room temperature, inadequate ventilation, excess indoor exposures chemical substance such as formaldehyde and VOC, and contamination of some allergens of dust for the health of students.

Personal outdoor air supply rate in buildings should be kept at current ventilation standards. Installation of mechanical ventilation is a way to ensure that the ventilation requirements are fulfilled. There is evidence that installation of displacement ventilation system gives beneficial effects health effects and reduced indoor exposure in classrooms. Return air ventilation systems should be avoided since it enhances the indoor level of volatile organic compounds and other indoor pollutants.

Schools are public buildings which should be expected to meet high standards of environmental quality. More effort is needed in the future to create healthy school environments in the future.

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Chapter 9
Microbial Ecology of Indoor Environments: The Ecological and Applied Aspects of Microbial Contamination in Archives, Libraries and Conservation Environments

Flavia Pinzari

9.1 Variability and Sources of Fungal Presence in Interior Environments

Fungal and bacterial spores and propagules found in the dust of indoor environments can be regarded as active inhabitants of dust, or as elements passively introduced by other sources (Davies 1960). If the concentration of viable fungal or bacterial spores belonging to the same strain exceeds 2–300 CFU/mg (Hunter et al. 1988; Bronswijk et al. 1986; Kalliokoski et al. 1996), they cannot be considered as being casually introduced, and must therefore be supposed to have been generated within the indoor environment.

In manmade habitats common sources of fungal or bacterial spores and propagules are so-called "amplification sites" which can produce characteristic patterns of species distribution in indoor dust. In fact, when active growth of fungal mycelia or bacterial biofilm takes place in a closed environment the biological composition of the dust can differ considerably from that found in outdoor environments, since it becomes dominated by a single abundant species (Miller 1992; Miller et al. 1988). Typical "amplification sites" are damp walls presenting mould growth and bacterial proliferation, or ventilation systems containing contaminated filters (Bouilly et al. 2005).

Additionally, the contribution to indoor microflora made by outdoor fungal and bacterial sources can vary widely. The introduction of spores to indoor air from the outside is usually related to weather conditions, such as wind speed, precipitation and daily temperature fluctuations, which play a role in defining the mechanisms by means of which spores and propagules are dispersed in natural environments (Ingold 1965; Li and Kendrick 1994, 1995; Gallo et al. 1999). The fungal component of dust biodiversity is greatly underestimated, either because only a few studies (to date) have provided thorough mycological characterizations of indoor dust (Samson et al.

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2002), or because some of the fungal species that colonise indoor environments are easily overlooked due to their peculiar growth requirements.

Apart from the natural variability in the number of different fungal and bacterial species that can be found in indoor environments, there is also variability in the statistics representing their numbers, depending on the sampling methods employed (Fig. 9.1) and the peculiarities of the environments investigated. In a survey carried out by Hoekstra et al. (1994) in 60 households in Northern Europe regarding the presence of fungal spores found in domestic dust, 108 fungal species belonging to 54 genera were detected. However, in most of the studies conducted a great variation in the species found in samples taken a few weeks apart or using different isolation media was observed.

A small number of surveys that can be used for reference when defining overall quality of indoor air are currently available (Verhoeff et al. 1990; Van Reenen-Hoekstra et al. 1991; Reponen et al. 1994; Li and Kendrick 1994; Pirhonen et al. 1996; Wu et al. 2000; Su et al. 2001; Shelton et al. 2002; Mendrela-Kuder 2003; Strauss 2004; Kalogerakis et al. 2005). Guidelines have been proposed in some countries based on different standards and sampling methods. For example, according to the Italian Official Document for Conservation of Indoor Cultural Heritage

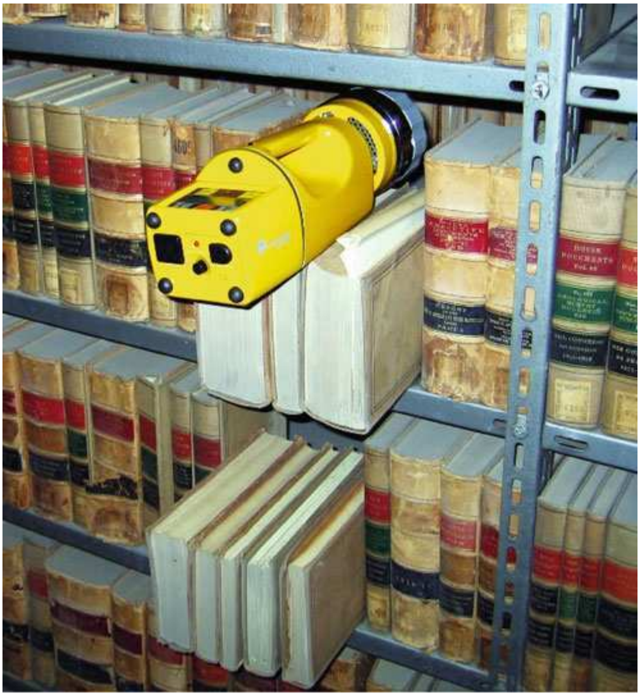

Fig. 9.1 Volumetric sampling of air using a Surface Air System (SAS) instrument in the storage area of a public library. Within the sampler a Petri contact plate coated with nutrient agar is exposed to a flow of air for a pre-defined sampling period

(*"Atto di indirizzo sui criteri tecnico-scientifici e sugli standard di funzionamento e sviluppo dei musei")*, the fixed limit for fungal contamination of museum environments is 150 colony forming units (CFUs) per m^3 (CFU/m^3). Several limits as regards colony forming units for each m^3 of indoor air have been proposed by international and national health organisations, such as the Commission of European Committees (Luxembourg), which in 1993 established different thresholds for domestic spaces and non-industrial indoor environments ranging from 25 to 10,000 CFU/m^3, and the World Health Organization (1988), which fixed a limit of 500 CFU/m^3, above which it is possible to hypothesise an indoor air quality problem (i.e. biological contamination). In addition, in 2008 at the pan-European level, international standards regarding sampling methods used for the detection and enumeration of moulds in the indoor environments were officially proposed as an ISO Standard (ISO/TC 146/DIS 16000-17/18/19).

Aerobiological surveys in indoor environments such as public offices, hospitals, schools and museums are usually based on lists of species of fungi and/or bacteria; details of the relationship between the findings and the "ecology" of the closed environment where the species were sampled is frequently lacking. Given the natural variability in the presence of fungal spores in the air (Jones and Harrison 2004; Liao et al. 2004), biological "air quality" in an indoor environment can be better defined by using bioindicators rather than by using a fixed number of CFUs. According to some authors (Samson et al. 1994), fungi which have as a growth requirement water activity (aw) above 0.85 can be regarded as indicator organisms for the presence of damp problems in indoor environments. A survey carried out by Salonen et al. (2007) during winter on 77 office buildings located in a subarctic climate zone using an impactor demonstrated that *Cladosporium* isolates were the commonest fungi detected in the samples collected from indoor air and in settled dust, in both mould-afflicted and "healthy"control buildings. According to Salonen et al. (2007), the airborne concentrations of *Penicillium*, *Aspergillus versicolor* and yeasts can be considered good indicators of mould-related problems in indoor environments.

Basilico et al. (2007) analysed the concentration and types of airborne fungal spores present in samples of indoor air collected in 49 houses situated in Santa Fe City (Argentina) during a survey which lasted for 1 year. The zone that was studied is characterized by a warm climate with an annual mean temperature of 18.6°C and relative humidity of 74.6%. The study has the merit of highlighting the relationship between airborne fungal concentrations and environmental factors such as area, season and presence/absence of a convection-type gas-fired heating system during winter. Indoor results showed the presence of thirteen dominant genera, among which *Cladosporium* and *Alternaria* were the most abundant (*Penicillium* and *Aspergillus* species were found at levels of 1.25 and 1.14%, respectively). In addition, Basilico et al. (2007) applied Multivariate Analyses of Variance to study the influence of environmental factors on concentrations of fungal flora, arriving in this way at a significant correlation of fungal concentrations in relation to season, area (urban, suburban etc.) and the presence of a convection-type gas-fired heating system during winter.

9.2 Dispersion

In order to raise aerial structures, fungi have developed the capacity to break surface tension and grow upwards into the air; this characteristic is crucial to their survival on land (Fig. 9.2). Once aerial structures have been established, these are able to prevent excess water loss and can perform their roles in sexual or asexual spore dispersal (Talbot 1997). Fungi which have to grow into the air in order to achieve reproduction and spore dispersal have evolved a morphogenetic class of proteins that respond to the aerial environment (Talbot 1997).

The recent discovery of "repellent" proteins suggests that fungi possess more than one mechanism dedicated to aerial development and dispersion. These proteins

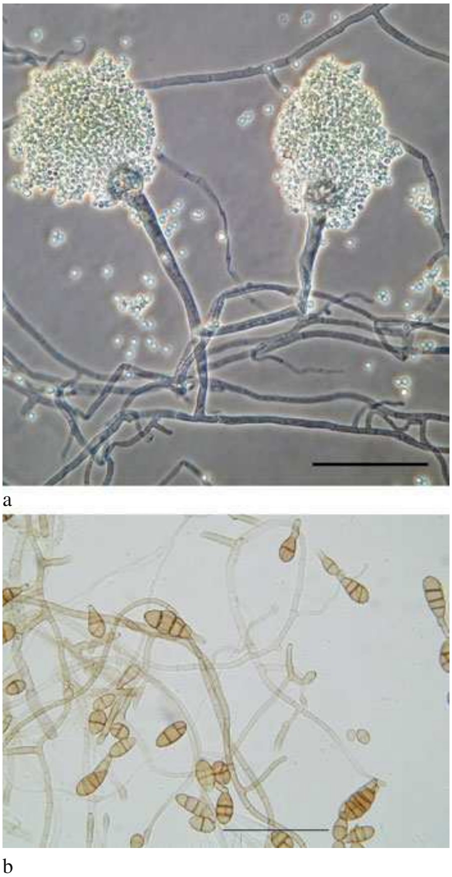

Fig. 9.2 (**a**) *Aspergillus versicolor* (Vuill.) Tiraboschi conidiophores with abundant production of conidia. Each conidium is one celled and thin-walled. Olympus A×60 optical microscope. Dark field. The bar indicates 10 μm. (**b**) *Alternaria alternata* (Fr.) Keissler mycelium and conidia. Each conidium consists in two or more cells with thick and melanised walls. The bar indicates 10 μm

are called hydrophobins and are able to react as interfaces between water and air, thus providing a hydrophobic coating for aerial fungal structures (Talbot 1997). The airborne fungal spores' concentration depends on the way in which they are released from the mycelium at the air-substratum interface. The quantity of spores deriving from a contaminated material which can be aerosolized can vary considerably in relation to the biology and ecology of an individual fungal species, and also in relation to chance events. According to Górny et al. (2001), the release of fungal spores from their source is driven by energy originating from external sources and may be significantly affected by environmental factors, such as air velocity. Gregory (1973) stated that the prevalent mechanism governing spore release in the case of indoor fungi is aerosolization caused by air currents. This may be true for some fungal species: for example, spore detachment from the mature mycelia of most *Aspergillus* and *Penicillium* species is caused principally by physical factors (Sivasubramani et al. 2004). Górny et al. (2001) found that fungal spore release from surfaces in indoor environments can be affected by a combination of factors, including the specific fungal species concerned. According to Górny et al. (2001), the release of *Aspergillus versicolor*, *Cladosporium cladosporioides*, and *Penicillium melinii* spores from agar and ceiling tile surfaces was affected in different ways by various parameters, such as air current velocity sweeping over surfaces, the texture of the surface, and vibration of contaminated material.

MacArthur and Wilson (1967) conceived the theory of island biogeography. This theory attempted to predict the number of species that could exist on a newly created island. Nowadays the theory is used to refer to any ecosystem surrounded by dissimilar ecosystems (Lomolino 2000). In this broadened definition an "island" is any area of suitable habitat surrounded by an expanse of unsuitable habitat. The term can also be applied to manmade "islands", such as expanses of grassland surrounded by highways or housing tracts.

A further extension of the "island" definition can be applied to the heterogeneous pattern of "microbial niches" that is present in indoor environments. The theory of island biogeography proposes that the number of species found on an undisturbed island is determined by immigration, emigration and extinction (Simberloff and Wilson 1969). Immigration and emigration are affected by the distance of an island from a source of colonists ("distance effect"). Islands that are more isolated are less likely to receive immigrants than islands that are less isolated. The rate of extinction, once a species manages to colonise an island, is affected by island size ("area effect" or the "species-area curve"). Habitat heterogeneity increases the number of species that will be successful following their immigration.

Throughout its history most of Earth's life forms have inhabited aquatic environments. Here, in the past, bacteria have ruled the two most important organic matter cycling processes, namely primary production (autotrophy) and decomposition. Because of their ability to translocate nutrients, fungal hyphae are better adapted than bacteria to cross nutrient-poor zones when searching for heterogeneously distributed nutrient resources in substrates (Ritz 1995). Just as there are variations found in the three-dimensional spaces located between soils and aquatic environments, indoor environments present a high degree of discontinuity between substrates, which are usually separated by large spaces filled with air. The colonisation of new patches of an indoor environment, where water and nutrients are available, can only be achieved by crossing or circumnavigating these "empty" spaces. Specific dispersion mechanisms can therefore determine the success of a fungal species and its diffusion in indoor "ecosystems". Air dispersion is the chief mechanism (Reponen 1995), but fungal spores and conidia can move through the air by adopting very different strategies (Ingold 1965). Active and passive dispersal mechanisms can produce very different results in indoor environments.

Ventilation is a very important variable in closed systems. Air circulation can promote spore dispersion, but at the same time it can desiccate fungal mycelium by preventing the establishment of microclimates and surface-driven humidity gradients. Some fungal species produce spores that in natural environments are mainly dispersed by insects and mites (Deacon 1997, 2005). Insects and fungi are closely associated in most environments, and many types of interaction that have arisen repeatedly have been observed among diverse taxa of these groups of organisms (Deacon 2005). These fungi are necrotrophic and biotrophic parasites, endosymbionts, insect-dispersed forms, and other obligate associates which provide nourishment for insects (Deacon 2005). The interactions in question are sometimes highly complex and may involve other organisms in addition to fungi and insects. The same mechanisms can occur in indoor environments. Moulds affecting archival and library materials (Zyska 1997) can display different types of interactions with the insects that eat the component materials of the heritage. Some of the pests that attack organic materials like wood, paper, leather and parchment can feed on mould spores, or represent the dispersive means for most of the fungal spores.

Not all fungal spores have evolved for air dispersion; there are several mechanisms which, in fungi, favour the colonisation of new areas or food patches. Insect-mediated fungal dispersion is well documented in natural environments (Ingold 1965), but it also occurs in indoor environments. Some "heritage eaters", such as Psocoptera and mites (Fig. 9.3), are often directly associable to the presence of moulds (Gallo et al. 1999; Green 2008). Conversely, insect infestations in libraries and archives can frequently be associated with fungally infected materials. Metabolic water, fragmented debris and the droppings produced by insects represent a perfect medium for fungal germination and growth. Some fungi produce spores that can pass through the intestinal tracts of insects and mites with no ill effects, and some insects and mites can feed directly on fungal structures (Green 2008).

9.3 Ecological Theories Applied to the Indoor Environment

The term "niche" in the ecological context refers to the way in which an organism or population utilises its immediate environment. An ecological niche is defined by different biotic and abiotic variables. According to the competitive exclusion principle, no two species can occupy the same niche in the same environment for very long. Ecological niches have been described by G.E. Hutchinson as "hypervolumes", that

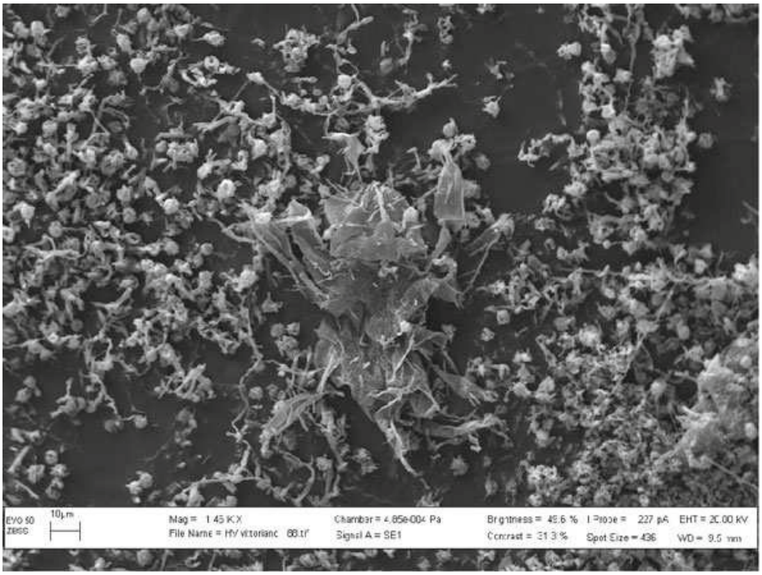

Fig. 9.3 Scanning Electron Microscope (SEM) image, showing fungal spores and mycelium and the exuvia of a mite (sampled from the cover of a book using adhesive tape). SEM ZEISS EVO50, Variable Pressure, observation of a non-metallised sample

is to say multi-dimensional resource spaces exploited by organisms. Indoor environments are composed of artificial niches in which manmade materials are stored and assembled to form simplified "ecosystems", where only a few "ruderal" species can grow and reproduce (Nielsen 2003). In these extreme circumstances scarce water and limited nutrients mean that only a few microbial and fungal species are able to dominate (Nielsen 2003). The chief limiting factor that determines fungal development in indoor environments is water. Spore germination only occurs when some water is available; for some fungal species a very small amount of water is sufficient to trigger the growth of a new mycelium (Chang et al. 1995; Grant et al. 1989; Nielsen 2002; Pasanen et al. 1992; Rowan et al. 1999).

The microbial species that can damage materials in indoor environments are chiefly primary colonisers capable of rapid growth even when water activity is low (i.e. a_W <0.8). When a substrate is attacked by a fungus, its water activity changes sufficiently to support the growth of other species (fungal and bacterial), as in natural successions (Pitt and Hocking 1985, 1997). Secondary colonisers are species that have a high resistance to stress; these species develop thanks to unstable microenvironments whose existences are linked to many variables, like small changes in air temperature or humidity due to night/day alternation. Such species often form resistant spores resembling dark, thick conidia. Poor ventilation and surface temperature dishomogeneity can produce water condensation points and local micro-climates with higher water availability than in the rest of an indoor environment. These circumstances are favourable to some fungal species; as a result these are able to

Fig. 9.4 Black moulds (*Chaetomium* sp.) flourishing on a water saturated volume following an episode of flooding

proliferate in places where the overall environmental conditions would otherwise appear to be hostile to microbial life.

A very different succession must be expected in indoor environments when water suddenly becomes available, such as in floods or when a water pipe bursts. Such situations are familiar to archivists and librarians who are well aware of the fact that when papers become saturated with water, moulds can subsequently develop very rapidly on them (Fig. 9.4). The moulds associated with water-damage ("water damage" moulds, Nielsen 2003) consist of fungal species that need a high water activity. These species can produce strong odours (*Trichoderma* spp), coloured stains (*Chaetomium* spp and *Epicoccum* spp) or toxic compounds (*Stachybotrys* spp) (Fig. 9.5). The relationship between water and the various substrates present in an archive or a library can be very complex and will determine the nature of the "microbial community" that develops in the "ecosystem". Small differences in substrate composition – i.e. the percentage of easily degradable carbon sources such as sugars and starch, or the presence of chemicals potentially sought by some species, like metals and lignin – can be a decisive factor for the formation of mycelia and the production of fruiting bodies by the fungi. Competition between fungal species in very narrow environmental "indoor niches" has been documented by several authors (Nielsen 2002; Moriyama et al. 1992; Wells and Boddy 2002).

The competition between fungal mycelia for water, nutrients and space in indoor environments also accounts for another variable, namely the time needed by the fungus to germinate or grow when a favourable situation arises. Indoor environments characterised by transient high humidity (such as bathrooms) typically support the growth of phylloplane fungi represented by species capable of re-starting their growth from the dry hyphal tips within 1 h following a rewetting event; this is

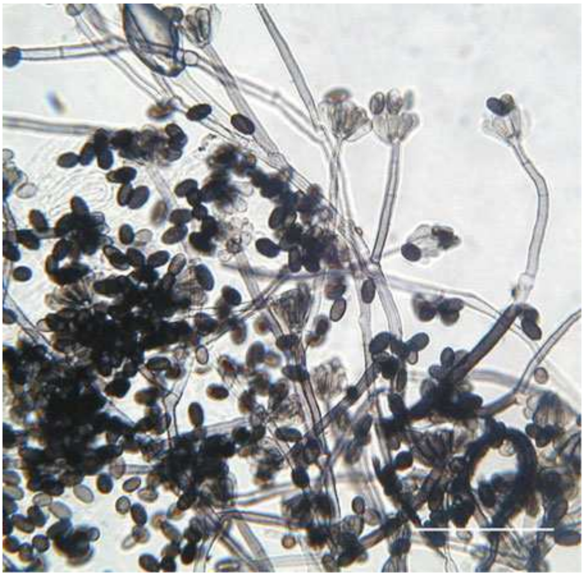

Fig. 9.5 Conidiophora and conidia of the fungus *Stachybotrys chartarum* (Ehrenb.) Hughes. Olympus A×60 optical microscope, bright field. The bar indicates 10 μm

the case with *Alternaria*, *Aureobasidium*, *Cladosporium*, *Phoma*, and *Ulocladium* genera (Nielsen 2003; Moriyama et al. 1992; Samson et al. 2002).

The mycelium of most of the moulds that require high water activity typically need longer time-lapses (1–2 days) before recommencing its growth following a sudden re-wetting event.

In unstable or unpredictable environments, "r-selection" predominates because the ability to reproduce quickly is crucial. The growth of "r-selected" fungi is favoured in fluctuating environments and is characterised by rapid development, small conidia, high fecundity, early maturity onset, etc. (Cooke and Rayner 1984; Rayner and Boddy 1988; Boddy 2000). These fungi are defined as "r-selected"; *"r"* represents "the intrinsic rate of growth". They are fast-growing, have a high reproductive facility and high dispersal capacity, but a short life span. Zygomycota, yeasts and fastgrowing ascomycetous fungi are considered "r-selected" and according to Frisvad et al. (2008) these are rather poor producers of secondary metabolites; they do, however, produce hormone-like compounds and carotenoids. The "k-selected" fungi are adaptive in more stable environments; "k" represents the "carrying capacity" of a specific habitat. In stable or predictable environments the ability to compete successfully for limited resources is fundamental and "k-strategist" fungi are typically very consistent in the way they use their niche. K-selected fungi are quite rare in the indoor environment and are mainly represented by endophtytic fungi and a few basidiomycetes. Some authors (for example, Boddy 2000) define further ecological groups of fungi: the "stress-tolerant" or "s-selected" fungi, which conversely are common in indoor environments. These fungi are specialised in occupying specific niches and their competitiveness is not really directed against other fungal species, but rather towards surviving in a very hostile environment. The "s-selected" fungal species that inhabit indoor environments can tolerate desiccation and grow in restrictive conditions.

Another ecological group of fungi is composed of the "competitive fungi" ("c-selected"). These are represented by fungal species that are strong producers of a wide range of bioactive secondary metabolites, which play a very important role in ecological chemical interactions (*Penicillium*, *Fusarium*, *Aspergillus* species) (Frisvad et al. 2008). This partitioning of fungal "behaviours" in the environment is not sharply circumscribed. The characteristics of the fungal species concerned can fall into one or more of the above-mentioned groups. This categorisation, although essentially artificial, can help us to understand some of the mechanisms at play in indoor environments. The abundance of species belonging to one of the groups – i.e. "stress-tolerant" or "r-strategist" fungi – can tell us something about the "ecosystem" that supports their growth and diffusion.

9.4 An Ecological Perspective

In natural environments the microbial communities that act to decompose organic matter have been closely studied and some authors have provided models that help to predict nutrient cycling (Boddy 2000). A fluctuating environment may facilitate the co-existence of species (Ylva et al. 2006; Naeem and Li 1997; Petchey et al. 1999; Chesson 2000) and high species diversity is important for maintaining ecosystem processes under changing environmental conditions (Yachi and Loreau 1999; Mulder et al. 2001). When applying these rules to indoor environments it becomes clear that "high species diversity" coincides with a high concentration of airborne microbial and fungal spores and propagules deposited on materials. A dust-rich indoor area offers greater diversity than a clean surface. Even more than a constantly humid environment in an indoor "ecosystem", fluctuating temperature and humidity can promote the presence of a large number of fungal species. The notion that a fluctuating environment permits co-existence of competing species in simple environments was first proposed as a mechanism to explain planktonic algal diversity (Hutchinson 1961).

In the natural environment the overall low number of species that persist in constant temperature and humidity conditions, regardless of the initial species diversity, agrees well with the view that intense competition is considered the most important interaction among fungi (Boddy 2000). Pair-wise interactions among fungi regularly result in the combative physical exclusion of one of the competitors (Holmer and Stenlid 1993). In contrast, the significantly greater number of species persisting in fluctuating temperature and water availability conditions suggests that fierce competition becomes less intense in a fluctuating environment. Niche complementarity was shown by Tiunov and Scheu (2005) to occur when sugar fungi and cellulolytic fungal species were combined on a cellulose substrate. Stabilising mechanisms are essential for species co-existence and can be fluctuation-independent, as with

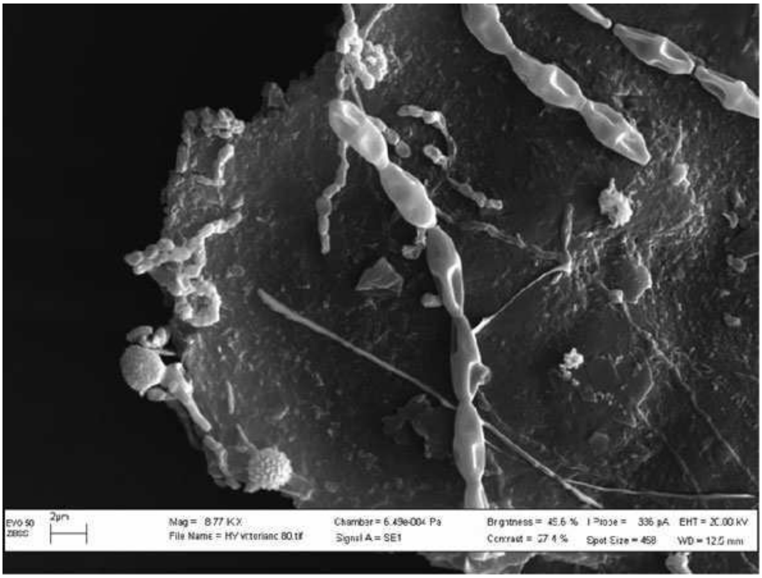

Fig. 9.6 Scanning Electron Microscope (SEM) image. The surface of a piece of adhesive tape used for sampling the parchment cover of a book. Various fungal and bacterial flora can be observed coexisting on a small area of the substrate. SEM ZEISS EVO50, Variable Pressure, observation of a metallised sample

resource partitioning, or dependent on fluctuations due to different responses to the environment (Chesson 2000; Wohl et al. 2004).

These mechanisms also occur in indoor environments, with the difference that the main variable is water availability, and that species occurrence is limited by their dispersal strategies. Studies conducted on deposited dust are rather few in number (Rao et al. 2005), but the biological characteristics of dust are highly dependent on the particular outdoor aerobiological situation, by seasonality of spore release by some phylloplane and soil fungi, and by overall atmospheric conditions (Halwagy 1989; Mendrela-Kuder 2003). In addition, substrata can support different fungal communities, depending on their specific water activity, carbon to nitrogen ratio, and the presence of small nutritive molecules such as sugars and peptides, which can assist in a spore's reactivation (Fig. 9.6).

9.5 The Substrate Factor

When mould spores land on a damp surface, they may start to grow and digest the material they are developing on, or alternatively they can survive in a dormant state. Biodegradation of materials by moulds can affect the integrity of the same because the fungus's hyphae penetrate the substrate. Damage can also occur as a result of enzymatic action. Moulds can produce a wide range of enzymes (proteinases, gelatinase, and cellulases) which are able to destroy the component materials of items included in collections (Fig. 9.7). Cellulose is the most abundant organic compound found on Earth (30–50% of plant dry weight) and, in natural

Fig. 9.7 (**a**) Scanning Electron Microscope (SEM) image. Paper attacked by a cellulolytic species of *Cladosporium*. SEM ZEISS EVO50, High Vacuum, observation of a non-metallised sample. (**b**) Books on metal shelving; their covers have been damaged by mould

environments, represents a major source of energy for microorganisms (Markham and Bazin 1991). The storage of books and archival materials inside buildings devoted to their preservation has created unique environments for cellulolytic fungal and microbial species to inhabit (Abdel-Mallek 1994). Microbial decomposition of cellulose can take place under both aerobic and anaerobic conditions. The ability to degrade cellulose aerobically is common among fungi and is especially well represented among the Ascomycota and Basidiomycota (and Deuteromycota). Aerobic cellulose degradation is also documented in several soil-dwelling bacterial species in both filamentous (e.g. *Streptomyces*, *Micromonospora*) and non-filamentous (e.g. *Bacillus*, *Cellulomonas*, *Cytophaga*) genera (Markham and Bazin 1991). Cellulolytic microbial and fungal species require available water in order to be metabolically active.

Although knowledge of the functional diversity and metabolic characteristics of moulds is important for both the prevention and treatment of biodeterioration in cultural heritage, very few studies have been performed in this area until now. In Pinzari et al. (2010) and Pinzari et al. (2008), a study based on the use of Biolog FF microplates was performed to obtain the metabolic fingerprint (Dobranic and Zak 1999) of the filamentous fungi responsible for degradation in library materials. During a survey carried out the historical library of S. Anselmo monastery in Rome, several samples of moulds were collected from the bindings of volumes damaged by fungi. Fungal strains were also isolated from the surrounding air using an impaction sampler (SAS), and from the library's walls, where colonies were clearly visible. The fungal strains collected were purified of bacterial contaminants, separated and identified. Each strain was then inoculated on to Biolog FF microplates following the Biolog Manual's protocol (Solit 2001). The plates were then read using a Biolog MicroLog microplate spectrophotometer at 490 nm (Fig. 9.8). Raw data (optical densities) were transferred to an Excel (Microsoft^{TM}) sheet according to sample (fungal strain), replicate (3 replicates each), and reading time (10 reading points, one every 24 h).

Following a background correction, average values for seven categories of substrates were calculated (polymers, carbohydrates, carboxylic acids, amines and amides, amino acids, and miscellaneous) in accordance with Buyer et al. (2001). Discriminant Analysis was employed to investigate any differences between the metabolic fingerprints of the fungi according to two classifying categories: sampled material (leather, fabric, air, plaster), and the sampled area of the library (upper level, first floor, ancient books section).

When using polymers, carbohydrates and carboxylic acids as variables in the analysis, the fungal strains were found to be significantly grouped in clusters (Fig. 9.9a). The results showed that the fungal strains that were detected in the air and on plaster surfaces were functionally similar to those which attacked the volumes with bindings made of fabric, while the fungal strains that developed on bindings made of leather consisted in a particular group of fungi with a metabolic profile that set them apart from the rest. A statistically significant separation of fungal strains was also attained for the sampled areas, indicating that different zones of the conservation environment under examination were colonised by fungal

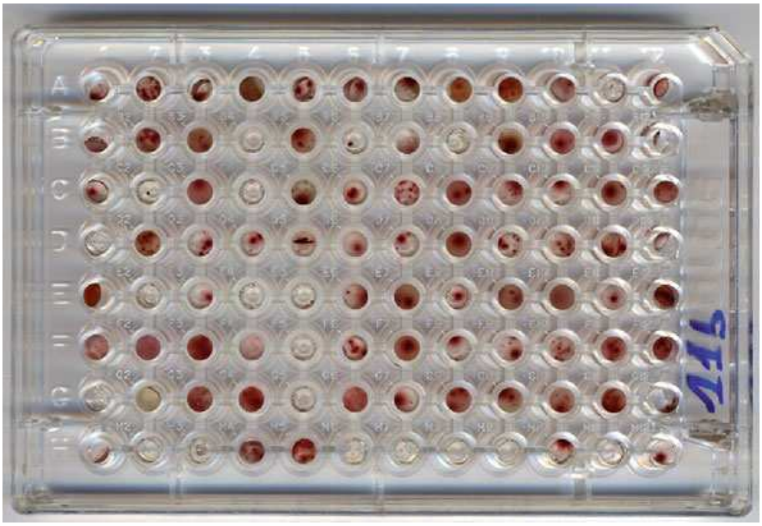

Fig. 9.8 A Biolog FF plate after inoculation with an airborne fungal species, and incubation at 26°C. The pink wells correspond to the substrate use. The dark wells are those where the fungus produced fruiting bodies or pigmented mycelium. The white wells in the plate indicate that the fungus was not able to degrade that particular substrate

communities with a different functional profile. The use of amines, amides and amino acids as variables resulted in a less distinct classification of the strains in the discriminant analysis (Fig. 9.9b), indicating that the potential activity of all the fungal strains was similar for the compounds containing nitrogen. It can therefore be hypothesised that the chief focus of competition between fungi that grow in the indoor environment of a library is represented by nitrogen uptake, or more generally by substrates that contain a source of nitrogen.

9.6 Dust as a Niche

In indoor environments, dust-borne and airborne biological agents may represent different ecological niches, and according to Rao et al. (2005) surface dust sampling can serve as a possible historical marker for cumulative exposures. Microbial communities in indoor environments are largely structured based on water availability and the supply of growth-limiting substrates that can enter the ecosystem by means of dust deposition (Hicks et al. 2005). The availability of growth-limiting resources restricts the diversity of biotic communities (Tilman et al. 1996), therefore higher levels of dust deposition should increase the supply of limiting resources (i.e. organic and inorganic substrates) (Lai 2002). According to a very precise study by Chudnovsky and Ben-Dor (2008), outdoor settled dust exhibits a higher mineral content compared with indoor dust. Dust deposition in indoor environments is quantitatively influenced by green areas and the total area of vegetation in the

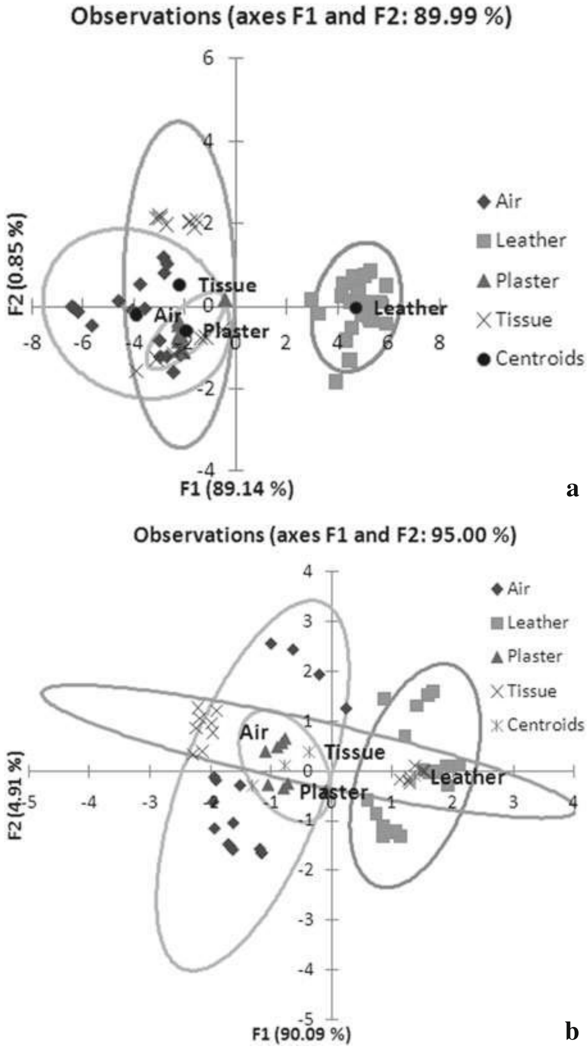

Fig. 9.9 (**a**) Discriminant Analysis that shows the grouping of fungal assemblages according to substrata and based on carbon sources; (**b**) DA Discriminant Analysis that shows the grouping of fungal assemblages according to substrata and based on nitrogen sources

vicinity of the sampled location. For office environments, the number of people working in the office and the "opening" of the office during the experiment was, according to the authors, the chief factors that affected dust precipitation. In 2008 a method was developed by Pinzari and Montanari (2008) to be applied when evaluating risk for stored library materials in relation to the metabolic diversity of the fungal communities inhabiting dust deposits on storage space surfaces (i.e. shelving).

Functional data relating to fungal spores can be useful when seeking to distinguish dust samples based on a different capacity of the active species to degrade clusters of compounds. This approach yields an evaluation of the biological harmfulness of dust to different classes of materials. The procedure consists in the direct inoculation of dust samples on to commercial microtiter plates (Biolog^{TM}) and involves colour formation through reduction with a tetrazolium dye (Bochner 1989) to assess utilization of 95 separate sole carbon sources during a 4–10 day incubation period. The fungal and/or bacterial species that induce colour formation in the wells are the fast-growing ones. The single time-point results are indicative of heterotrophic fungal population density and total potential heterotrophic activity, while the multiple time-point data identify differences between communities in terms of metabolic potential on various classes of substrates. The method is far less time-consuming and technically much simpler than either isolate identification or phylogenetic analysis. The study by Pinzari et al. (2010), based on the sampling of settled dust in accordance with Pinzari and Montanari (2008), was specifically developed to analyse and compare the metabolic diversity of fungal communities present on the surfaces of three different storage "environments" in an Italian public library.

The results obtained showed that the three samples of dust, corresponding to the same number of storage "environments", were successfully differentiated based on the "substrate utilisation patterns" of the fungal communities inhabiting the shelves where samples were collected (Figs. 9.10 and 9.11). The study showed how a recently deposited dust can possess higher catabolic potentiality when compared with an "old dust". The substrata that were most distinctive and which significantly

Fig. 9.10 Standardised swab sampling of dust from books' surface using a 5×5 cm frame

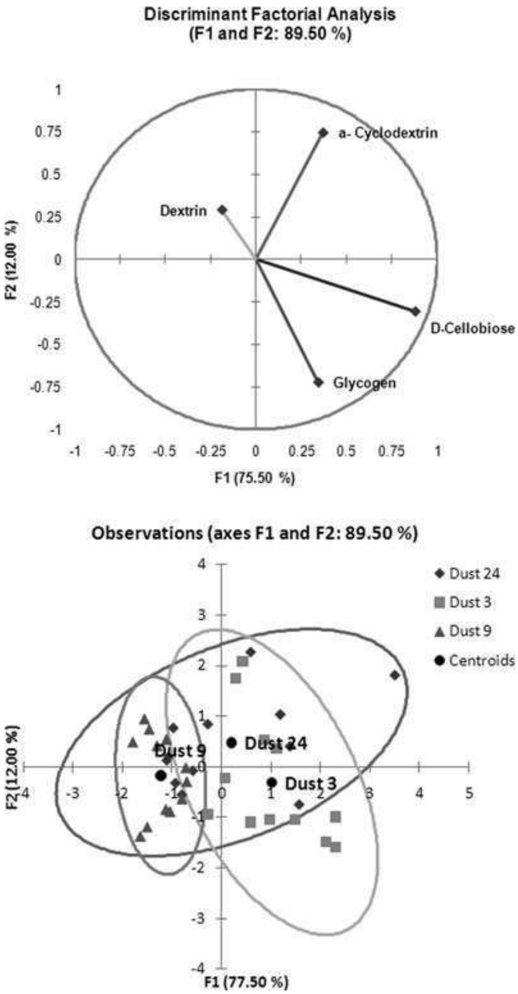

Fig. 9.11 (**a**) Discriminant Analysis (DA) that shows the grouping of fungal communities according to the age of the dust (3, 9 and 24 months of settlement) and based on polymers and cellobiose, plot of variables; (**b**) plot of observations and centroids of the groups

differentiated dust samples were all found among cellobiose and cyclodextrine, which form part of the microbial catabolic pathway of starch and cellulose degradation processes. These results suggested that the structure of the fungal community inhabiting an indoor environment can be influenced by the predominant substrate.

9.7 Odour Patterns

Microbial volatile organic compounds (MVOCs) are produced as metabolic by-products of bacteria and fungi when they start colonising nutrient-rich substrates, even before any visible sign of microbial growth appears. Spoilage fungi produce volatiles which are characteristic and different from those produced by bacteria or the substrates themselves (Kaminski et al. 1974). The most frequently produced volatile compounds include 3-methyl-1-butanol, 1-hexanol, 1-octen-3-ol, 2-heptanone, and 3-octanone, as identified by gas chromatography and mass spectrometry (Kaminski et al. 1974; Larsen and Frisvad 1995; Linton and Wright 1993). Production of a volatile compound can serve to remove inhibitory intermediates from the metabolism under unfavourable conditions, or may have inhibitory effects on other fungi and act as a self-regulatory growth and development mechanism (Linton and Wright 1993). In some cases these odorous compounds are fruity or flowery in nature. They are the product of a coevolution with micro and mesofauna and function to attract arthropod dispersers (e.g. insects transferring mould conidia to new growth sites). Alternatively, a musty or earthy odour can be used to deter grazing and feeding by invertebrates, or at least to lend a distinctly "inedible" odour to mould colonies and their underlying nutritional substrates (Lin and Phelan 1992; Humphris et al. 2002). A few such volatiles have been found to be irritating to vertebrates (Nikulin et al. 1997). In indoor environments organic volatiles have been related to some types of sick building syndrome (Li and Yang 2004). Each microbial species has a defined MVOC profile which can be subject to considerable modification in response to external factors, such as cultivation on different substrata (Wheatley et al. 1997), growth phase (Magan and Evans 2000; Bruce et al. 1996), temperature, pH, light and CO_2 or O_2 levels. Although many variables influence the production of microbial volatile compounds, some MVOCs can be considered common to the majority of detrimental species and spoiling situations; they can be used as early indicators of biocontamination (Pinzari et al. 2004; Canhoto et al. 2004; Olsson et al. 2000; Di Natale et al. 1997; Magan and Evans 2000).

In the study carried out by Renda et al. (2008), an electronic nose was used to evaluate the relationship between different paper grades and mycelium age on MVOCs production by indoor fungi typically found in libraries. An electronic nose is a portable device consisting in an array of electronic chemical sensors with partial specificity and an appropriate pattern-recognition system capable of recognising simple or complex odours (Gardner and Bartlett 1994). An electronic nose is equipped with three elements that replicate the three phases of the human olfactory system: (1) detection by the sensor array which is exposed to the volatiles, (2) signal processing by conversion of the sensor signals into a readable format, and (3) recognition of odours by means of software analysis of the data which allows us to transpose the information contained in the odour into a "volatile pattern". An electronic nose does not supply detailed chemical information on the volatile compounds produced by active fungi, but provides a qualitative picture ("volatile pattern") of the mixture of compounds present in the sample (Turner and Magan 2004). Renda et al. (2008) studied the odorous patterns produced by some filamentous fungi frequently associated with the biodeterioration of library materials by employing different sensor arrays. In order to evaluate which variables can influence the production of volatile compounds by fungi when paper spoilage occurs, several factors were taken into account, such as the quality of the substrate (i.e. different grades of paper), the metabolic state of the fungi (germination, active growth,

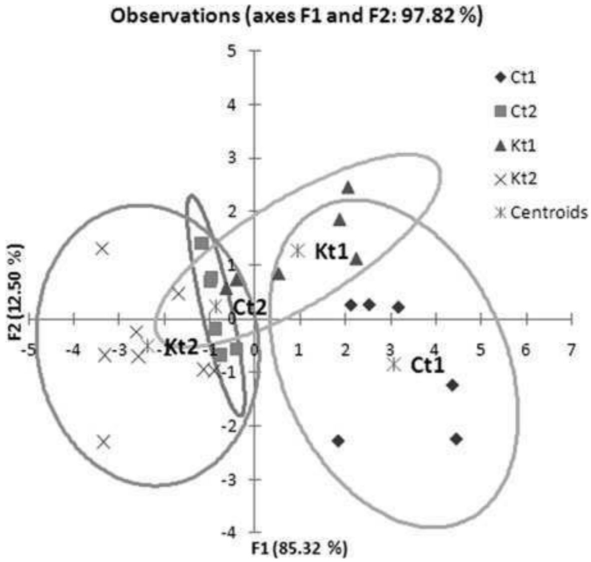

Fig. 9.12 Discriminant Analysis showing the ability of the electronic nose to distinguish between odorous signals emitted from fungal mycelium of different ages. Kt and Ct are two different strains of the same fungal species (*Chaetomium globosum* Kunze), 1 and 2 are the odorous signals respectively after 7 and 21 days of incubation

starvation), the fungal inter-intra specific variability in relation to volatile production (different strains of the same species, and different species) and the different type of sensors used to detect the "odorous fingerprint".

Odorous patterns presented significant differences in relation to the age of the mycelia (i.e. the different incubation times undergone by the paper samples) as shown in Fig. 9.12 where discriminant analysis (DA) was conducted on the *e-NOSE* signals produced by *Chaetomium globosum* over different incubation times.

Additionally, there are significant differences in the volatile emissions of fungal strains belonging to the same species that grow on different paper grades, and differences in the amount of volatiles emissions from pure fungal cultures on paper and mixed cultures. In conclusion, fungi produce odorous signals when paper spoilage occurs. The amount and quality of the volatiles produced by fungi can vary greatly, depending on the species concerned, the substrate's characteristics, and the co-occurrence of different strains on the same substrate, and the age and quantity of the mycelia.

9.8 Conclusions

Information on the relationship between exposure to fungal spores and their effects is necessary in order to be able to understand and manage the diseases they can cause in humans, animals and plants. In most of the environmental studies carried out in the last 20 years or so the experimental approach consisted in examining the quantitative associations between airborne fungi and respiratory problems, analyses of the compositions of microbes in air samples, and the calculation of the relevant concentrations according to species or higher taxa groupings. The bulk of aerobiological studies published up to now have involved volumetric sampling performed using several different systems (Strauss 2004; Parat et al. 1997; Van Reenen-Hoekstra et al. 1991; Reponen et al. 1994; Pirhonen et al. 1996; Mendrela-Kuder 2003; Li and Kendrick 1994; Wu et al. 2000; Picco and Rodolfi 2000; Su et al. 2001; Shelton et al. 2002; Nielsen 2003; Li and Yang 2004; Kalogerakis et al. 2005). Only a few studies have investigated deposited dust in order to identify the types and concentrations of biological agents and the particles to which the occupants of buildings may be exposed (Kanaani et al. 2008). Isolation by culture of fungi and bacteria is an established method that is widely accepted for the quantification and identification of microorganisms present in environmental samples. Many factors were found to influence the results obtained from indoor biological surveys; these factors include: the method of sample collection, the ways in which dust was prepared for inoculation on to growth media, and the culture media chosen for specific categories of agents (Nielsen 2002). The concentration of mesothermic and thermophilic bacteria, hydrophilic and xerophilic fungi, and specific genera and species depends on the nutritive selective mean used in isolation procedures. The natural variability of fungal and bacterial assemblages in air and dust in indoor environments renders quantitative estimates almost useless for the definition of indoor air quality. Sick building symptoms cannot properly be correlated to a mere number of CFUs (Singh 1994). Qualitative analysis of the aerodiffused fungal spores seems to be more valid as a source of information. In fact, measurement of merely the quantity of the microbial charge is of little value if the species present and their pathogenic potential for humans and deteriogenic activity in artefacts are not known (Nugari and Roccardi 2001). Biological "air quality" in indoor environments can be better defined by using bioindicators rather than referring to a fixed number of CFUs. The characterisation of microbial communities in organic dust samples by means of chemical markers such as 3-hydroxy fatty acids (markers of endotoxin), ergosterol (marker for fungal biomass), and muramic acid (marker for peptidoglycan/bacterial biomass) has been applied by some authors (Szponar and Larsson 2001 and literature therein) with interesting results. This method made it possible to distinguish quite well between dust samples collected from different environments.

The presence of "indicator species" that suggest the presence of specific environmental niches which act as amplification sites for moulds could be of great value when conducting indoor environmental quality studies. Conventional methods for detecting airborne fungal spores rely on either optical identification or culturing and can be time-consuming and/or unreliable. The detection and identification of marker-species or groups of species can be very difficult and subject to culturing limits, namely the culturability of strains and the production, in vitro, of diagnostic characters. To overcome such drawbacks, molecular techniques have recently been introduced for the detection and identification of microorganisms in indoor dust, air samples and manmade matrices (Michaelsen et al. 2006; 2009). Purification of DNA from conventional spore samplers and detection of bacterial and fungal diversity and identity was performed in some studies using polymerase chain reaction (PCR)-based methods. Some authors proved that the detection limit was about 10 spores or less in the PCR (Calderon et al. 2002). The selection of indicator species and physiological groups of organisms that can be used as markers of unsuitable indoor conditions should be carried out by studying the ecology of the "indoor microbial communities". Both the partitioning of fungal "behaviours" in the environment and the characteristics of the fungal species can help in the understanding of some of the mechanisms that produce indoor environments. The abundance of species belonging to one of the "ecological" groups such as the stress-tolerant or the "r-strategist" fungi can tell us something about the "ecosystem" that supports their growth and diffusion. A better understanding of the natural mechanisms that support the establishment of different species assemblages in indoor environments could be of help in defining a new approach to assuring environmental quality for humans and cultural assets. Indoor environments, although manmade and artificial, represent niches for microbes and fungi to inhabit. In these places materials are stored and assembled to form simplified "ecosystems" where microbial species can grow and reproduce. Ecological insight into materials spoilage and indoor niche colonisation by bacteria, insects and fungi could represent a successful approach for modelling and predicting microbial dynamics in manmade environments.

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Chapter 10
Indoor Air Quality: Monitoring and Modeling Protocol for Urban School Buildings

Radha Goyal and Mukesh Khare

10.1 Introduction

Indoor air quality (IAQ) refers to the quality of the air inside buildings as represented by concentrations of pollutants and thermal (temperature and relative humidity) conditions that affect the health, comfort, and performance of occupants. The growing proliferation of chemical pollutants in consumer and commercial products, the tendency toward tighter building envelopes and reduced ventilation to save energy, and pressures to defer maintenance and other building services to reduce costs have fostered indoor air quality problems in most of the buildings. As a result, occupant's complaints of odors, stale and stuffy air, and symptoms of illness or discomfort breed undesirable conflicts among occupants/owners/tenants/building managers. The U. S. Environmental Protection Agency and its Science Advisory Board have consistently ranked indoor air pollution among the top four environmental risks to the public as people spend almost 90% of their time inside the buildings. Indoor air pollution poses many challenges to the health professional, especially for infants, the elderly, persons with chronic diseases. The locations of highest concern are those involving prolonged, continuing exposure – that is, the home, school, and workplace. Therefore, it has become one of the most important issues of environment and health worldwide considering the principle of human rights to health that every one has the right to breathe healthy air.

The schools have complex indoor environments influenced by many factors, such as, the number and age of occupants, their activities, building design, sources of pollution inside the building; outdoor pollutant concentration and ventilation conditions (Goyal and Khare 2009; Goyal 2009; Clements-Croome et al. 2008; Hanssen 1993; Hanssen and Mathisen 1987; Lee and Chang 2000; Daisey et al. 2003).

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- Inadequate ventilation – increases indoor pollutant levels by not bringing in enough outdoor air to dilute emissions from indoor sources and by not carrying indoor air pollutants out of the classrooms.
- High temperature and humidity levels – increase concentrations of some pollutants.
- There are many sources of indoor air pollution in schools. These include combustion sources such as oil, gas, kerosene, coal; building materials and furnishings as diverse as deteriorated, asbestos-containing insulation, cabinetry or furniture made of certain pressed wood products; products for cleaning and maintenance, personal care, or hobbies; cooling systems and humidification devices; and outdoor sources such as radon, pesticides, and outdoor air pollution.
- Outdoor air enters and leaves the building by infiltration, natural ventilation, and mechanical ventilation. In a process known as infiltration, outdoor air flows into the house through openings, joints, and cracks in walls, floors, and ceilings, and around windows and doors. In natural ventilation, air moves through opened windows and doors. Air movement associated with infiltration and natural ventilation is caused by air temperature differences between indoors and outdoors and also by the indoor/outdoor wind pressure difference.
- High pollutant concentrations can remain in the indoor air for long periods after some of these activities.

Urban schools, in particular, are located in close proximity to high-density roadways and may experience significant concentrations of outdoor pollutants. They present a much higher occupancy than any other building (four times as many occupants per unit of area than in office buildings). Many recent studies have shown that schools have significant indoor environmental problems, while ventilation levels are below the recommended rates (Daisey et al. 2003; Myhrvold et al. 1996; ISIAQ 2000; Wargocki et al. 2005; Clements-Croome et al. 2008). Inadequate ventilation may lead to *unacceptable IAQ* conditions in schools, and are cause of *sick building syndrome*, increased complaints by the students, and increase rate of absenteeism. It may also results in high indoor pollutant concentration, which has a potential adverse impact on the health and learning capacity of students as they are more susceptible to indoor air pollution due to their higher breathing and metabolic rate and spend almost 8–10 h of a day inside classrooms, which is more than in any other building environment except their home (American Lung Association 2005). In the recent past, studies estimate that more than 50% of school children have some kind of allergy or asthma (Mendall and Heath 2005; Annesi-Maesano et al. 2007).

However, monitoring/measurement of IAQ parameters in schools pose many challenges to the environmental engineers and scientists as they are resource intensive. A solution oriented approach requires a steering committee of experts to provide their opinions on the design, planning and implementation of IAQ monitoring/measurement and control programs. The experts need to identify the key parameters that are to be measured/monitored in indoor school environment. In the past, many such measurements are performed by researchers to test the postulated hypothesis about the effects between the complaints and the sources (ISIAQ 2000). The causes of the complaints may be manifold that may include technical, chemical, physical, medical, psychological, sociological and economical factors. Correspondingly, the investigation strategies in such buildings are multi-interdisciplinary (Molhave 1986). The successful investigation depends upon the efficient coordination between various experts in such multi-factorial relations. In order to coordinate such co-operation a protocol covering sampling/monitoring, analyses, prediction and evaluation becomes an essential tool. However, this protocol must also define the specific *goals* and specify as to how they are achieved in such multi-factorial environment. The multi-factorial team may consists of experts like, building managers, heating, ventilation and air conditioning (HVAC) engineers, those performing the sampling and analyses (e.g. analyst), those making predictions of IAQ (e.g. the IAQ modelers) and lastly those making the evaluation of the building and taking decisions (e.g. the controlling authorities). Besides, the protocol must further ensure proper collection and recording of all information needed for the specific goals.

10.2 Steps Involved in IAQ Monitoring and Modeling Protocol for School Buildings

i. Selection of the school building type i.e. naturally ventilated and/or mechanically ventilated (HVAC)
ii. Conducting an IAQ building audit;
iii. Diagnosing IAQ related health problems;
iv. Selection of pollutants of concern;
v. Designing the monitoring programme of selected pollutants of concern;
vi. Setting up of IAQ guideline values for selected pollutants
vii. Establishing an IAQ management and maintenance program to reduce IAQ risks;
viii. Protecting occupants from exposures to construction/renovation contaminants; and
ix. Calculating the cost, revenue, and productivity impacts of planned IAQ activities.

10.3 Major Areas of Investigation

IAQ monitoring and modeling protocol needs to incorporate *three major areas* of investigation: *Environmental measurements*, *building and ventilation parameters*, and an *occupant questionnaire*. Framework for understanding how indoor and outdoor sources of pollution together with the ventilation affect the IAQ in buildings is one of the essential requirements. The monitoring protocol also include the *schedule* *of measurements*, the *specifications of the measurement equipments*, how to *select the representative space(s),* and how to *select the sampling sites in each space*. Data collection programs allow entry of majority of data and its findings in an accessible database so that it can be used by any interested party for a number of applications i.e. developing the distribution of IAQ/building/ventilation characteristics, predicting IAQ (modeling), developing new hypothesis, establishing standard protocols, examining the relationship of symptoms to building and ventilation characteristics, exposure assessment/modeling, developing guidelines for building design and orientation, construction, operation and maintenance and so on and so forth.

10.4 Components of IAQ

The *first* step in the preparation of an IAQ protocol is the definition of the sampling objectives. These objectives are generally problem oriented and so need "mapping" or documentation of complaints in the school building, control of compliance with standard or exposure limits and identification of the sources. Other objectives are the evaluation of the methods for measurements of pollutants, individual exposures of the receptors within the building, the identification of the effects of the variations in ventilations on IAQ. Each of these objectives call for different protocols and a detailed description of the aim is essentially the first step in any planning of the protocol. Once the sampling/monitoring objectives have been defined, the *second* step is to establish a list of all relevant sampling/monitoring variables and their variation range. The components involved in IAQ monitoring and modeling protocol for school buildings is as given below:

1. Identification of relevant measuring parameters
2. Sampling locations
3. Time of sampling/monitoring
4. Duration of sampling/monitoring
5. Number of samples/monitored data
6. Instrumentation
7. Calibration
8. Building and ventilation characterization
9. Occupant questionnaire
10. Sampling/monitoring administration
11. IAQ prediction models

10.4.1 Identification of Relevant Measuring Parameters

10.4.1.1 Environmental Parameters

Biological contaminants – allergens or microbiological, bioaerosols; chemical contaminants – Respirable suspended particulate matters (RSPM) i.e. PM_{10}, $PM_{2.5}$ and

$PM_{1.0}$, settled dust, gases (CO_2, CO, SO_x, NO_x, O_3) and volatile organic compounds (VOC's) including formaldehyde; and physical environment – Humidity, air movement (air flow, i.e. air change per hour, ACH), ambient indoor temperature.

The *biological contaminant measurements* firstly include capturing of bioaerosols from the air. Different air sampling techniques can be used to realize the goal of capturing indoor bioaerosols. The major bioaerosol sampler types are impactors and sieve samplers, impingers, centrifugal samplers and filter cassette. The possible subsequent analysis involves cultivation, microscopic analysis, biochemical analysis and immunoassays.

The c*hemical contaminants measurements* include measuring carbon dioxide (CO_2) and other possible indoor contaminants. CO_2 measurements are done by using *sorbent tubes*, which are readily available and are inexpensive. However they are with accuracy of only 25% and are not of much value for indoor air quality diagnostics. *Digital infrared spectrometry* though more expensive is mostly used with more accurate and appropriate measurements. Indoor CO_2 should be measured at peak values. However, if measurements in the occupied space are above 1,000 ppm, one has to then check for improperly vented combustion appliances, which could also be producing carbon monoxide (CO). The CO_2 levels outdoors are also required to be investigated simultaneously to estimate the indoor-outdoor (I/O) values and compare with thresholds values specified as 15 and 20 cfm per occupant (ASHRAE 1989). If these conditions fail to explain the exceedances in the CO_2 levels (i.e. >1,000 PPM), it may be then a valid presumption that the outdoor air ventilation rate is too low. Real-time measurements of CO_2 with data-logging equipment can be also be used to see how CO_2 values rise and fall in an occupied space during the day, reflecting the pattern of changing occupancy, or changing outdoor air ventilation rates. This can provide clues as to what is happening in the building and this information can help in the diagnostic process. Most of the IAQ problems can be solved with investigation of CO_2 and ventilation indoors without measuring specific contaminants. However, their measurements are sometimes helpful to clearly identify the sources and target contaminants to measure specific contaminants that have no acute affects but which could cause serious long term illness. This would help in taking mitigation measures to control the contaminant. When measurements are taken, qualified, experienced persons should take them and adhere to protocols and quality assurance procedures. Other essential parameters for IAQ measurement may include RSPM ($PM_{1.0}$ may be considered under desirable category); volatile organic carbons (VOC) including formaldehyde; O_3 and CO.

The *Physical environment* includes the measurement of temperature and relative humidity. Generally, independent measurements of temperature and relative humidity will be sufficient. However, some instruments will integrate these and other measurements and provide a read out of thermal comfort consistent with ASHRAE standard 55.2. 2007. For temperature and humidity measurements, instruments can be a simple *thermometer* and *humidity gauge*, a *sling psychrometer*, or an *electronic thermo hygrometer*. Such meters integrate several thermal comfort parameters and will provide a direct indication as to whether thermal comfort is in the acceptable range according to ASHRAE standard 55.2. 2007.

10.4.1.2 Building and Ventilation Parameters

Emission controlling variables: it includes the building site (near to road, away from road) and type (single/double/multistoried with its height), orientation of exits (doors, windows, ventilators), the construction material used, ventilation type (natural, mechanical, HVAC), outdoor pollution (traffic, industry, residences etc.) emission rates, elimination rates (sinks, e.g. plantation, carpets, wall papers etc).

10.4.1.3 Observational Data

Co-variables for human reactions: number of occupants (children and staff) in the classrooms, age group, genetic factors, personal co-factors, activities of occupants social environment, work environment, exposure times. *Human Reactions* – symptoms from eyes, nose and upper airways, throat, mouth, lower airways, stomach, heart, ear, hyper-reactivity, skin reactions, heat balance, neurological effects, psychological effects, changes in human activity patterns. *Non human reactions* – from animals and plants and effects of buildings and other properties.

10.4.2 Identification of Sampling Locations

The optimal sampling site depends on the sampling objectives. If the sampling is planned for a specific environments (offices, residential dwellings etc.), the locations are preferred inside these environments. However, if the sampling/monitoring are representative of a given type of residences, commercial buildings, schools, hospitals, the investigators must first ensure the representatives in the selected sampling sites. After selecting proper sampling/monitoring sites, the sampling/monitoring locations inside the environment or building must be considered. This is important as the air inside the environment is not uniformly distributed. One strategy is to locate and investigate the areas of highest concentrations of contaminants. Woods et al. (1985) and Maldonado and Woods (1983) have suggested a procedure for choosing the sampling locations indoors using four concepts:

i. Location of the problem or contaminant source.
ii. The relative exposure index (REI) or
iii. The ventilation effectiveness (VE) and
iv. Occurrence of complaints

REI and VE methods use tracer gas technique for identifications of problem areas within the building. Later, for mathematical analysis and predictions, each sampling/monitoring location may represent a homogeneous microenvironment which means that variance of variables under consideration in each microenvironment will be smaller than variance among the averages for different microenvironments (Moschandreas 1981). Therefore different microenvironments constitute together the entire non-homogeneous sampling/monitoring microenvironments while each sampling/monitoring location is representing a homogeneous microenvironment. Each of this microenvironment must be decided prior to sampling/monitoring and separate sampling/monitoring protocol may be fixed for each of them. The size of the microenvironment depends upon the variations in space and time of the selected variable.

10.4.3 Time of Sampling/Monitoring

The contaminants concentrations indoors are related with cofactors such as humidity, human activity and air temperature. The time of sampling/monitoring must then be chosen accordingly so as to minimize the influence of the cofactors e.g. when the potential cofactors are expected to be constant and at average level. Such choice of time may not be acceptable or achievable all the time in relation to the overall aims of the investigations. Hence the sampling/monitoring programme must always allow estimate of the range of variations of relevant cofactors. In one of the recently conducted IAQ investigations for naturally ventilated school buildings in tropical climatic conditions, the monitoring/sampling timing protocols used is given in Table 10.1.

Similarly, for other types of dwellings, the proposed sampling/monitoring protocol is suggested as below (industrial establishments are not covered):

- Residential (morning and evening, 1 h in each case)
- Offices (Any two working hours)
- Health care units (morning and evening, 1 h in each case)
- Restaurants (any 2 h in the evening)

Table 10.1 Monitoring/sampling timing protocol (Goyal 2009)

Temporal variations	
Hourly variations	Every half an hour (class periods change after every half an hour)
Daily variations	From 8.0 am to 2.0 pm continuous (School hours)
Weekly variations	Weekdays (Monday, Wednesday and Friday) and weekends (Saturday and Sunday)
Seasonal variations	Non winter months (August, September, October, March, and April) and winter months (November, December, January and February). *For rest of the months schools are closed*

10.4.4 Duration of Sampling/Monitoring

The sampling duration must represent "peak" exposure and "average" exposure indoors. Both long term and short term sampling/monitoring may be required to reflect the desired time resolution of the sampling/monitoring programme. The greatest time resolution obtainable is the shortest sampling/monitoring duration and interval. In addition, the sampling/monitoring efficiency together with the sensitivity of the analytical method also determine the sampling/monitoring duration. Short time sampling/monitoring (<15 min) is chosen for investigating acute effects; investigation of chronic effects are evaluated by carrying out sampling/monitoring for longer duration of several hours or even days. For the school building, the suggested duration of sampling/monitoring is for hours of the school running as significant variations in air pollutant concentrations (especially particulates and CO_2) occur every half an hour with change in class hour and activities of occupants.

10.4.5 Number of Samples/Monitored Data

The number of samples or data points must be planned prior to start of sampling/monitoring. It is needed so that the results are within the desired confidence limits. To accomplish this, pilot studies are conducted. Corn (1985) has described thumb rule to find out the number of samples/data points in the desired confidence interval. In any event, minimum three samples/monitored data should be collected before any statement is made. If the range of these exceed 25% of their average, additional samples/monitored data points should be obtained. NIOSH (1984) has described the procedure for maintaining the quality control of the analysis report. The number of samples may be based on the following criterion:

- By means of random numbers
- All corners, central place at all floors
- Building/house orientations
- Pre-dominant wind direction (up-wind and down wind)
- Depending of the fuel usage
- Income group

In schools the number of samples depends upon its location (proximity to the road), type of school buildings and activities inside the classrooms and school premises. School samples should be taken before and after the school hours and according to the variations in the activities inside the classrooms. Generally schools are running for 6–8 h and classroom activities changes after every half an hour period to an hour period. Accordingly number of samples should be decided to get the data incorporating all variations.

10.4.6 Instrumentation

For each of the relevant variables, separate sampling/monitoring instructions accompany the analytical protocol. The preparation of sampling/monitoring instructions must ensure that the finally selected sampling/monitoring and analytical method meet the objectives of investigations. That requires consultations with laboratory prior to the selection of the analytical methods. Table 10.2 describes a few common sampling/monitoring and analytical methods for measurement and analysis of the ambient indoor air pollutants and corresponding exposure factors. Optical laser aerosol spectrometer (LAS), IR based IAQ monitors, are most common and user friendly instrument used for continuous monitoring of RSPM, CO and CO_2, respectively (Blondeau et al. 2005; Branis et al. 2005; Fromme et al. 2007; Goyal and Khare 2009).

Direct airflow rate measurements, especially in naturally ventilated schools are difficult though various techniques are available in literature. Therefore CO_2 measurements are used to estimate the airflow (ventilation) rate using ASHRAE formulations as indoor CO_2 concentration is considered as *surrogate index* of ventilation rate (Persily 1993; Scheff et al. 2000; Goyal and Khare 2009).

10.4.7 Calibration

The sampling/monitoring instruments must be calibrated against a secondary standard prior to and immediately following sampling/monitoring. Besides, instruments should be regularly checked for its calibration against primary standards.

10.4.8 Building and Ventilation Characterization

Characterization of *building parameters*, i.e. type, size, age, location, building fabric, its furnishing and equipment, its occupants and their activities need to incorporate in IAQ protocol. The elements of *ventilation*, i.e. *airflow rate, air volume and air velocity* from openings in *natural systems* or from *heating ventilation and air conditioning (HVAC) system* are important to IAQ. Its information is important to develop the protocols for the operating set points and schedules consistent with good IAQ performance. Measurement instruments and techniques, which are generally available to building personnel, can be extremely useful in assessing the performance of the right ventilation system for both exhausting and diluting pollutants. Useful measuring tools include: *Smoke tube* and *hot wire anemometer* to measure airflow rate (Mueller and Vogel 1994; Karimpanah and Sandberg 1996), *pressurization test method* and *Flow hood* to measure volumetric airflow (Schijndel 1991), *Velocity meter (particle – streak velocimetry technique*) to measure air velocity

Table 10.2 Sampling and measuring procedure/instrumentation for IAQ study

Contaminant	Sampling procedure/instrument	Analytical procedure	Reference
VOC	Dual section, charcoal tube, polymer absorber	Solvent elution and GC MS; SKC low flow samplers with tenax or charcoal	SKC passive VOC sampler
PM_{10}, $PM_{2.5}$, $PM_{1.0}$	Filters, low volume particulate samplers, particle size analyser, beta attenuation	Gravimetric, infra red based monitors	GRIMM Aerosol Dust Monitor 1.108 (2003)
CO_2	Real time	IR based IAQ monitors	ACGIH (1978)
CO	Real time	IR based IAQ monitors	
O_3	Real time	IR based O_3 monitors	
Formaldehyde (CH_2O)	Real time or liquids in impinger	IR based Formaldehyde monitors or chromotropic/acetyl acetone method	Goddish 1985; Bisgaard et al. 1983
Microbiological contaminants	Modified Anderson samplers	Light scattering device	Dimmick and Wolochow 1979
Air change per hour (ACH)	CO_2 Measurements/Airflow meter	Estimation	Scheff et al. 2000; Wadden and Scheff 1983
Volume of building	Ultrasonic ruler	Ultraviolet rays	Zircon DM S40 Sonic measure (Zircon Corporation, Campbell, CA)
Personal computer	Window 7.0	USB port and TRACKPRO version 3.4 for downloading and mathematical software	

(Zhao et al. 1996), *CO_2 measurement technique* to estimate the percentage of outdoor air or to generally evaluate outdoor air ventilation (Persily 1993; Scheff et al. 2000; Goyal and Khare 2009). It acts as *surrogate* index for analyzing the ventilation and so the IAQ. Besides, *air flow grids* can also be used to measure differential pressure and air flows in the buildings.

10.4.9 Occupant Questionnaire

The sampling methods for biological effects are numerous. Therefore to simplify the measurement protocol for biological effects of indoor pollutants, the "questionnaire" tool is generally used. The questionnaire will collect information on various factors, i.e. *general information on building* (as mentioned in building characteristics), its *environmental and ventilation condition*, *occupants and their work responsibilities*, *SBS symptoms and occupant's perception on their health*. However, there are "gaps" in this tool such as, the questionnaire is neither able to prove causality, nor document whether the complaints are caused by "hypersensitivity" or high level of indoor pollutants. Inspite of these shortcomings, the questionnaire tool is invariably used in analyzing the IAQ problems (Gupta et al. 2007).

10.4.10 Sampling/Monitoring Administration

The protocol must include proper numbering of all samples/monitored data, data sheets for each variable or co-variable. Strict storage norms and routine for the collected data must be established to secure the validity of the samples/data. Active information plan must be distributed to the occupants of the building before any study is started as the success of the IAQ study depends upon the cooperation of the individual occupant, building manager, the producer of the building material, the authorities, the resident welfare associations etc. The information activities should not be biased to any individual stakeholder of the site being investigated.

10.4.11 IAQ Prediction Models

Predictions of IAQ for different types of buildings are essential in order to avoid repeated IAQ monitoring which involves money and manpower. Various modelling techniques are used to develop the IAQ models that includes the most used and simple technique based on mass balance approach. For many studies in IAQ, wind tunnel simulations can also be used which may provide coefficients controlling the air change rate (Hall et al. 1999), resuspension and/or re-entrainment of the settled particulates etc (Gomes et al. 2007). Such studies would help in eliminating uncertainties affecting the predictive efficiency of the IAQ models for RSPM (Goyal and Khare 2010). In nutshell, Fig. 10.1 describes the proposed IAQ monitoring and modeling protocol for urban schools.

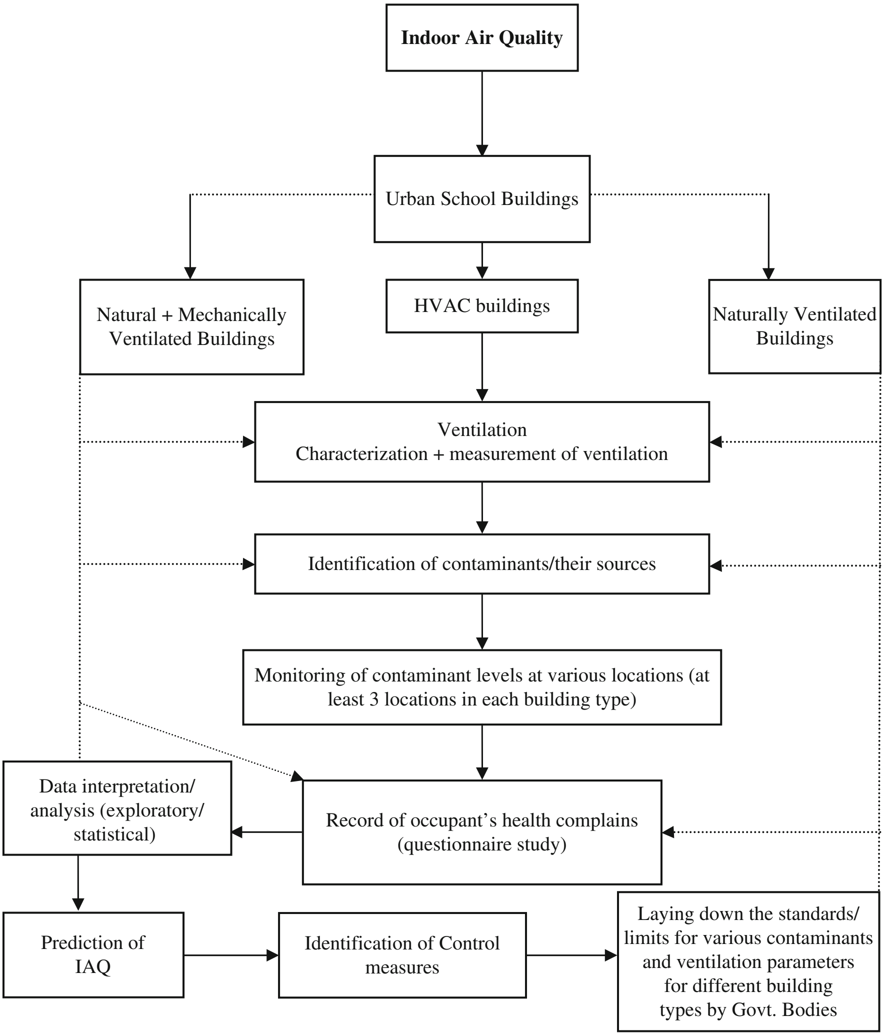

Fig. 10.1 An IAQ monitoring and modeling protocol for urban schools

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Chapter 11
Mould Growth on Library Materials Stored in Compactus-Type Shelving Units

Flavia Pinzari and Mariasanta Montanari

11.1 Introduction

Compactus-type shelving is one of the systems of choice used for the conservation of materials in libraries, archives and museums (Fig. 11.1). These high-density storage systems are also referred to as "movable shelving" and are employed by many institutions suffering from limited space. These systems minimize the amount of space required for storage by compacting blocks of shelves (or cabinets of drawers) tightly together. The blocks slide along tracks and can therefore be moved apart (opened) for the retrieval of items positioned on a particular block and then moved back together again (closed). Compactus shelving can also guarantee protection against dust deposition (Gallo and Regni 1998). These characteristics are advantageous for the preservation and storage of materials, but they can also become problematical when used in conservation environments lacking climate control systems. Compactus shelving can be considered ideal equipment for preventive conservation when the overall climatic situation is ideal. Resistance to heat and humidity exchange between the micro-environment within the compactus units and the outer environment can represent a severe peril to stored objects, especially when these are composed of hygroscopic materials. Recommended standards for preserving documents of all kinds are now well understood (18–20°C and 50/55% RH for books and periodicals, and 5°C and 35% RH for colour print photographs). The reality is that in most cases it is difficult to maintain a stable temperature and/or relative humidity level, even with the benefit of air conditioning. Specific climatic and economic conditions play an important role, and these should not be underestimated. In some conservation environments compactus-type shelving systems have caused, indirectly, serious degradation phenomena to occur. The problems caused by movable shelving systems were found to be more at the micro-environmental level rather than at a macro-level. During the course of several investigations in libraries and

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Fi A detail of the depository at the Estense Public Library equipped with compactus-type shelving

archives, a range of causes led to the same results, namely the development, within compactus shelving blocks, of moulds on volumes' bindings, especially when made of leather, parchment or cotton fibres.

Due to the frequency of occurrence of mould on library and archival materials stored within compactus shelving and the similarity in the appearance of such "infections", a study was undertaken which was aimed at pinpointing any common factors, above and beyond the mere presence of compactus shelving that provoked the development of such degradation phenomena.

In this chapter the results obtained from six different diagnostic surveys conducted in depositories located in Italy (all containing compactus shelving) are described; additionally, the solutions applied to combat deterioration phenomena are discussed. Four depositories are located in Rome, one in Genoa, and the sixth in Modena (Table 11.1). The volumes stored in the depositories of these libraries

Table 11.1 Depositories investigated in the present study (ND not defined)

Library or depository	Location	Size of collection
Berio Civic Library	Genoa (Italy)	150,000 volumes
Estense Public Library	Modena (Italy)	ND
St Apollinare Universitary Library, French Academy	Rome (Italy)	ND
Historical Library of Finance	Rome (Italy)	100,000 volumes
Angelica State Library	Rome (Italy)	200,000 volumes
Library of the Belgium Academy	Rome (Italy)	80,000 volumes

Fig. 11.2 Volumes stored in compactus-type shelving units and affected by moulds at the Estense Public Library. Only books with bindings made of leather, parchment or canvas presented with mould growth

were all found to be in an overall good state of preservation. In addition, environmental parameters are well-monitored and stable, and a good prevention policy with periodic dusting of stored materials is in place.

Nevertheless, some volumes stored within the compactus shelving presented with mould growth on their covers, as documented in Figs. 11.2 and 11.3. The fungal mycelia, in all the observed materials, were consistently characterised by their scattered appearance, with the colonies taking the form of light coloured spots measuring 0.5–1 cm in diameter.

The Biblioteca Angelica has been a State Library since 1873. It is one of the world's great collections of rare books and manuscripts. It is named after Angelo Rocca (1546–1620), an Augustinian Bishop, who headed the Vatican's Printing House during the time of Pope Sixtus V.

The Library's 200,000 volumes include the Ancient Book Collection, an outstanding set of works published between the fifteenth and eighteenth centuries. The Angelica houses more than 1,100 incunabula, including an edition of Cicero's *De Oratore* (1465, the first book printed in Italy) and one of the earliest known copies of Dante's Divine Comedy.

The Library of the Belgium Academy houses about 80,000 volumes, including those belonging to the Belgium Historical Institute in Rome and the National Princess Marie-José Foundation. Seventy percent of the volumes are on topics such as history, the arts and archaeology, and the history of sciences and religions.

The Berio Civic Library was built by the abbot Giuseppe Vespasiano Berio in the second half of the sixteenth century. Today the building (which has been completely restored) is also a cultural centre which is open to the public. The Berio Library collected a great wealth of precious books and documents between the fifteenth and

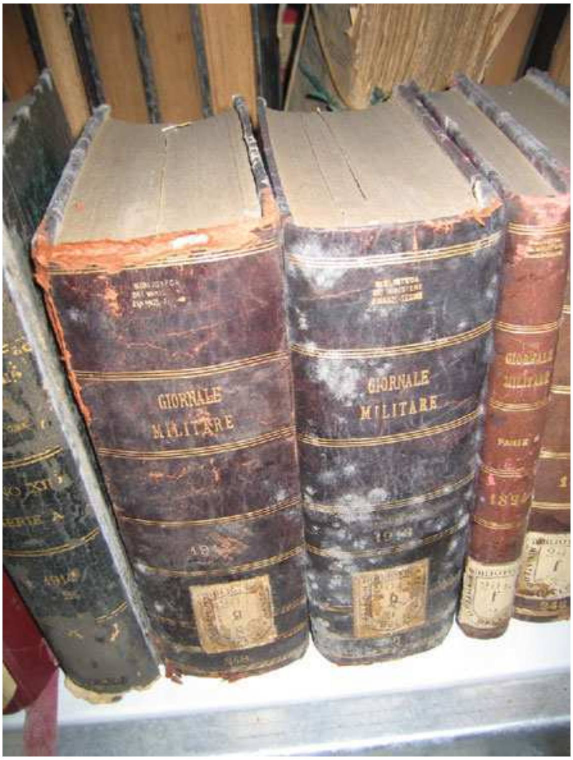

Fig. 11.3 Volumes stored in compactus-type shelving units and affected by mould at the Historical Library of Finance. Damage was very localised and limited (as anticipated in the introduction) to only a few portions of the bindings

eighteenth centuries; these include parchments, coats-of-arms, manuscripts, illuminated codices, maps, autographed letters and the collections of some of Genoa's old and important families.

The G. Apollinaire Library is part of the French-Italian Studies Centre; it was founded as the "*Bibliothèque française de Rome*", being the library of the French Embassy in Rome. Today it is a University Library (the fund was donated to the capital's *Roma Tre* University in 1999), but also functions as the hub of the "*Centre culturel français*". It is housed in the Palazzo Capizucchi, which dates from the sixteenth century.

The Historical Library of Finance is the oldest of the libraries located in the Palace of Finance in Rome. Heir to the Library of the Ministry of Finance of the Kingdom of Sardinia (1857), it also houses the collections of other pre-unification States. From the Unification of Italy to date, this library collection has gradually been enriched with government publications, periodicals and monographs addressing primarily, but not exclusively, legal, financial, and historical subjects. Currently, there are about 100,000 items in the catalogue; these are mainly printed books produced between the late eighteenth and mid-twentieth century.

The Estense Public Library in Modena was originally the Estense dukes' library, which was subsequently moved from Ferrara to the Ducal Palace in Modena, and was opened to the public in 1764 (indeed, it was one of the first to be opened to the public) and has been located in the present-day building, the Museum's Palace, since 1833. The collection originates from the ancient Este dukes' library, which was created in fourteenth century, and was later enriched with precious volumes under Niccolò III, Borso and Ercole I. Among the most valuable volumes in the collection is the famous Borso d'Este Bible, a masterpiece of Ferrarese manuscript illumination. A description of a survey carried out on the compactus shelving system in this Library is reported in Montanari et al. (2007).

11.2 Materials and Methods

The study consisted in an environmental and biological assessment of both the hygienic conditions and state of conservation of structures and materials.

Climatic and water content data – Climatic measurements were performed by using a number of hygro-thermometer probes positioned vertically along the inside of compactus shelving units (ranging from 15 cm above the floor to the uppermost shelf). Climatic measurements were collected throughout the depositories contemporaneously. The instruments used for the collection of climatic data were digital hygro-thermometers (Hygrolog-D Rotronic AY – Switzerland). Data relating to the water content of books were acquired by means of Aqua-Boy devices (ENERCORP Instruments Ltd, Toronto, Canada); these are water content meters which are based on the measurement of the electrical conductivity of materials. All changes in resistance within the relevant measuring ranges are sufficiently pronounced to ensure a high degree of accuracy for the readings. The electrical (reading value) accuracy of the Aqua-Boy is ±0.1%, while reproducibility is ±0.2% in relation to the absolute readings on the meter.

Swab sampling – As part of the investigation, sampling of fungal structures on damaged library materials was carried out. Sterile cotton swabs were used to obtain samples suitable for fungal and bacterial culturing and identification. To collect a sample, a swab was wiped across the entire area showing visible damage.

Adhesive tape sampling – Removable adhesive tape was used to collect samples of fungal mycelia and sporulating structures from the parts of the bindings hosting fungal structures. The colonies were brought into contact with the adhesive side of the tape by applying very light pressure. Next, the sample tape was transferred to a glass slide using a drop of mounting fluid so as to facilitate microscopic examination (Samson et al. 2002), or alternatively to a metal stub for SEM (Scanning Electron Microscope) observation.

Agar/broth cultures – Fungal structures sampled with cotton swabs were inoculated directly on to agar plates coated with different types of nutritive media; the swabs were then immersed in sterile Czapek broth (Samson et al. 2002). The Petri dishes employed for culturing the fungal and bacterial strains were prepared with the following substrates: PDA (Potato Dextrose Agar), MEA (Malt Extract Agar), M40Y (Malt Yeast Agar with 40% of saccharose), DG18 (Dichloran Glycerol

Agar), all in accordance with Samson et al. (2002). The last two substrates are used as a medium to promote the growth of xerophilic and osmophilic species.

Optical microscope observations – Illuminated microscopic examination of mounted slides with applied adhesive tape samples and fungal structures was carried out using an Olympus AX60 microscope fitted with a digital camera.

Scanning Electron Microscope observations – SEM images of adhesive tapes bearing captured fungal structures were made using an EVO 50 Scanning Electron Microscope produced by the Carl-Zeiss Electron Microscopy Group (Oxford, UK). The SEM instrument used for this study is a Variable Pressure model that can be used with non-conductive specimens without the need for metallization (Goldstein et al. 2003). Tape fragments measuring 5–10 mm in diameter bearing the fungal structures were cut and mounted on to a 12 mm metal stub using double-sided carbon adhesive tape. The sample areas were examined using a 20 kV electron beam, and both a variable pressure secondary electrons (VPSE) detector and an electron backscattered diffraction (BSD) detector were used to acquire SEM images of samples at various levels of magnification.

Aerobiological investigations – Atmospheric aerosol sampling was carried out using the gravitational deposition method: i.e. collection by means of gravity-driven settling of particles on Petri dishes coated with a suitable culture medium. Culture dishes with a diameter of 9 cm containing MEA and DG18 media were used. The plates were placed on the shelves within and outside the compactus units, in the same places where the digital hygro-thermometers were positioned. The sampling period duration was 1 h. Following exposure to air, the plates were placed in a incubator at 27°C for 7 days and checked daily: Colony Forming Units (CFU) counts were performed.

Statistical analysis – Principal Components Analysis was applied to several sets of environmental data so as to assess the overall variability of the water content values and, at the same time, to identify the main components (eigenvectors), which consist in factor scores, with increased variability of the cumulative data. Analysis of variance (ANOVA) was also applied in order to effect multiple comparisons; Fisher's LSD test (LSD: Least Significant Difference) was used for this purpose – this is a sort of Student test which assumes that all the averages for the various categories are the same, with the aim of highlighting significant differences at 95% confidence intervals. Calculations were performed using XLSTAT Addinsoft software (Fahmy 2003).

11.3 Results and Discussion

All the six study cases examined disclosed moulds that had grown on books (especially on their spines) stored in compactus shelving units. Conversely, the volumes stored on open metal shelving in the same environments where the compactus units are located proved to be free of mould. Significantly, damage was very localised and limited – as anticipated in the introduction – to only some parts of the bindings.

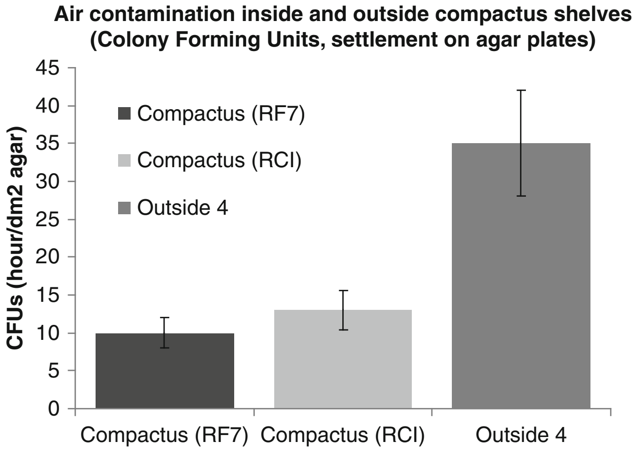

Fig. 11.4 The prevailing situation at the Library of the Belgium Academy: a significantly lower charge of vital aero-diffused microflora within the compactus shelving units was found in comparison to the surrounding "open" environment

Moreover, only books with bindings made of leather, parchment or canvas presented with fungal efflorescence (Fig. 11.2), while bound volumes and bindings made from cardboard and paperbound volumes were found to be free of mould. These observations are equally valid for all the cases investigated. The analysis of air quality carried out by means of gravity-driven collection of CFUs disclosed the presence of a significantly lower charge of vital aero-diffused microflora within the compactus shelving units compared with the environment outside the units. This situation was found in most of the depositories investigated, although any differences were more significant in those spaces where a higher overall environmental spore charge was present. Figure 11.4 reports, as a mid-range example, the situation recorded at the Library of the Belgium Academy. The air outside the enclosed compactus environment showed a significantly higher number of CFUs, when compared with the air within two different enclosed compactus environments. The air quality in the depository was determined to be within acceptable limits, in relation to ISO/DIS 16000-18, ISO TC 146/SC 6 (2008).

The measurements reported in the bar chart shown in Fig. 11.4 were collected by means of spore settlement on agar coated plates; the air inside compactus units was measured with the shelves kept closed, while the air outside the units was measured taking care not to introduce misleading variables (i.e. ventilation, air movement caused by human motion, or open windows). From the qualitative point of view, airborne communities within and outside compactus shelving units were composed of fungal spores and propagules (mainly *Aspergillus, Penicillium, Cladosporium, Alternaria, Geotrichum, Gliocladium* genera), various yeasts and bacterial cells. Sampling of fungal material performed directly on library materials using swabs and adhesive tape showed that the efflorescence was actually composed of fungal

Fig. 11.5 A fragment of adhesive tape directly observed through an optical microscope (Olympus A×60, light field) reveals the presence of mature *Aspergillus* fruiting structures (conidiophora), with chains of conidia

Fig. 11.6 A fragment of adhesive tape used for sampling the mould efflorescence present on volumes in the Angelica Library. The mould appeared whitish in colour when observed on materials and green-dull grey when sampled using transparent tape

mycelia and that the actively growing strains belonged to species different from those found in air samples (Figs. 11.5 and 11.6).

This discrepancy between the composition of the microbial and fungal assemblage in samples taken from the air and those collected directly from mould-affected materials was conspicuous in all the depositories analysed.

The illuminated microscope observation of adhesive tape samples revealed fruiting structures with spores belonging mainly to species of xerophilic or osmophilic fungi, genera that are known to be capable of growing in conditions characterised by low water activity, such as *Eurotium* species, and xerophilic *Aspergillus* species (*Aspergillus restrictus, Aspergillus penicilloides*, etc.). It was possible to attribute some of the fungal structures sampled from the volumes affected by moulds to the *Aspergillus* genus (Figs. 11.6 and 11.7), but not to any particular species because the diagnostic features were too far from those described in the systematic keys. In fact, fungi can display very different appearances depending on the substrate upon which they develop (Samson et al. 2002), and most of the descriptions and measurements

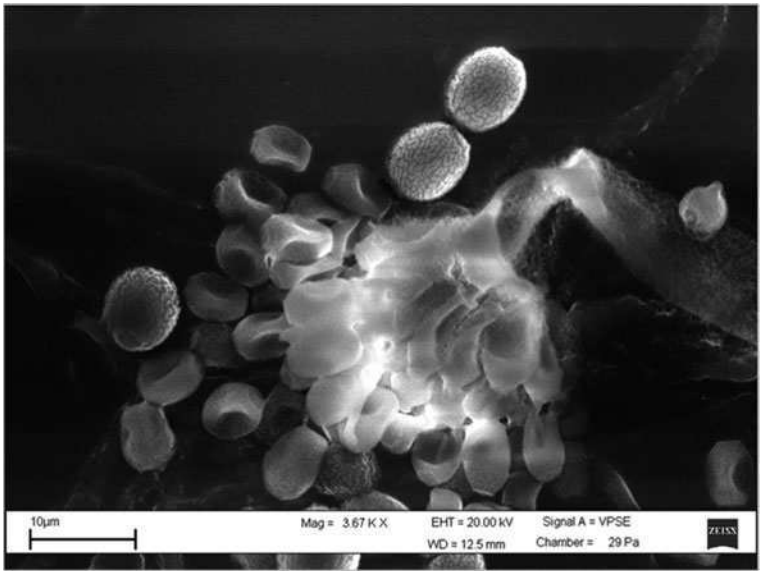

Fig. 11.7 Scanning electron micrograph of the adhesive tape supporting the fungal structures that developed on books. The image was obtained by applying the environmental mode and using atmospheric pressure to prevent shrinkage of biological structures. The sample was not metallised. The features of the conidia resembled those of some *Aspergillus* species belonging to the *Glaucus* group (i.e. *Eurotium amstelodami*), but no positive identification could be arrived at since it has not yet been possible to produce living cultures of the fungus

of fruiting bodies and spores relate to the strains cultured on standard nutritive agar. Additionally, several attempts to grow cultures of fungal isolates from the xerophilic species that developed within the compactus shelving units were unsuccessful, probably because of the very peculiar nutritional attitudes of these fungi and to an overall scant viability of the same.

Conservators and librarians working in all the depositories investigated and frequenting the environments where mould-affected compactus shelving is present reported typical symptoms of so-called "sick building syndrome"; the said personnel suffered from a number of health problems that can be attributed to the presence of fungal and bacterial spores and volatile organic compounds produced by actively growing micro-organisms. The results of the environmental monitoring activity indicated that apart from the generally consistent maintenance of standard climatic conditions in all the evaluated situations (the average relative humidity value ranged from 50 to 60%, and temperature from 20 to 22°C), a humidity gradient was present inside most of the compactus shelving units housing books affected by mould, and a higher water content was observed (mainly) close to the floor, although the gradient was fairly similar between the upper and lower shelves (Fig. 11.8a and b). In addition, the relative humidity level within the compactus units was slightly but constantly higher than that on the outside, as shown by the bar chart seen in Fig. 11.9. The microclimatic differences disclosed in all the analysed situations

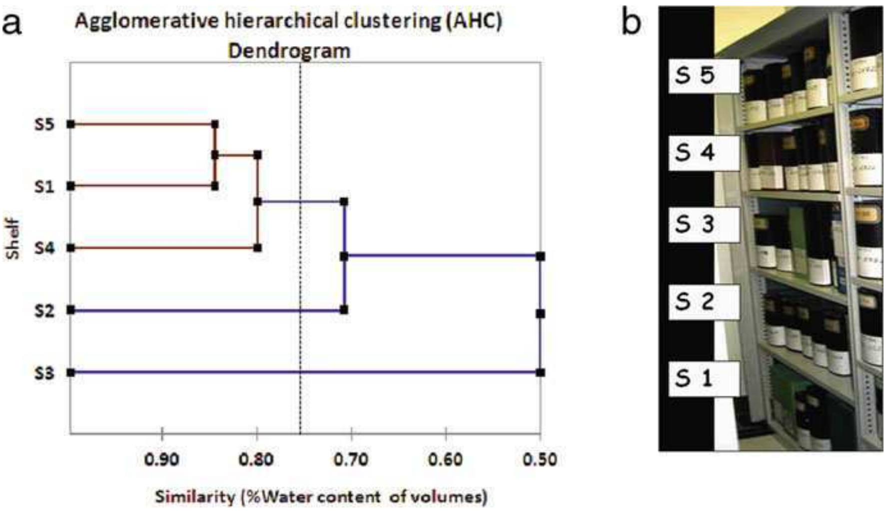

Fig. 11.8 (**a**) A clustering dendrogram showing the results of a comparative analysis performed at the Angelica Library and based on the water content of all the volumes contained in a compactus shelving unit. The data obtained from volumes placed on different shelves of the same stack were compared through the application of Principal Component Analysis and the correlation matrix visualised as an agglomerative dendrogram; (**b**) The stack where the measurements were taken, with the relevant numbering of the shelves as reported in the dendrogram

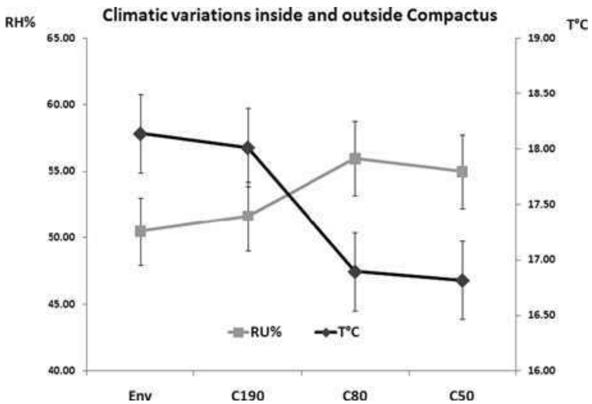

Fig. 11.9 A diagram showing the differences between environmental relative humidity (RH%) and Temperature (T°C) both within and on the outside a compactus shelving unit (data from the survey performed at the St Apollinare University Library). In the diagram, labels C190, C80 and C50 relate to shelves at different heights from the floor (190, 80 and 50 cm), while "Env" indicates the average values obtained outside the compactus shelving units. The shelf closest to the floor was found to have a higher value of RH and a lower value of T°C

result in a variation of water content in some volumes. A slight difference in water content between the covers and inner parts of volumes (i.e. text block) can trigger the growth of mould. This hypothesis is supported by data gathered in a number of different depositories.

Measurements of water content in volumes both affected and unaffected by moulds, all stored in the same stack, revealed two interesting points. In the first place, a difference, albeit small, between the values of water content of the cover and the inner parts of volumes is associated with the presence of moulds (Fig. 11.10). A second important point is related to the different capacities of materials to adsorb environmental/ambient water: Fig. 11.11 shows how a greater difference between the text block and the cover of a volume was found in items characterised by a leather binding.

In order to avoid the necessity of mass disinfection of materials using toxic gases, the problem of mould efflorescence in most of the depositories has been tackled by applying a combination of low-impact/toxicity treatments aimed at halting damage to materials and leaving premises safe and healthy for staff to work in. The operations carried out were as follows: (i) the HVAC was checked for efficacy, and ventilation grilles were cleaned and checked to verify their correct functioning; (ii) HVAC filters were changed more frequently; (iii) the side panels of the compactus units were removed so as to facilitate ventilation; (iv) books were mechanically dusted within a safety cabinet, (v) fungal efflorescence was removed manually by specialised personnel using soft brushes and a vacuum cleaner within a safety cabinet fitted with HEPA filters and the appropriate health and safety devices. In Fig. 11.12, the impact on mould growth by simply removing the side panels from the compactus units is shown.

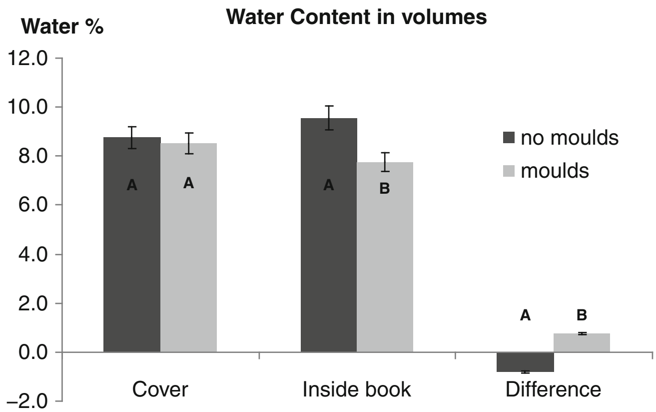

Fig. 11.10 The water content difference in volumes with and without mould at the Library of the Belgium Academy. ANOVA statistical analysis and the Fisher test were used to group observations based on their environmental parameters: a different letter (A, B, C) indicates a statistically significant difference between the averages. When two letters are present, it signifies that the particular sample simultaneously belongs to two different groups

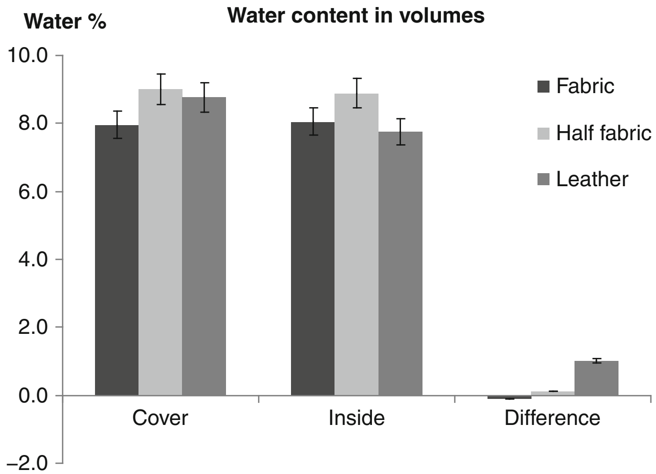

Fig. 11.11 The water content difference in volumes with different types of binding at the Library of the Belgium Academy

Following the volumes' reclamation/rehabilitation and the adoption of most of the recommended steps, a further investigation at some of the depositories was conducted after an interval of approximately 20 months. Visual inspections and photographic comparisons of the state of conservation of the books and the development of mould were performed. Almost everywhere biodeterioration phenomena

Fig. 11.12 A volume from the Estense Public Library before (*left*) and after (*right*) a few weeks following the removal of the side panels from the compactus units to facilitate ventilation. Clear and evident regression of mycelia was observed

appeared to be substantially reduced, and all the volumes that were previously affected by mould efflorescence appeared to be in the same condition as they were following their cleaning 20 months prior.

11.4 Conclusions

The hypothesis formulated to explain the occurrence of damage in compactus-stored volumes is composed of a sum of microclimatic events including: (i) a lack of ventilation within compactus units; (ii) resistance to climatic changes within the compactus units in relation to the macroclimate in the depository; (iii) the hygroscopic behaviour of binding materials used in the volumes; (iv) a higher susceptibility to humidity of the exposed parts of the books (i.e. spine, upper edge and fore edge); (v) the fact that Heating, Ventilation and Air-Conditioning systems (HVAC) had to be switched off during the night and on weekends in some depositories due to outdated safety rules, thereby causing fluctuations in climatic parameters and eventually causing condensation to develop on enclosed shelves and materials; (vi) seasonal changes. Among the broad range of situations examined over a roughly 10-year period of surveying activity, the causes of mould development in compactus-type shelving units varied according to the different situations encountered: (a) small libraries with no funds or poor knowledge used compactus shelving simply to save space and lacked air conditioning; (b) libraries with an apparently perfectly functioning air conditioning system positioned air venting modules inappropriately in relation to the compactus shelving units, thus causing incorrect air circulation/currents and the occurrence of non-uniform climatic parameters along and among the shelves; (c) libraries with efficient air conditioning units but affected by structural problems such as rising damp in the floors and along the walls. Frequent visual inspection of materials stored within compactus shelving units is highly recommended, notwithstanding the presence of a well-functioning HVAC and maintenance of optimal standard climatic values. Micro-environmental anomalies and localised deterioration phenomena, if promptly detected can be easily contained and resolved, while invasive reclamation/rehabilitation of materials should, as far as possible, be avoided and implemented only as a last resort.

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Chapter 12
Is Your Library Building Sick? A Case Study from the Main Library of Sultan Qaboos University at Sultanate of Oman

Sabah A. Abdul-Wahab and Nahed Mohamed Bassiouni Salem

12.1 Introduction

Library buildings were exposed over time to great developments in accordance with their needs, the needs of the users, and the change of their objectives. These developments came in parallel to the constant scientific and technical progress. This development clearly influenced the library buildings and the activities that are conducted within these buildings as well as their architectural design. Hence, most studies produced dealt with the implications of such developments on libraries and the services they offer. Many researchers focused their attention on describing the architectural elements of libraries and their development. Some researchers focused upon the stages of development that library buildings went through, and studying the impact of modern technical developments on their functions (AlSareehi and Hambeshi 2001). Other researchers described the safety and security systems (AlSareehi 2005), while yet others focused upon the architectural design of libraries (Hassan 2005). At the same time, the absence of studies that focus on the environmental dimention of library buildings and introducing Sick Building Syndrome (SBS) was noticed.

Internationally, light was not thrown upon the pollution inside buildings until the late 1970s, when complaints increased in some advanced countries of various pathological symptoms which occurred in air-conditioned, air-tight buildings. These came to be known as the Sick Building Syndrome, including library buildings (Apter et al. 1994; Fisk 2000). One of the signs of this disease is that the person suffers from a set of symptoms closely related to his/her presence in the building, without the identification of any clear causes, and his/her relief of these symptoms when he/she are out of the building (Cando 1999; WHO 2005). Medical sources indicate that over 50 symptoms, some or all of which may appear on those who suffer from this condition. Since these symptoms are varied and diverse, with no obvious link between them, the pathological condition which collectively describes

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these symptoms is medically known as a "syndrome". The most important symptoms include: headache, dizziness, faintness, rashes, nose inflammation, difficulty breathing, difficult concentrating, laziness, rapid exhaustion and fatigue (WHO 2005).

Reviewing the foreign intellectual output, we find only a limited number of studies dealing with this topic. The researchers of this study did not find any studies produced in the Arab intellectual output, focusing adequately on this topic. This is what drew the researchers attention to the environmental dimension to the issue, and the necessity to examine the interior environment of library buildings, to determine the extent to which the personnel are exposed to SBS. This was achieved by selecting the building of the SQU Library as a case study.

12.2 Literature Review

The issue of SBS in library buildings has not received much attention despite its importance and its impact on the quality of the performance of the information specialist. Hence, the relevant studies published internationally remain limited, while Arab studies related to the topic are a rarity. What the researchers could find in the Arab intellectual output dealt only with the description of lighting and airing in terms of definitions included in studies of library buildings. However, no light was shed on the extent to which the interior environment impacts upon the health of the librarians, and the extent to which this is reflected in their performance.

In the early nineties, the Library of Congress (1991) undertook a study to assess the nature of pathological symptoms the personnel of the Madison Building of the Library in Washington suffer from. The results of the study indicated a close correlation between the symptoms and between the sense of comfort with the temperature and the perception of smells. The study did not observe any environmental pollutants exceeding permissible limits, with the exception of one site, where a high concentration of mould was recorded. Moreover some problems relating to the work-place were observed, such as: uncomfortable seats, long working-hours at computer screens, and insufficient lighting. The conclusion of the study proposed some recommendations for improving the maintenance and ventilation of the building, as well as reducing work pressure.

Concerning SBS in Hong Kong, a questionnaire was distributed in one of the library buildings in Hong Kong as a case study to identify the environmental conditions of the library building, the quality of ventilation in it, and the bacteria spreading in it. Interviews were held with the personnel at the library to identify their true feeling towards the interior environment, and the SBS of the environment in the building. The correlation between three factors was analyzed: the feelings of the staff, the interior environment of the library, and the symptoms perceived by the staff in the library. There was a discrepancy between the views voiced by the library staff, which resulted in the inability to reach definitive conclusions from the study (Au Yeung et al. 1991).

In Britain, a study was conducted on SBS. A questionnaire was prepared for this purpose and sent to all academic libraries in Britain, and a sample of public libraries, to identify the causes leading to SBS in libraries. Through the analysis of the questionnaire outcome, evidence was derived to prove the existence of SBS in the libraries that were included in the study. The results also showed that air-conditioned library buildings are more harmful than library buildings that rely upon natural ventilation (Morris and Dennison 1995).

In Italy, 16 libraries were included in a study aiming at identifying the extent of exposure to collective dust and volatile organic compounds such as Formaldehyde. To this end, data on the temperature, the relative humidity, and ventilation rates inside the libraries were collected, as well as samples of the air inside and outside the buildings of these libraries. The results showed the existence of Formaldehyde concentrations in 10 libraries out of 16. Volative organic compounds were also observed in all the libraries included in the study. There was no correlation between the volatile organic compounds, the formaldehyde and the collective dust (Fantuzzi et al. 1996).

In Northern Italy four libraries were studied to identify the concentration of some pollutants such as dust, formaldehyde and other volative organic compounds, such as benzin, tolouine, and axiline, to assess the environmental condition of these libraries and the extent to which this affects the library users. This study was conducted due to the increase in SBS symptoms which were observed on the people who spend most of their time in various indoor environments. The findings of the study indicated that the library users were uncomfortable. The main reason for this was the bad ventilation. The findings also indicated that the most important symptoms suffered by library users included: feeling hot, eye-inflammations, dry throat, and difficulty breathing (Righi et al. 2002).

For the construction of a healthy library with quality air, an approach has been designed that can be successfully adopted in many cases (Pereira 2004). This approach not only aimed at reducing emissions resulting from construction-materials used in libraries, but also to remove them. This approach consisted of a number of steps: the assessment of the specifications and characteristics of building materials; interviewing the construction workers and the supervisors; analyzing the samples used in construction; the examination of construction materials; and the verification of air quality.

In Egypt, Morshidi (2004) studied the public library of the neighborhood, tackling the criteria for designing library buildings, reviewing the necessary prerequisites in construction materials and interior décor to realize thermal and vocal behavior ideal for such buildings in accordance with international criteria. The study also discussed the technical equipment of the library buildings, including the natural and artificial lighting of various spaces of the building, protecting the building and its holdings from the adverse impact of fluctuating humidity rates, and the prerequisites essential in the case of relying upon the natural ventilation of library buildings. The study also discussed the means for the maintenance and preservation of the library holdings, adequate means of protecting the building against fire-hazards, and safeguarding the building against robbery. However, the study did not touch upon the SBS in library buildings.

In Turkey, a study was conducted on the various environmental aspects of university library buildings, taking the main library of the Yildiz Technical University in Turkey as a case study (Balanli et al. 2007). The survey study started with the distribution of a questionnaire to 22 main libraries affiliated to various Turkish universities. The results of the questionnaire showed that 70% of these libraries have fewer users than expected. To explain the poor number of users, the study focused on environmental aspects of the Yildiz Technical University library building as a case study, aiming to discover the negative effects of the environmental features of the building upon library use.

These previous studies have provided ample evidence and significant lessons on the necessity of paying attention to SBS in library buildings. In this context, these studies reiterated the necessity that SBS in library buildings studies should start by relying upon questionnaires, taking these into consideration to ascertain that library staff suffer from pathological symptoms related to SBS. Hence the current study relies upon a questionnaire to monitor such symptoms. It deals with the environment of the Main Library at SQU, highlighting the symptoms accompanying SBS. In addition to this general objective, the study has a number of more specific objectives, as follows:

1. To throw light upon SBS in library buildings, focusing on the necessity to study and research the issue, in particular in the light of the absence of any relevant Arab studies of the issue.
2. To find out the extent to which the new building of the SQU Library enjoys a better interior environment, in comparison to the interior environment of the old building.
3. To reveal the extent to which the personnel of the SQU Main Library suffer from SBS.
4. To reveal the extent to which the personnel of the SQU Main Library are environmentally aware, and their knowledge of SBS.
5. To set a number of recommendations and solutions that are intended to ameliorate SBS.
6. To enrich the Arab intellectual output specializing on the issue of the interior environment of library buildings.

12.3 Methodology

To realize the goals of this study, it relied on three approaches: a descriptive survey approach to determine the extent to which environmental dimensions have been observed in the building of the SQU Main Library. This is done through a set of tools, most important of which are questionnaires and interviews. The second approach is a case study, which is limited to the study of the SQU Library in both the old and the new buildings. Finally, the comparative approach, to demonstrate the extent to which the interior environment of the SQU new library building has improved in comparison to the old building. The timeframe for conducting the applied aspect of the study extended from January to June 2009. The data for the study was collected via a questionnaire distributed to the library staff. The questionnaire was divided into six sections, the first of which collected personal information on the employee, such as the employee's gender, age, blood-type, academic degree, job-title, smoking habits, work-place inside the library and the number of hours they spend in the building. The second section deals with the evaluation of the work environment by collecting information on the ventilation, the lighting, and the quietness in the building. The third section aims to identify the SBS symptoms suffered by the staff inside the library building. The fourth section seeks to collect data on the degree to which the work environment inside the library building is under control in terms of temperature, ventilation, humidity, lighting, and noise. On the other hand, Sect. 5 collects various information on the internal environment of the library building, whereas Sect. 6 aims to determine the extent to which the study community is aware of SBS in library buildings, as well as to record their comments and observations concerning the main topics covered by the questionnaire. It is worth mentioning that this questionnaire was evaluated by three referees. Their observations were taken into account, and the necessary changes were made.

The total study community consisted of 59 employees, who represent the total number of employees at the SQU Main Library and who received the questionnaire. The total number of questionnaires retrieved was 48, with a loss of 11 questionnaires. Thus the number of retrieved questionnaires was the final total number of the study community.

12.4 Description of the Old and the New Buildings of the Main Library

The old library building of the Main Library was constructed together with the buildings of the Sultan Qaboos University in 1986. It was located amidst the faculty buildings facing the Faculty of Engineering, covering an area of 7,800 m^2. The building consisted of three floors: the ground floor held the technical operations and periodicals sections. The first floor provided the two main entrances to the Library, and held the lending and references sections. There were also two reading halls, one for ladies and one for men. The second floor held the administrative offices, the office of the director of the library, the office for public services and the Oman Room. There were also the book-shelves, where the books were logically arranged on open shelves in accordance with the Library of Congress classification system. In addition there were two large reading halls, one for the ladies and one for the men, as well as two medium-size halls for lectures and meetings.

The new library building was inaugurated in March 2009, and is located amonst the buildings of the Cultural Premises of the University. It faces the University Dome, and is at a distance from the Faculty buildings, unlike the location of the old building, which lay at the heart of the Faculty buildings. It covers an area of 17,600 m^2, and consists of seven floors:

The Basement: It is an underground floor, holding the technical operations section (acquisitions, indexing, classification, and library systems).

The Ground Floor: It starts with the library entrance, and holds the lending and reference service sections. In addition, there are two large reading halls, one for the ladies and one for the men. Immediately behind the lending desk there are the shelves holding the reference sources and academic dissertations. It was observed that the ceiling above the reference shelves was lower than the Ground Floor ceiling. The receptionists and the lending officer share a desk facing the main door to the library. As a result, the personnel are exposed to the direct sunlight flooding in through the huge windows above the main door to the library. This leads to its direct reflection into the eyes of the librarians, and sometimes causes blurred vision.

The Mezzanine Floor: It is located between the Ground Floor and the First Floor, and holds the book shelves, which begin with the code (A-JZ).

The First Floor: It holds the shelves which begin with the code (K-QA706).

The Second Floor: It holds the shelves which begin with the code (Q706-Z). It is noticed that the ceiling in the area designated for book shelves is much lower, which causes severe headaches for the users of these shelves.

The Third Floor: It holds the shelves with back-issues of foreign-language periodicals. To the right there is the office of the library director and his coordinator, and the office of the deputy director for public services and her coordinator. Facing these offices is a small waiting-area to receive visitors. To the left of the floor are the offices of the administrative director and the administrative staff. Next to them are the offices of the periodicals director and the staff of the periodicals section. The floor also includes two reading halls, one for the ladies and one for the men. It is observed that artificial lighting on the floor is poor, and there are only few small windows, which do not allow the passage of sufficient natural light.

The Fourth Floor: It holds the Arabic-language periodicals and recent issues of foreign-language periodicals. This floor is not fully equipped. It includes two large reading halls, one for the ladies and one for the men.

It is worth mentioning here that the Oman Room was moved to another building, and is no longer part of the library sections in the new building. There are also parking areas on a slope to the rear of the library. The disadvantage of this location is the absence of drainage systems, which causes pools of rainwater on the lower walls of the building (the Basement) in the case of heavy rainfall, which occasionally occur in the Sultanate. The accumulation of the water is assisted by the fact that the parking area is on a slope, as mentioned above.

12.5 Results

Table 12.1 shows the personal data and the description of the study community. It illustrates the size of the study community in accordance with the variables of gender (male/female), age, blood type, academic qualification, smoking habits, job-title,

Table 12.1 Personal data of study community (total number of study community = 48)

Data	Number	Percentage (%)	Number of total responses (100%)		Number of unresponsive cases
Gender			48	100%	0
Male	37	77.1			
Female	11	22.9			
Age			44	100%	4
20–30	8	18.2			
31–40	30	68.2			
41–50	4	9.1			
50-	2	4.5			
Blood type			46	100%	2
O	24	52.2			
A	11	23.0			
B	7	15.2			
AB	4	8.7			
Academic qualification			46	100%	2
Secondary	10	21.7			
University	20	43.5			
MA	14	30.4			
PhD	2	4.3			
Smoking habit			46	100%	2
Non-smoker	44	96.6			
Constant	1	2.2			
Rarely	1	2.2			
Occupation employee			48	100%	0
Head of Department	37	77.1			
Deputy Director	8	16.7			
Director	3	6.3			
Work place within the library			48	100%	0
Director's office	1	2.1			
Administration	4	8.3			
Technical operations	17	35.4			
Periodicals	5	10.4			
Library systems	1	2.1			
Public services	2	4.2			
Reference hall	7	14.6			
Interlibrary loan department	9	18.8			
Filing and archiving	2	4.2			
Study community	48	100%			

and work-place within the library. The table illustrates the recurrences and the percentages for the members of the study community in terms of the seven variables shown in the table.

It becomes clear from Table 12.1 that the percentage of males amounted to around three quarters of the study community. This is not in agreement with the usual expectation of an increased percentage of females in the field of librarianship and information sciences (el Areeni 1994). The reason may be that males had a greater chance at receiving an education in comparison to their female peers in the early phases of education in the Omani society. Table 12.1 shows that the age group for most members of the study community was between 31 and 40 years (68.2%). This was followed by the age group between 21 and 30 years (18.2%). This is indicative of the fact that the greater majority of the study community is young people, who have a higher resistance to diseases. The data revealed that more than half the study community belonged to the blood-type O (52.2%), followed by blood-type A (23.9%), B (15.2%), and AB (8.7%). The table also indicated that more than three quarters of the study community were holders of university degrees (43.5%), MA holders (30.4%), and PhD holders (4.3%) versus a percentage of 21.7% of high-school graduates. This is indicative of a high degree of academic knowledge amongst the study community, which realizes the required authenticity for the findings of the research. It is also clear from the data in the table that the majority of the study community were non-smokers (95.6%). Hence it is possible to exclude the health impact of the smoking variable from the findings sought in the current study.

Table 12.1 also illustrates that about a quarter of the study community occupy the post of head of department (16.7%), and deputy head (6.3%), in contrast to 77.1% of the personnel working in the different library departments. The data also revealed that more than a third of the study community work in the technical operations section (35.4%), the second third work in the lending (18.8%) and references (14.6%) sections, whereas the last third is distributed across the remaining departments of the library.

Table 12.2 illustrates the interior environment in both the old and the new library buildings, through a description of a set of variables inside the buildings: ventilation, lighting, noise, and smells. These are the usual variables taken into consideration when studying the causes of SBS (Wyon 1992; Spengler and Samet 2003). The data reported in Table 12.2 indicate the recurrence and the percentage of these variables.

The data reported in Table 12.2 also indicate the clear discrepancy in the percentages of these variables between the old and the new buildings. It is obvious that the air is more sufficient in the new building (71.1%) in comparison to the old building (47.8%). The data also indicate that the air in the new building is drier (45.2%) than the air in the old building (34.9). In comparison, the percentage of humidity in the new building decreased to 22.2% in comparison to the old building (36.4%), while the percentage of dust in the air of the new building (12.8%) was less than that in the old building (22.2%). On the other hand, the new building is

Table 12.2 Evaluation of the work environment (total number of study community = 48)

	The old building			The new building		
	Yes	No	Total	Yes	No	Total
Variables within the building	%	%	100%	%	%	100%
Does the building have sufficient ventilation?	22	24	46	32	13	45
	47.8	52.2	100%	71.1	28.9	100%
Is the air in the building dry?	15	28	43	19	23	42
	34.9	65.1	100%	45.2	54.8	100%
Is the air in the building humid?	16	28	44	10	35	45
	36.4	63.6	100%	22.2	77.8	100%
Is the air in the building very hot?	6	39	45	8	38	46
	13.3	86.7	100%	17.4	82.6	100%
Is the air in the building very cold?	12	33	45	24	21	45
	26.7	73.3	100%	53.3	46.7	100%
Is the lighting adequate?	38	7	45	30	14	44
	84.4	15.6	100%	68.2	31.8	100%
Is the place dark?	6	40	46	14	32	46
	13.0	87.0	100%	30.4	69.6	100%
Is the level of noise in the building reasonable?	26	19	45	38	8	46
	57.8	42.2	100%	82.6	17.4	100%
Does the library have sufficient ventilation?	18	29	47	34	12	46
	38.3	61.7	100%	73.9	26.1	100%
Are there any undesirable smells?	14	31	45	4	42	46
	31.1	68.9	100%	8.7	91.3	100%
Is the air in the building dusty?	10	35	45	6	41	47
	22.2	77.8	100%	12.8	87.2	100%

very cold (53.3%) in comparison with the old building (26.7%). Hence it is possible to conclude that there is a slight improvement in the interior environment of the new building as compared with the old building in terms of sufficient ventilation, humidity, and dust percentage. In this context, the researchers refer to previous studies that discussed the symptoms of SBS in library buildings and their relationship to the changes in environmental variables inside the building, such as temperature (Wyon 1992; Reinikainen and Jaakkola 2001), relative humidity (Reinikainen et al. 1991; Reinikainen and Jaakkola 2001), and ventilation (Godish and Spengler 1996; Wargocki et al. 2002).

On the contrary, it was observed that the percentage of lighting in the new building (68.2%) was less than that in the old building (84.4%). This may be due to the lesser area of windows allowing natural light in on most floors of the new building, in particular the basement and the upper floors, in addition to the poor artificial lighting in most parts of the building. The findings showed that the new building was calmer than the old one, where the percentage of quietness in the new building was 73.9% while it was only 38.3% in the old building. On the other hand, the data illustrated the high percentage of undesirable smells in the old building (31.1%) in comparison to the new building (8.7%).

Table 12.3 Pathological symptoms in the building (total number of study community = 48)

		The old building		The new building	
Serial	Symptoms	Number	%	Number	%
1.	Dry throat	13	27.1	15	31.3
2.	Headache	16	33.3	9	18.8
3.	General weakness accompanied by Dizziness	12	25.0	6	12.5
4.	Fainting	3	6.3	0	0.0
5.	Insomnia or difficulty in sleeping	5	10.4	4	8.3
6.	Nose congestion	13	27.1	17	35.4
7.	Problems with sinuses	17	35.4	11	22.9
8.	Dryness of the nose	5	10.4	3	6.3
9.	Irritation of the eyes	16	33.3	10	20.8
10.	Dryness of the eyes	7	14.6	5	10.4
11.	Difficulty breathing	4	8.3	7	14.6
12.	Chronic cough	4	8.3	3	6.3
13.	Bronchitis	6	12.5	6	12.5
14.	Laryngitis	6	12.5	9	18.8
15.	Blurred vision	9	18.8	7	14.6
16.	Skin diseases (Eczema, rash, itching)	7	14.6	3	6.3
17.	Fatigue and lethargy	12	25.0	8	16.7
18.	Easily tired and worn-out	15	31.3	9	18.8
19.	Difficulty in concentration	9	18.8	6	12.5
20.	Nausea and vertigo	2	4.2	5	10.4
21.	Drowsiness	9	18.8	8	16.7
22.	Mood swings	11	22.9	11	22.9
23.	Other symptoms (specify)	2	4.2	1	2.1

Table 12.3 indicates the most prominent SBS symptoms suffered by the library personnel in both the old and the new buildings. It can be seen that some symptoms may vary, while others are constant symptoms particular to each building. The findings showed that the most prominent symptoms of SBS in the old building are: sinusitis (35.4%), eye inflammation (33.3%), headache (33.3%), rapid feelings of exhaustion and fatigue (31.3%), throat dryness (27.1%), weariness and laziness (25.0%), and general weakness and dizziness (25.0%). The most prominent symptoms of SBS in the new building are: nasal congestion (35.4%), throat dryness (31.3%), sinusitis (22.9%), eye inflammation (20.8%), mood swings (22.9%), laryngitis (18.8%), and headache (18.8%). These findings are indicative of the fact that the study community members suffer from some pathological symptoms in the new building despite its newness.

In the same context, Table 12.3 illustrates the extent to which SBS symptoms in library buildings have been reduced after the transfer of the library personnel from the old to the new building. Comparing the data in Table 12.3, it becomes clear that these symptoms did not vanish in the new building nor were they even reduced in number. The difference was only a variation in their percentage. There is no doubt that there was a decrease in the percentage of some of the pathological symptoms particular to the old building when the personnel were moved to the new building, such as headaches which reduced from 33.3 to 18.8%, sinusitis from 35.4 to 22.9%, and eye inflammation from 33.3 to 20.8%.

However, this did not prevent the increase in the percentages of pathological symptoms particular to the new building, in comparison to the old building, such as nasal congestion from 27.1 to 35.4%, throat dryness from 27.1 to 31.3%, laryngitis from 12.5 to 18.8%, and breathing difficulties from 8.3 to 14.6%. This comes in agreement with what Righi et al. (2002) reported in their study, which stated that the most important symptoms suffered by the library users were dryness of the throat, eye inflammation and breathing difficulties.

Table 12.4 is an extension of Table 12.3 which ascertain the extent to which the old and the new buildings suffer from SBS, by attaining evidence that proves that the symptoms suffered by the personnel in Table 12.3 are merely symptoms correlated with their presence inside the building, and that these symptoms decrease or disappear when they leave the building. The results of Table 12.4 indicate that the SBS symptoms are experienced by the library personnel only inside the building at a percentage of 62.5% in the old building, and 44.8% in the new building. Accordingly it is possible to claim that both the old and the new library buildings suffer from SBS. This is supported by the employees who pointed out that they did not experience these symptoms once they left the old building (69.6%) and the new building (80.8%). It is also supported by the fact that they do not experience these symptoms on their holidays (79.2%) in the old building and at a higher percentage (92.3%) in the new building.

Table 12.4 Further questions about the symptoms (total number of study community = 48)

	The old building			The new building		
	Yes	No	Total	Yes	No	Total
The questions	%	%	100%	%	%	100%
Do you only suffer from these symptoms inside the building?	20 62.5	12 37.5	32 100%	13 44.8	16 55.2	29 100%
Do you suffer from these symptoms in a particular area of the building?	9 45.0	11 55.0	20 100%	8 30.8	18 69.2	26 100%
Do these symptoms affect your work capacity and cause an increase in your absenteeism?	10 40.0	15 60.0	25 100%	12 44.4	15 55.6	27 100%
Do you suffer from these symptoms after you have left the building?	7 30.4	16 69.6	23 100%	3 19.2	21 80.8	26 100%
Do you suffer from these symptoms on your days-off?	5 20.8	19 79.2	24 100%	2 7.7	24 92.3	26 100%
Do the symptoms abate if the windows of the building are open?	14 66.7	7 33.3	24 100%	15 65.2	8 34.8	23 100%
Do the symptoms abate if plants are put in the workplace?	8 38.1	13 61.9	21 100%	10 40.0	15 60.0	25 100%

Table 12.4 also provides the extent to which SBS in library buildings impact the decrease in work-efficiency and the increase in absentism. The data in the table show that these symptoms influence the work efficiency of 40.0% of the study community in the old building, and leads to an increase of absentism. The percentage is very similar to that of the new building (44.4%). Hence the impact of SBS on the performance of the staff in the library, whether in the old or the new building, is illustrated. This result is in agreement with the findings of previous studies (Raw 1994; Seppanen 1999; Fisk 2000; Balanli et al. 2007). Table 12.4 also highlights that the suffering of the personnel from these symptoms decreases when windows are opened in both the old and the new buildings. The table indicates a percentage of 66.7% of the study community in the old building and 65.2% in the new building. These figures are rather high and close in both buildings, emphasizing the importance of ventilation and its positive impact on the improvement of the interior environment of the library building. This was reiterated in previous studies (Morris and Dennison 1995; Wargocki et al. 2002). It is important to remember that if open windows are essential for ventilation, the open windows should be covered with screens to prevent insects and dust. These screens should also be removable, so as to be washed regularly. The symptoms also decrease when plants are placed in the work area. The percentage of personnel in agreement reached 38.1% in the old building and 40.0% in the new building. These are some of the measures recommended by previous studies, in particular using certain plants such as daisies and taro plants. These plants absorb the gases emitted by the furniture, the paint and the mould (Niemelä et al. 2006).

Table 12.5 illustrates the possibility of controlling the interior climate of both the old and the new buildings. The data in the table indicate the decrease in the possibility of controlling the temperature in the new building (34.5%) in comparison to the old building (87.5). This explains the complaints put forth by the employees

Table 12.5 The degree of control over the work environment (total number of study community = 48)

	The old building			The new building		
	Yes	No	Total	Yes	No	Total
Variables within the building	%	%	100%	%	%	100%
Can the degree of heat in the building be controlled?	40 87.0	6 13.0	46 100%	16 34.0	31 66.0	47 100%
Can the ventilation in the building be controlled?	25 54.3	21 45.7	46 100%	17 36.2	30 63.8	47 100%
Can the humidity in the building be controlled?	15 32.6	31 67.4	46 100%	11 24.4	34 75.6	45 100%
Can the lighting in the building be controlled?	34 75.6	11 24.4	45 100%	25 54.3	21 45.7	46 100%
Can the level of noise in the building be controlled?	18 39.1	28 60.9	46 100%	24 53.3	21 46.7	45 100%

in the new building concerning the excessive coldness they suffer from, as shown in Table 12.2. Ideally speaking, the temperature should be controllable to range between 20 and 21°C. This temperature range is indicated as being bearable by both the library staff and users, and being adequate for most library holdings (Niso 2001). It is important to take into account that it is sometimes difficult to attain this temperature range in the Sultanate of Oman, in particular in the Capital, Muscat, due to the high humidity. This is applicable to the decrease in the possibility of controlling the temperature in the new building and the possibility of controlling the ventilation. The percentage of controlling ventilation in the new building is 36.2% while it is 54.3% in the old building. This is due to the fixed windows in the new building, designed to be kept closed. The percentage of controlling humidity in the new building is 24.4% in comparison to 32.6% in the old building. It is worth mentioning that some employees pointed to the high rate of humidity in the corners of some of the rooms in the new building.

In terms of the possibility to control lighting, Table 12.5 shows that it decreases in the new building (54.3%) in comparison to the old building (75.6%), in accordance with Table 12.2. The table illustrates that the percentage of controlling the degree of noise in the new building (53.3%) is higher than that in the old building (39.1%). This explains the results of Table 12.2 stating that the new building is quieter than the old building.

Table 12.6 disusses further relevant aspects that should be examined when studying the interior environment of buildings (Bass et al. 2003; Norbäck and Nordström 2008). The results reported by Table 12.6 can be summarized in the following points:

- Higher condensation of humidity on the walls and windows of the old building (34.8%) in comparison to the new building (14.9%). The condensation of humidity on the walls and windows can be reduced by lowering the humidity rate inside the library building. For this purpose the recommended rate of humidity falls between 30 and 50% (Niso 2001). Also, reduced regular ventilation at 37.0% was observed in the old building, a percentage very close to that of the new building (34.1%). Higher mildew and mould were observed in the old building (34.8%) than in the new building (20.5%). A high percentage of the study community indicated that windows and doors were not opened in the new building (85.1%) and the old building (70.2%). A higher percentage of the study community reported that the old building (93.3%) and the new building (91.5%) did not contain a separate ventilation system particular for the photocopying machines. This is predicted to contribute to a heightened concentration of emissions from these machines, which is not ameliorated directly and rapidly. It is also worth indicating that mildew mainly form as a result of high humidity and the lack of fresh air flow in the area. Mildew forms on humid surfaces, including materials such as paper and book-covers, causing their damage. The cleanliness of storage areas and keeping the materials in good condition is of great importance, since dust and dirt damage the materials and provide a rich environment for mildew formation (Niso 2001).

Table 12.6 Diverse questions (total number of study community = 48)

	The old building			The new building		
	Yes	No	Total	Yes	No	Total
The Questions	%	%	100%	%	%	100%
Are there any indication in the building such as condensation of humidity on the walls and windows?	16 34.8	30 65.2	46 100%	7 14.9	40 85.1	47 100%
Are there smart curtains that self-lock in the case of a fire breaking out to prevent it from spreading throughout the building?	5 10.6	43 89.4	47 100%	3 6.8	41 93.2	44 100%
Is there systematic ventilation?	17 37.0	29 63.0	46 100%	15 34.1	29 65.9	44 100%
Are the windows and doors opened to improve the flow of air?	14 29.8	33 70.2	47 100%	7 14.9	40 85.1	47 100%
Does the building have a separate, ventilation system designated for photocopying areas?	3 6.7	42 93.3	45 100%	4 8.5	43 91.5	47 100%
Is the building designed to allow natural light in?	26 59.1	18 40.9	44 100%	30 68.2	14 31.8	44 100%
Is the building designed to allow sun rays in?	32 69.6	14 30.4	46 100%	32 71.1	13 28.9	45 100%
Is the furniture arranged so as to allow natural light in?	28 60.9	18 39.1	46 100%	35 83.3	7 16.7	42 100%
Are the ventilation filters that hold back particles regularly cleaned?	26 66.7	13 33.3	39 100%	26 66.7	13 33.3	39 100%
Are the furniture and shelves of the library dusted?	35 76.1	11 23.9	46 100%	31 68.9	14 31.1	45 100%
Have you noticed mildew and mould in the library?	16 34.8	30 65.2	46 100%	9 20.5	35 79.5	44 100%
Are the air conditioners cleaned, maintained and dusted?	39 83.0	8 17.0	47 100%	25 65.8	13 34.2	38 100%
Is the carpet in your office cleaned?	35 83.3	7 16.7	42 100%	25 65.8	13 34.2	38 100%
Are chemical detergents used by the library?	40 90.9	4 9.1	44 100%	34 82.9	7 17.1	41 100%
Are pesticides (for insects, ants, rats) used by the library?	26 70.3	11 29.7	37 100%	19 63.3	11 36.7	30 100%
Is the building regularly sprayed?	23 60.5	15 39.5	38 100%	14 46.7	16 53.3	30 100%
Is the area ventilated after spraying or the use of pesticides?	18 46.2	21 53.8	39 100%	14 50.0	14 50.0	28 100%
Do you suffer from particular symptoms directly after the place has been sprayed?	9 36	16 64.0	25 100%	5 22.7	17 77.3	22 100%

- The design of the new building allows a greater percentage of natural lighting (68.2%) than the old building (59.1%). It also allows for more sunlight (71.1%) than the old building (69.6%). It was also observed that the furniture distribution in the new building allows a higher percentage of natural light penetration (83.3%) than the old building (60.9%). However, the researcher observed on their visit to the new library building the strong natural lighting and the penetrating sun entering through the large window panes to the front of the building on the ground floor. On the other hand, the strength of natural lighting decreases on the upper floors of the building due to the smaller size of the windows, which prevents sufficient natural light from entering. It was also observed that the area designated for book-shelves in the new building has a low ceiling, and the spaces between the shelves are very narrow, which does not allow for sufficient natural lighting to penetrate. Matters were made worse due to limited artificial lighting. Moreover, the shelves-users soon suffer from headaches due to the bad ventilation.
- An increase in the cleaning and maintenance of air-conditioners, significantly removing dust from them in the old building (83.0%), higher than in the new building (65.8%). Previous studies have indicated the existence of a close correlation between SBS in library buildings and the lack of maintenance of air conditioning systems in these buildings, as well as neglecting the regular cleaning of carpets (Wargocki et al. 2002).
- A higher percentage of use of detergents in the cleaning of the new building (90.9%) in comparison to the old building (82.9%). The data also indicated that the old building was regularly sprayed (60.5%), at a rate higher than in the new building (46.7%). These data showed that the percentage of ventilation of the area after spraying is relatively higher in the new building (50.0%) than in the old building (46.2%). The symptoms that the employees experienced after the spraying were relatively few reaching 36.0% in the old building and 22.7% in the new building.

  Table 12.7 shows the pathological symptoms in both the old and the new buildings in terms of gender (male/female). Reading the data and percentages in the Table, the following indicators were concluded:
- Males complained of 22 pathological symptoms or signs in the new building and of all pathological symptoms (23 symptoms) in the old building. The number of these symptoms decreased with the females to 18 symptoms in the old building and 19 symptoms in the new building, i.e. the increase of only one symptom in the new building.
- Comparing the symptoms affecting the males and the females, it was observed that there is a great similarity in the most prominent of pathological symptoms affecting either gender whether in the old or the new building. These symptoms included: sinusitis, eye inflammation, headache, rapid fatigue and exhaustion, and dryness of the throat.
- There are pathological symptoms in the old building affecting males at a higher rate than females, namely: dryness of the eyes, blurred vision, fatigue and laziness. However, it was observed that in the new building the rate of females complaining of the self-same symptoms was higher than that of the males. Other

Table 12.7 Pathological symptoms in the building according to gender (total number of study community = 48)

		The old building			The new building		
		Male	Female	Total	Male	Female	Total
Serial	Symptoms	%	%	100%	%	%	100%
1.	Dryness of the throat	10 76.9	3 23.1	13 100%	10 66.7	5 33.3	15 100%
2.	Headache	12 75.0	4 25.0	16 100%	6 66.7	3 33.3	9 100%
3.	General weakness accompanied by dizziness	9 75.0	3 25.0	12 100%	5 83.3	1 16.7	6 100%
4.	Fainting	3 100.0	0 0.0	3 100%	0 0.0	0 0.0	0 100%
5.	Insomnia or difficulty in sleeping	4 80.0	1 20.0	5 100%	2 50.0	2 50.0	4 100%
6.	Nose congestion	10 76.9	3 23.1	13 100%	15 88.2	2 11.8	17 100%
7.	Problems with sinuses	13 76.5	4 23.5	17 100%	8 72.7	3 27.3	11 100%
8.	Dryness of the nose	5 100.0	0 0.0	5 100%	2 66.7	1 33.3	3 100%
9.	Irritation of the eyes	12 75.0	4 25.0	16 100%	7 70.0	3 30.0	10 100%
10.	Dryness of the eyes	6 85.7	1 14.3	7 100%	3 60.0	2 40.0	5 100%
11.	Difficulty breathing	3 75.0	1 25.0	4 100%	6 85.7	1 14.3	7 100%
12.	Chronic cough	4 100.0	0 0.0	4 100%	3 100.0	0 0.0	3 100%
13.	Bronchitis	5 83.3	1 16.7	6 100%	5 83.3	1 16.7	6 100%
14.	Laryngitis	5 83.3	1 16.7	6 100%	7 77.8	2 22.2	9 100%
15.	Blurred vision	8 88.9	1 11.1	9 100%	3 42.9	4 57.1	7 100%
16.	Skin diseases (Eczema, rash, itching)	5 71.4	2 28.6	7 100%	2 66.7	1 33.3	3 100%
17.	Fatigue and exhaustion	11 91.7	1 8.3	12 100%	5 62.5	3 37.5	8 100%
18.	Easily tired and worn-out	11 73.3	4 26.7	15 100%	6 66.7	3 33.3	9 100%
19.	Difficulty in concentration	9 100.0	0 0.0	9 100%	4 66.7	2 33.3	6 100%
20.	Nausea and dizziness	1 50.0	1 50.0	2 100%	5 100.0	0 0.0	5 100%
21.	Drowsiness	6 66.7	3 33.3	9 100%	5 62.5	3 37.5	8 100%8
22.	Mood swings	8 72.7	3 27.3	11 100%	6 54.5	5 45.5	11 100%

symptoms became prominent in the females, such as: dryness of the throat and mood swings.

- From a different aspect, the findings in the old building resulted in pathological symptoms at a rate higher in females than in males, such as: rapid fatigue and exhaustion, drowsiness, and mood swings. It was also observed that the rate of complaint amongst females of the self-same symptoms was higher than amongst males in the new building.
- The females complained of some new pathological symptoms in the new building, such as difficulties in concentration and nasal dryness. Females did not complain of these symptoms in the old building.
- An overall reading of the findings in the table shows that the rate of complaints of various pathological symptoms in the new building decreased in comparison to the old building. Among these symptoms were: sinusitis, eye inflammation, and rapid fatigue and exhaustion. This did not prevent their disappearance, but in fact led to an increase in their manifestation in females more than in males. This is decisive evidence as to the fact that environmental principles were not observed when designing the new building.

Table 12.8 identifies the pathological symptoms suffered by the personnel in accordance with their blood types. The findings indicate that the members of the study community with blood type A, suffered from all symptoms, whether in the old or the new buildings. These are followed by blood type O members, whereas it was observed that members with blood type B suffered less from these symptoms,

Table 12.8 The majority of symptoms in the building according to blood type (total number of study community = 48)

Blood type	The majority of symptoms in the old building	The majority of symptoms in the new building
O	Headache Irritation of the eyes Problems with sinuses Congestion of the nose	Dryness of the throat Congestion of the nose Headache Mood swings
A	Problems with sinuses Dryness of the throat Difficulty in concentration Bronchitis	Congestion of the nose Dryness of the throat Problems with sinuses Laryngitis
B	Irritation of the eyes Problems with sinuses Dryness of the throat Congestion of the nose	Dryness of the throat Irritation of the eyes Mood swings Drowsiness
AB	Problems with sinuses Congestion of the nose Difficulty in concentration Irritation of the eyes	Congestion of the nose Problems with sinuses Dryness of the eyes Irritation of the eyes

whether in the old or the new buildings. Table 12.8 illustrates the four most important pathological symptoms suffered by each blood group. In the light of the givens reported in this table, we conclude the following indicators:

- The complaints of all four blood-type carriers were in agreement in terms of the common symptoms suffered in the old building, such as sinusitis, followed by nasal congestion and eye inflammation. At the same time, other symptoms become prominent in the new building, such as throat dryness, suffered by blood types O, A, and B, and nasal congestion suffered by blood types AB, A and O.
- Comparing the pathological symptoms of each blood type, the difference in the most prominent symptoms of each blood type is observed in both the old and new building. In the old building, headache comes at the top of the symptoms particular to blood type O, whereas sinusitis is the most prominent pathological symptom particular to blood type A and AB, and eye inflammation particular to blood type B.
- In the new building other pathological symptoms particular to each blood type appeared. Throat dryness is considered one of the most prominent pathological symptoms of the blood types O and B, whereas nasal congestion is particular to the blood types AB and A.
- It was observed that there were some pathological symptoms suffered by the personnel whether in the old or the new building. It was observed that these symptoms were closely related to the blood type of the carrier. For example, headache and nasal congestion were complaints of blood-type O carriers. Sinusitis and dryness of the throat were complaints of blood-type AB and A carriers. Blood-type B carriers complained of dryness of the throat and the increase in another pathological symptom, namely eye inflammation.

Tables 12.9 and 12.10 identify the most prominent pathological symptoms in accordance to the workplace in both the old and the new buildings, and whether there was a decrease in these symptoms after the transfer to the new building. By reading and comparing the givens in the Tables 12.9 and 12.10, the following becomes obvious:

- There are departments in the library where the personnel do not complain of any pathological symptoms, whether in the old or the new buildings. These departments are: the director's office, the administration and the library systems. This is due to the vast spaces enjoyed by these departments and the constant care for their cleanliness and ventilation. This is in agreement with the findings of previous studies (Eriksson and Stenberg 2006). It was also observed that there were no complaints of any symptoms suffered by the employees of the Public Services Section in the new building. It is worth mentioning that the workers in these departments occupy the posts of deputy managers and heads of departments.
- There are departments in the old building where the complaints of the personnel of most symptoms increase. Foremost is the lending section (20 pathological

Table 12.9 Pathological symptoms in the old building according to the workplace (total number of study community = 48)

Symptoms	Director's office	Administration	Technical operations	Periodicals	Library systems	Public services	Reference hall	Interlibrary loan dep.	Filing and archiving	Total
Dryness of the throat			6 (46.2)	3 (23.1)				4 (30.8)		13 (100%)
Headache			5 (31.3)			1 (6.3)	3 (18.8)	5 (31.3)	2 (12.5)	16 (100%)
General weakness accompanied by dizziness			4 (33.3)	1 (8.3)		1 (8.3)	3 (25)	3 (25)		12 (100%)
Fainting				1 (33.3)				2 (66.7)		3 (100%)
Insomnia or difficulty in sleeping			1 (20.0)	1 (20.0)			1 (20.0)	2 (40.0)		5 (100%)
Nose congestion			7 (53.8)	2 (15.4)		1 (7.7)	1 (7.7)	2 (15.4)		13 (100%)
Problems with sinuses			9 (52.9)	1 (5.9)		1 (5.9)	3 (17.6)	3 (17.6)		17 (100%)
Dryness of the nose			1 (20.0)				1 (20.0)	3 (60.0)		5 (100%)
Irritation of the eyes			8 (50.0)	1 (6.3)		1 (6.3)	2 (12.5)	4 (25.0)		16 (100%)
Dryness of the eyes			3 (42.9)	1 (14.3)			1 (14.3)	1 (14.3)	1 (14.3)	7 (100%)
Difficulty breathing			3 (75.0)				1 (25.0)			4 (100%)
Chronic cough			1 (25.0)	1 (25.0)				1 (25.0)	1 (25.0)	4 (100%)
Bronchitis			4 (66.7)					2 (33.3)		6 (100%)
Laryngitis			4 (66.7)	1 (16.7)					1 (16.7)	6 (100%)
Blurred vision			2 (22.2)				3 (33.3)	4 (44.4)		9 (100%)

Table 12.10 Pathological symptoms in the new building according to the workplace (total number of study community = 48)

Symptoms	Director's office	Administration	Technical operations	Periodicals	Library systems	Public services	Reference hall	Interlibrary loan dep.	Filing and archiving	Total
Dryness of the throat			9 (60.0)				1 (6.7)	4 (26.7)	1 (6.7)	15 (100%)
Headache			3 (33.3)	1 (11.1)				5 (55.6)		9 (100%)
General weakness accompanied by dizziness			2 (33.3)				1 (16.7)	3 (50.0)		6 (100%)
Fainting										
Insomnia or difficulty in sleeping			2 (50.0)					2 (50.0)		4 (100%)
Nose congestion			6 (35.3)	1 (5.9)			2 (11.8)	6 (35.3)	2 (11.8)	17 (100%)
Problems with sinuses			6 (54.5)	1 (9.1)			2 (18.2)	2 (18.2)		11 (100%)
Dryness of the nose				1 (33.3)			1 (33.3)	1 (33.3)		3 (100%)
Irritation of the eyes			5 (50.0)	1 (10.0)				3 (30.0)	1 (10.0)	10 (100%)
Dryness of the eyes			2 (40.0)	1 (20.0)				2 (40.0)		5 (100%)
Difficulty breathing			2 (28.6)	1 (14.3)			2 (28.6)	2 (28.6)		7 (100%)
Chronic cough							1 (33.3)	1 (33.3)	1 (33.3)	3 (100%)
Bronchitis			3 (50.0)	1 (16.7)			1 (16.7)		1 (16.7)	6 (100%)

Table 12.10 (continued)

Symptoms	Director's office	Administration	Technical operations	Periodicals	Library systems	Public services	Reference hall	Interlibrary loan dep.	Filing and archiving	Total
Laryngitis			2 (22.2)	1 (11.1)			2 (22.2)	3 (33.3)	1 (11.1)	9 (100%)
Blurred vision			5 (71.4)	1 (14.3)			1 (14.3)			7 (100%)
Skin diseases (Eczema, rash, itching)			1 (33.3)				1 (33.3)	1 (33.3)		3 (100%)
Fatigue and lethargy			3 (37.5)	1 (12.5)			1 (12.5)	3 (37.5)		8 (100%)
Easily tired and worn-out			4 (44.4)	1 (11.1)				3 (33.3)	1 (11.1)	9 (100%)
Difficulty in concentration			1 (16.7)				1 (16.7)	4 (66.7)		6 (100%)
Nausea and vertigo				1 (20.0)			1 (20.0)	3 (60.0)		5 (100%)
Drowsiness			4 (50.0)					4 (50.0)		8 (100%)
Mood swings			5 (45.5)	1 (9.1)			1 (9.1)	3 (27.3)	1 (9.1)	11 (100%)
Other symptoms (specify)								1 (100.0)		1 (100%)

symptoms), followed by the technical operations (19 symptoms), then the references section (16 symptoms), and finally the journals section (13 symptoms). On the other hand, the number of symptoms suffered by the personnel of the Public Services Department (8 symptoms), the Filing and Archiving Department (6 symptoms) would decrease. In comparison with the new building, it becomes obvious that the number of these symptoms did not decrease except by minimal rates. The number of symptoms decreased to 18 symptoms in the Technical Operations Department, to 15 symptoms in the References Department, whereas their number increased in the Journals Department to 14 symptoms, and 8 symptoms in the Filing and Archiving Department.

- There are other prominent symptoms in each library department in the old building, the percentages of which changed in the new building. In the Technical Operations Department in the old building, for instance, there were symptoms such as bronchitis, breathing difficulties, laryngitis, and nasal congestion, as the most prominent pathological symptoms. In comparison, in the new building a decrease in the percentage of these symptoms was observed, and an increase in the percentage of other symptoms such as sinusitis, dryness of the throat, and blurred vision. It is worth indicating here the poor location of the Technical Operations Department on the ground floor of the old building, which became worse when this department was moved to the basement in the new building. This floor is characterized by a low ceiling, the limited area of windows, and the low percentage of ventilation and natural light. It was observed that the complaints of the workers in the Lending Department increased in regard to nasal dryness, blurred vision and difficulties in concentration. Conditions did not improve with the move to the new building. Despite the low percentage of some symptoms such as nasal dryness, and the absence of complaints of some other symptoms such as bronchitis, and blurred vision. However, there are other symptoms complaints of which increased, such as headaches, eye dryness, and skin diseases. On the other hand, symptoms of skin diseases, blurred vision, and mood swings as major pathological symptoms appeared in the References Section. Percentages of these symptoms in the new building are less, yet other symptoms such as nasal dryness, chronic coughing, and breathing difficulties appear, whereas complaints of some other symptoms disappeared, such as dryness of the throat and bronchitis. This is due to the change of the place of the Journals Section in the new building, where it now occupied the third floor, having previously held the ground floor in the old building. It was also observed that the workers in the Public Services Department did not complain of any pathological symptoms after their move to the new building. This may be due to the change in their work place in the new building where they are now on the third floor, next to the director's office. They had previously been in the basement (the underground floor) in the old building. The Technical Operations Department saw the highest percentage of complaints of the majority of pathological symptoms, whether in the old or the new buildings.

Tables 12.11 and 12.12 identify the extent of differences between the interior work environments in each library department. The two Tables describe the interior

Table 12.11 Evaluation of the work environment in the old building according to the workplace (total number of study community = 48)

Variables within the workplace	Director's office	Administration	Technical operations	Periodicals	Library systems	Public services	Reference hall	Interlibrary loan dept.	Filing and archiving	Total
Does the building have sufficient ventilation?		1 (4.5)	10 (45.5)	3 (13.6)	1 (4.5)		2 (9.1)	4 (18.2)	1 (4.5)	22 (100%)
Is the air in the building dry?		1 (6.7)	5 (33.3)	2 (13.3)			2 (13.3)	5 (33.3)		15 (100%)
Is the air in the building humid?	1 (6.3)	2 (12.5)	4 (25.0)	3 (18.8)		1 (6.3)	4 (25.0)	1 (6.3)		16 (100%)
Is the air in the building very hot?		1 (16.7)		1 (16.7)		1 (16.7)	2 (33.3)	1 (16.7)		6 (100%)
Is the air in the building very cold?		1 (8.3)	8 (66.7)				1 (8.3)	2 (16.7)		12 (100%)
Is the lighting adequate?	1 (2.6)	3 (7.9)	16 (42.1)	4 (10.5)	1 (2.6)	1 (2.6)	5 (13.2)	7 (18.4)		38 (100%)
Is the place dark?		2 (33.3)	1 (16.7)				1 (16.7)	2 (33.3)		6 (100%)
Is the level of noise in the building reasonable?	1 (3.8)	2 (7.7)	12 (46.2)	4 (15.4)	1 (3.8)		2 (7.7)	2 (7.7)	2 (7.7)	26 (100%)
Does the library have sufficient ventilation?		1 (5.6)	9 (50.0)	1 (5.6)	1 (5.6)		2 (11.1)	2 (11.1)	2 (11.1)	18 (100%)
Are there any undesirable smells?		2 (14.3)	4 (28.6)	1 (7.1)		2 (14.3)	2 (14.3)	2 (14.3)	1 (7.1)	14 (100%)
Is the air in the building dusty?			4 (40.0)	2 (20.0)			1 (10.0)	2 (20.0)	1 (10.0)	10 (100%)

Table 12.12 Evaluation of the work environment in the new building according to the workplace (total number of study community = 48)

Variables within the workplace	Director's office	Administration	Technical operations	Periodicals	Library systems	Public services	Reference hall	Interlibrary loan dep.	Filing and archiving	Total
Does the building have sufficient ventilation?	1 (3.1)	4 (12.5)	6 (18.8)	5 (15.6)	1 (3.1)	2 (6.3)	6 (18.8)	6 (18.8)	1 (3.1)	32 (100%)
Is the air in the building dry?		2 (10.5)	6 (31.6)	2 (10.5)		1 (5.3)	3 (15.8)	5 (26.3)		19 (100%)
Is the air in the building humid?		1 (10.0)	2 (20.0)	2 (20.0)	1 (10.0)		3 (30.0)	1 (10.0)		10 (100%)
Is the air in the building very hot?			7 (87.5)	1 (12.5)						8 (100%)
Is the air in the building very cold?		1 (4.2)	7 (29.2)			2 (8.3)	7 (29.2)	5 (20.8)	2 (8.3)	24 (100%)
Is the lighting adequate?	1 (3.3)	3 (10.0)	7 (23.3)	5 (16.7)	1 (3.3)	2 (6.7)	6 (20.0)	4 (13.3)	1 (3.3)	30 (100%)
Is the place dark?		1 (7.1)	7 (50.0)	1 (7.1)			1 (7.1)	2 (14.3)	2 (14.3)	14 (100%)
Is the level of noise in the building reasonable?		3 (7.9)	15 (39.5)	5 (13.2)	1 (2.6)	2 (5.3)	6 (15.8)	5 (13.2)	1 (2.6)	38 (100%)
Does the library have sufficient ventilation?	1 (2.9)	4 (11.8)	11 (32.4)	4 (11.8)	1 (2.9)	2 (5.9)	5 (14.7)	4 (11.8)	2 (5.9)	34 (100%)
Are there any undesirable smells?			4 (100.0)							4 (100%)

environment of the library departments in both the old and the new buildings in terms of ventilation, lights, quietness and smells. Reading and comparing the data on both the old and the new buildings reported in each table, the following set of indicators was concluded:

- All departments in the new building stated that there was sufficient air. However, complaints of the coldness of the air increased in six departments in the new building in comparison to only four in the old building. On the other hand, complaints of the heat were concentrated in the Technical Operations and the Journals Departments in the new building. Meanwhile the percentage of complaint of humidity decreased in six departments in the new building, in comparison to seven departments in the old building.
- All the departments in the new building agreed that the lighting was adequate. At the same time complaints of the place being gloomy increased in the Technical Operations Department in the new building in comparison to the old one. This is due to the poor artificial lights distribution in some places of the new building, where lights are abundant in some parts but absent from others.
- The perception of quietness in the new building increased and the highest percentage came from the Technical Operations Department in the new building. This is considered an advantage since the employees in this department need a high level of concentration to perform their tasks.
- The percentage of complaints of undesirable smells increased in the old building, in particular in the Technical Operations Department, followed by the Lending and References Departments. On the contrary, there are no complaints of undesirable smells in all departments of the library in the new building, with the exception of the Technical Operations Department. The employees of the department explained it in terms of the smells particular to new buildings, namely the paint vapours, and the glue used for woods or carpet-fixing. These smells are of extreme danger to human health and the experience of SBS in library buildings. This was pointed out by some studies, maintaining that 30% of the new building population in fact does suffer from SBS (Righi et al. 2002). A comprehensive reading of the two tables illustrates some aspects of the interior environment of some departments in the new building, in terms of the smells, reduced dust in the air, increased percentage of quietness, whereas complaints increased of the coldness of the air, and the experience of heat increased in the Technical Operations and Journals departments.

The two researchers also attempted to determine the extent to which the library employees are aware of SBS in library building. The analysis of the questionnaire data showed that a great percentage of the study community (91.5%) do not have any idea or knowledge about this disease. This may be ascribed to the lack of Arabic studies dealing with this issue, and the fact that architectural designers of library buildings disregard the environmental dimension and the healthiness of the interior environment of library buildings, focusing only on the economic dimension. The findings illustrated through the questionnaire that three individuals of the study community have pointed out their personal efforts to understand SBS in library buildings. On the other hand, a librarian maintained his knowledge of this issue, having completed a PhD dissertation in a foreign country. He also praised the attention paid by foreign governments to the observation of the soundness of the interior environment of library buildings, paying environmental allowances added to the pay-checks of the librarians.

The last part of the questionnaire contained an open question, through which the librarians could express their personal view concerning the items mentioned in the questionnaire or on their personal impressions of the interior environment of the new building. These observations focused upon ventilation, cleanliness, noise, coldness, lighting, and equipment. These observations stress upon the existence of problems relating to the design and furnishing of the new building, which reflect upon the soundness of the interior environment which had a direct impact upon the individuals of the study community who experience the symptoms of SBS in library buildings. This in turn is predicted to affect the efficiency of the librarian in accomplishing his/her tasks. The observations of the study community may be summarized in the following points:

Ventilation:

- The importance of paying attention to the renewal of air inside the new building.
- Providing the librarians with the ability to control the opening of windows aiming at renewing the air inside the offices.
- The importance of ventilation in the toilettes.
- The importance of paying attention to ventilation in the Technical Operations Department since this department is located in the basement (the underground floor).

Cleanliness:

- The importance to pay attention to the constant cleanliness of the new building.
- The importance of cleaning the books, journals and references on a daily basis, to avoid the accumulation of dust.
- To use insecticides in the new building.

Noise:

- To reduce the noise inside the library building, aiming at providing quietness for the employees and users alike.
- To propose the assignment of a committee, the responsibility of which is to preserve the quietness inside the library.

Coldness:

- Complaints of the coldness of the air in the new building, and the inability to control the temperature inside the building. This necessitates that each employee be granted the ability to control the temperature inside the building.
- Switching off the air conditioners after 8:00 pm in the new building.

Lighting:

- Complaints of poor natural lights, in particular in the Technical Operations Department.
- Complaints of poor artificial lights in various areas of the new building, in particular in the Technical Operations Department and at the book shelves.

Equipments:

- The lowered ceiling in the Technical Operations Department and at the book shelves prevented natural ventilation and lighting in the new building.
- The seats in the library are uncomfortable and give a feeling of discomfort in the new building.
- The absence of special furnishings for first aid in the new building.
- The absence of an area designated for prayers in the new building, and a cafeteria for snacks.

Experiencing the symptoms:

Some members of the study community pointed out that they experienced pathological symptoms in specific places within the new building, such as: the book shelves, the photocopying machines, the basement and the upper floor.

12.6 Conclusion and Recommendations

12.6.1 Conclusion

This chapter seeks to identify the extent to which the librarians of the SQU Main Library in both the old and the new building are exposed to SBS symptoms in library buildings. The data of the study were collected through a questionnaire distributed to the members of the study community. Through the analysis of the data, the study has reached various findings that can be summarized in the following points:

- Both the old and the new buildings suffer from SBS in library buildings.
- The new building enjoys s relatively better environment than the old building in some environmental aspects, such as quietness, the scarcity of undesirable smells,

and the sufficiency and dryness of the air. On the other hand, the percentage of the improvement of the interior environment in the new building in some other environmental aspects, such as lighting and coldness decreased.

- Pathological symptoms such as sinusitis, eye inflammation, dryness of the throat and headaches are some of the most prominent symptoms suffered by the librarians in both the old and the new buildings.
- The number of pathological symptoms suffered by the librarians did not decrease with their move from the old to the new building, but their degree of their experience of some of these symptoms decreased. These symptoms include: headaches, sinusitis and headaches.
- The effect of SBS symptoms in library buildings on the efficacy of the librarians was observed, as well as the increase of absenteeism in both the old and the new buildings.
- The degree of control of the temperature, the humidity, ventilation and lighting decreases in the new building in comparison to the old building. The reverse is true of the degree of control of the noise, which is greater in the new building than in the old one.
- The condensation of humidity on the walls of the new building was less than in the old.
- Regular ventilation was low in both the old and the new buildings.
- Neither the old nor the new buildings had a separate ventilation system for the photocopying areas.
- The percentage of mildew and mould was less in the new building than it was in the old.
- The new building allows the entrance of natural light and sunshine at a larger rate than the old building.
- The number of pathological symptoms experienced by males was larger than that experienced by females in both the old and the new buildings.
- Both males and females complained of the same pathological symptoms in the old and the new buildings, namely sinusitis, eye inflammation, headaches, rapid exhaustion and fatigue, and dryness of the throat.
- Females experienced a higher rate of pathological symptoms than males in the new building.
- Librarians with blood-type A are the most susceptible to all pathological symptoms, followed by blood-type O. The number of symptoms experienced by librarians of blood-type B was lower.
- There is a strong correlation between the carrier of a certain blood type and suffering from certain pathological symptoms whether in the old or the new buildings, such as: the carriers of blood-type O suffer from headaches and nasal congestion; the carriers of blood-types A and AB suffer from sinusitis and dryness of the throat; the carriers of blood-types B suffer from dryness of the throat and eye inflammation.
- Librarians working in the director's office, the administration and the library systems department did not suffer from any symptoms, whether in the old or the new buildings.

- The librarians working in the Lending and Technical Operations Departments are the most susceptible to all pathological symptoms, whether in the old or the new buildings.
- Complaints by librarians working in the Journals Section lessened when they were moved to the new building.
- The complaints by librarians working in the Technical Operations Department increased in comparison to the complaints by other librarians working in the other departments, whether in the old or the new buildings.
- Complaints of the cold air increased in six departments of the new building, in comparison to only four departments in the old one. At the same time, the librarians working in the Technical Operations and Journals Departments complained of the high temperature of the air inside the new building.
- A high rate of complaints of the gloominess of the Technical Operations Department in the new building.
- The rate of complaints of humidity in the air decreased in six departments of the new building in comparison to seven departments in the old building.
- The experience of quietness in the new building was higher than in the old building, in particular in the Technical Operations Department.
- There were no complaints of undesirable smells in the new building, with the exception of the Technical Operations Department.

12.7 Recommendations of the Study

In the light of the results concluded by the study, and in addition to the comments made by the members of the study community, the study recommends the following:

- Taking the environmental dimensions into consideration when designing a library, as well as the expected impact of SBS in library buildings upon librarians.
- The necessity of exchanging the fixed windows in the new library building with movable windows, which allow the librarians to constantly open and close them, to improve the air-flow and renew the air inside the building.
- To introduce a special ventilation system in the building as a whole, and in the photocopying areas in particular, to provide the librarians and the users with fresh air, and expel accumulating pollutants and humidity.
- Using modern techniques to increase the amount of clean filtered air entering the building, in particular in the Technical Operations Department, due to the department's location in the basement.
- Installing filters to purify the internal air of pollutants. It is recommended to use activated carbon which absorbs pollutants.
- To find a system that helps the librarians to control the temperature inside their offices and in other parts of the building.
- To regulate the humidity rate inside the building to avoid the condensation of water on the walls and windows, by installing fans that absorb the bad air and excessive humidity expelling it outside the building.

- To seek to amend the design of the shelf areas aiming at providing higher ceilings, since library users suffer from headaches due to the low ceilings.
- The necessity to increase the areas designated for windows in the basement and on the upper floors of the building to permit the utmost possible amount of natural light in.
- Artificial lights should be redistributed to and increased in all corners of the new building.
- The necessity of moving the Technical Operations Department from the basement to any other floor, due to the high rate of complaints by the workers in this department of SBS. This department is important in that it provides indirect services at the library which contribute to the success of the library in its provision of direct library services.
- It is essential to constantly care for the cleanliness of the building, as well as dusting the desks and the stationary.
- The necessity of regularly spraying the building with insecticides to get rid of insects and rodents. It is important to air the building well after the process, and to ascertain that the place is clean of all traces of insecticides before the librarians are allowed to resume their work.
- To promote the environmental awareness of librarians, by organizing various workshops that illustrate the ways to handle and communicate with the interior environment of the library building.
- To provide the new building with various services that are bound to help in the preservation of the library environment, such as a cafeteria, which would be a place for the employees to take a break and have snacks and drinks, away from the library environment. Also, an area designated for prayers, and an infirmery.
- The necessity to amend the sewage in the parking area, to avoid the accumulation of rain water on the lower walls of the building which may cause serious damage to the building due to the increase in humidity as well as the formation of mildew and mould.
- To conduct this study again after a period of time on the new building to measure the extent to which the environmental condition inside the building has improved or deteriorated, and its impact upon the librarians.
- To evaluate the interior environmental condition of the new building scientifically using genuine scales on the temperature, the relative humidity, and the rate of ventilation in the various areas inside the new building. Also, to gauge the quality of the air, taking different samples of air inside the new building to determine the concentration of some pollutants, specify their possible sources and compare them to the permitted values.
- To conduct further studies in this field on other libraries to reveal the SBS symptoms suffered by librarians in library buildings and the extent to which these impact upon their performance and efficiency. This study also recommends further studies in this field to reveal the SBS symptoms suffered by the users inside library buildings and the extent to which these impact upon their visits to the library.

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Chapter 13
The Interaction Between the Physical Environment and People

Derek J. Clements-Croome

13.1 People: Environmental Sensory Design

> The work experience of every worker in every office, factory, warehouse, shop or bank is intimately affected by the qualities and organization of the physical work environment. The building they work in and the way it is laid out will give govern proximity to colleagues, visibility to a supervisor, the degree of acoustic and visual privacy, the levels of temperature and light they work under, and the quality of the air they breathe. It will very often affect their health (Baldry 1999).

As human beings, we live through our primary senses using sight, hearing, touch, smell and taste, with each one stimulated by the environment around us. Intelligent buildings therefore, should provide a pleasant multi-sensory experience for the occupant and assist in maximizing productivity of the workforce. Sensory design however, is much more than setting temperature levels for thermal comfort, any design brief should set specific criteria for daylight (sight), air quality (smell which is linked to taste), temperature (touch), and sound (hearing). But this alone is not enough to maximize productivity and produce a conducive work environment, as each sense possess a range of various gradients of sensitivity which combine with other senses to create a holistic environment experience. The specified criteria are just the starting point for the design team; the main aim is to achieve an environment which is inspiring and conducive to well-being and productivity. Intelligent buildings should therefore have environments which are delightful to work and live, and require creative thought and sensitivity in there conception. Too often, time and money limit the time for thinking, but we should at least try to establish what defines an organizations motivational environment. Whether designing a new building or refitting an old one the client must describe in words the character of the spaces they need for the building and then the integrated team have to interpret these requirements in terms of sensory aesthetics, function, sustainability and value.

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Over the past 20 years, it has been empirically assessed that most building environments possess a direct effect upon an occupants personal well being and performance, however, it is only through more recent studies that a clearer understanding of the occupied environment has been discovered. Bako-biro et al. (2008) have shown that learning in primary school children is affected by the CO_2 levels and hence the ventilation. In UK, the Building Schools Exhibition and Conference (CIBSE 1999) asked head teachers if they felt modern buildings affect learning. Around 78% said they felt there was a clear link between the quality of school design and levels of pupil attainment. Williams (2005) reported a similar conclusion for 12 primary schools which he had assessed using the Building Quality Assessment method.

Sickness Building Syndrome (SBS) is categorized, when 20% of buildings occupant complain of a similar medical condition due to an unknown cause over period of at least 2 weeks, whilst in the building. However, some research questions whether the underlying factors of SBS are perhaps biased to those who complain more than others, or those who are more sensitive and more susceptible to environmental influences. Perhaps the latter group should be used as a sensitive indicator? Fisk (1999) showed the impact nationally in the US of having poor indoor environmental conditions.

Miller et al. (2009) prove their hypothesis that healthy buildings reduce the number of sick days and increase productivity making and also makes it easier to recruit and retain staff, by surveying over 500 LEED or Energy Star buildings. More evidence which supports this argument that sustainable buildings decrease business costs, energy running costs, and as society awareness of green buildings deepens the demand for sustainable buildings increases, so the value of the built asset increases as described in various studies (Thomson and Jonas 2008; Newell 2009; Clements-Croome 2004). Legislation is forcing the pace. The question is now – can one afford not to be sustainable? Bernstein and Russo (2010) wrote that US environmentally labeled buildings rent for 2–3% more and have higher occupancy rates decreased operating costs but in 2008 an increased building value of 10%. Newell (2009) quoted evidence showing that LEED rated buildings cost 6% more to build; have occupancy rates over 4% higher; command 2–6% higher rents; save 10–50% in energy consumption.

For existing buildings refurbishment, Newell (2009) considered the Empire State Building. The plan is to reduce energy consumption by 38%; achieve annual savings of $4.4 m giving a payback of 3 years; reduce carbon emissions by 105,000 metric tons over 15 years; project completion in 2 years.

Intelligent buildings should be a multi-sensory experience. If an environment is to be conducive to health and well-being it must display the following characteristics:

- A fresh thermal environment
- Ventilation rates to provide fresh air with good distribution and acceptable levels of CO_2
- Good natural lighting

- Minimal lighting glare from within and external to the space
- Spatial settings to suit various types of working
- Ergonomic work places so as to minimise muscular-skeletal disorders
- Minimum pollution from external sources including noise

Personal control of these factors is important. Central control for items like security is fine but people prefer to have some degree of control over their immediate environment.

Freshness is an under used term in design yet occupants often talk of the need for a fresh environment. Many factors can contribute such as colour, spatiality and more often the air quality. The air quality is a combination of CO_2 level, temperature, relative humidity and air movement. Work by Clements-Croome (2008) gave a relationship between fresh air requirements FA (l/s per person) and air temperature Ta (deg C) for relative humidity range of 40–60% as:

$$\mathrm{Ln}\,(\mathrm{FA}) = 0.2085\mathrm{T_a} - 3.37$$

For a "moderately" fresh environment as judged by a sample of UK office workers requires a fresh air rated 2.2 l/s per person at 20°C, 6.3 at 25°C and 17.9 at 30°C. Environments judged as "very fresh" would need higher amounts of fresh air.

The location of the building with respect to Nature is important as well. Ulrich (1984) showed how views out from hospital windows on to greenery improved recovery rates. Alvarsson et al. (2010) showed that the sounds of Nature aids physiological stress recovery. Greenery and still or running water relieve the body and spirit in very hot climates.

Fisk (1999) discussed the correlation between infectious disease transmission, respiratory illness, allergies and asthma and suggests air quality is a major issue in managing these issues including the eradication of odours. The direct affects of poor performing environments can be summarized as follows:

- Lost man hours due to sickness
- Inability to reach true operational potential
- Reduction in Gross Domestic Product
- Unable to maximise organisational profit
- A demoralised work force
- Increase in operation and maintenance costs
- Increased staff turnover

The issue therefore becomes one of economics. If organisational performance is a factor of the individual, then the design of the building should concentrate on user centered design principles and in satisfying the occupant within the workplace. Evans et al. (1998) concluded that a ratio defined as the Total Cost of Ownership (TCO), or whole life value cost ratio, for a building was 1:5:200 but these values will vary but the ratio scales remain similar.

1: Design and Construction costs – cheapest is not always the long term solution
5: Operating and maintenance costs – driven by the building design.
200: Business operating costs – salaries and other organisational costs; productivity which is influenced by the building design and management as well as the ethos of the organisation, social and motivational issues.

Hughes et al. (2004), Wu and Clements-Croome (2005) gave other ratios. However the main conclusion remains that business operating costs dominate and are long term.

Not only research evidence but several surveys carried out in practice showed that properly designed, maintained and managed buildings can lead to significant improvements in productivity (Clements-Croome 2004).

13.2 The Nature of Productivity

For an organisation to be successful and to meet the necessary targets, the performance expressed by the productivity of its employees is of vital importance. In many occupations people work closely with computers within an organisation which is usually housed in a building. Today, technology allows people to work easily while they are travelling, or at home, and this goes some way to improving productivity. There are still, however, many people who have a regular workplace which demarcates the volume of space for private work but is linked to other workplaces as well as to social and public spaces. People produce less when they are tired; have personal worries; suffer stress from dissatisfaction with the job or the organisation. The physical environment can enhance one's work and put people in a better mood, but an unsatisfactory environment can hinder work output.

Concentration of the mind is vital for good work performance. Absolute alertness and attention are essential if one is to concentrate. There is some personal discipline involved in attaining and maintaining concentration, but again the environment can be conducive to this by affecting one's mood or frame of mind; however, it can also be distracting and can contribute to a loss of concentration.

A number of personal factors which depend on the physical and mental health of an individual, and a number of external factors which depend on the environment and work-related systems, influence the level of productivity.

Experimental work on comfort often looks at responses of a *group* as a whole and this tends to mask *individuals*' need for sympathetic surroundings to work and live in. People also need to have a fair degree of personal control about various factors in their environment. They react to the environment as a whole, not in discrete parts, unless a particular aspect is taxing the sensory system.

Research at Rochester University in New York suggested that the mind can affect the immune system. Stress can decrease the body's defences and increase the likelihood of illness, resulting in a lowering of well-being.

Stresses come from a variety of sources: the organisation, the job, the person and the environment. It is likely that building sickness syndrome is triggered by unfavourable combinations of environmental conditions which stress the mind and body and lower the immune system, leaving the body more sensitive to environmental conditions. The biological chain seems to be that stress acts on mind and brain, to which the hypothalamus reacts and the hormone ACTH is released, and then the hormone cortisol in the blood increases to a damaging level. This chain of events interferes with human performance and consequently productivity is lowered.

13.3 Multi-sensory Experience

Buildings should provide a multi-sensory experience for people and uplift the spirit. A walk through a forest is invigorating and healing due to the interaction of all sense modalities; this has been referred to as the *polyphony of the senses*. One's sense of reality is strengthened and articulated by the interaction of the senses. Architecture is an extension of nature into the manmade realm and provides the ground for perception, and the horizon to experience from which one can learn to understand the world. Buildings filter the passage of light, air and sound between the inside and outdoor environments; they also mark out the passage of time by the views and shadows they offer to the occupants.

Although the five basic senses are often studied as individual systems covering visual, auditory, taste, smell, orientation and the haptic sensations, there is interplay between the senses. For example, eyes want to collaborate with the other senses. All the senses can be regarded as extensions of the sense of touch, because the senses as a whole define the interface between the skin and the world. The combination of sight and touch allows the person to get a scale of space, distance or solidity.

Qualitative attributes in building design are often only considered at a superficial level. For example, in the case of light, the level of illuminance, the glare index and the daylight factor are normally taken into account. But in great spaces of architecture there is a constant deep breathing of shadow and light; shadow inhales, whereas illumination exhales light. The light in Le Corbusier's Chapel at Ronchamps, for example, gives the atmosphere of sanctity and peace. How should we consider hue, saturation and chroma in lighting design, for example?

Buildings provide contrast between interiors and exteriors. The link between them is provided by windows. The need for windows is complex but it includes the need for an interesting view, contact with the outside world and, at a fundamental level, it provides contrast for people carrying out work in buildings. Much work today is done by sitting at computers at close quarters and requires eye muscles to be constrained to provide the appropriate focal length of vision, whereas when one looks outside towards the horizon the eyes are focused on infinity and the muscles are relaxed.

There are all kinds of other subtleties, such as the need to recreate the wavelength profile of natural light in artificial light sources, which need to be taken into account. Light affects mood. How can this be taken into account in design?

The surfaces of the building set the boundaries for sound. The shape of the interior spaces and the texture of surfaces determine the pattern of sound rays throughout the space. Every building has its characteristic sound of intimacy or monumentality, invitation or rejection, hospitality or hostility.

A space is conceived and appreciated through its echo as much as through its visual shape, but the acoustic concept usually remains an unconscious background experience.

It is said that buildings are composed as the architecture of space, whereas music represents the architecture of time. The sense of sound combines the threads of this notion. Without people and machines, buildings are silent. Buildings can provide sanctuary or peace and isolate people from a noisy, fast-moving world. The ever-increasing speed of change can temporarily be reduced by the atmosphere created in a building. The opposite is true when working with computers or watching television, for example. Architecture emancipates us from the embrace of the present and allows us to experience the slow healing flow of time. Again, buildings provide the contrast between the passing of history and the time-scales of life today.

The most persistent memory of any space is often its odour. "Walking through the gardens of memory, I discover that my recollections are associated with the senses", wrote the Chilean writer Isabel Allende (The Times, April 1998). Every building has its individual scent. Our sense of smell is acutely sensitive. Strong emotional and past experiences are awakened by the olfactory sense. Again think of the varying olfactory experiences such as in a leather shop, a cheese stall, an Indian restaurant, a cosmetic department or a flower shop; all awaken our memories and give, or do not give pleasure. Wine and whisky connoisseurs know that flavour is best sensed using the nose, whereas texture is sensed in the mouth. Odours can influence cognitive processes which affect creative task performance as well as personal memories. These tasks are influenced by moods, and odours can affect these also (Warren and Warrenburg 1993; Erlichman and Bastone 1991; Baron 1990a). Various parts of the human body are particularly sensitive to touch. The hands are not normally clothed and act as our touch sensors. But the skin of the body reads the texture, weight, density and temperature of our surroundings.

Proust gives a poetic description of a space of intimate warmth next to a fireplace sensed by the skin: "it is like an immaterial alcove, a warm cave carved into the room itself, a zone of hot weather with floating boundaries".

There is a subtle transference between tactile, taste and temperature experiences. Vision can be transferred to taste or temperature senses; certain odours, for example, may evoke oral or temperature sensations. The remarkable world-famous percussionist Evelyn Glennie is deaf but senses sound through her hands and feet and other parts of her body. Marble evokes a cool and fresh sensation. Architectural experience brings the world into a most intimate contact with the body.

13.4 Well-Being

Well-being reflects one's feelings about oneself in relation to one's world. Warr (1998a, b) proposed a view of well-being which comprises three scales: pleasure to displeasure; comfort to anxiety; enthusiasm to depression. There are job and outside-work attributes which characterize one's state of wellbeing at any point in time and these can overlap with one another. Wellbeing is only one aspect of mental health; other factors include personal feelings about one's competence, aspirations and degree of personal control. It is a much more comprehensive concept than the over used word *comfort*. Freshness is an under used word but it has positive nuances in terms of air quality, colours, temperature, daylight and space. A lack of productivity shows up in many ways, such as absenteeism, arriving late and leaving early, over-long lunch breaks, careless mistakes, overwork, boredom, frustration with the management and the environment.

Work reported in (Newman 2010) reviewed the impact of well-being on staff and research performance. The Higher Education Funding Council for England is encouraging universities to invest in wellbeing which can reduce absenteeism and staff turnover. A report by PricewaterhouseCoopers LLP in 2008 on *Building the Case for Wellness* stated that for every £1 spent, well-being brings a return of £4.17. Daly (2010) made a similar evidence case for hospitals. Well-being is connected with overall satisfaction, happiness and quality of life. It is a more encompassing word than comfort. Well-being depends on the management ethos of the organisation; the social ambience; personal factors but the physical environment also has a major role to play (Clements-Croome 2004). Anderson and French (2010) at the Institute of Well-Being at Cambridge University discussed the deeper significance of well-being. Heschong (1979) reported productivity tends to be increased when occupants are satisfied with their environment.

Townsend (1997) said that people in the workplace can be encouraged to use both halves of their brain. The left-hand part is concerned with logic, whereas the right-hand side is concerned with feeling, intuition and imagination (Ornstein 1973). If logic and imagination work together, problem-solving becomes more enjoyable and more creative. Of course some people thrive on change while others prefer to do repetitive types of work. There seems to be no doubt that the industrial and commercial worlds can play a leading role in increasing the awareness of their workforce of all of these possibilities. It is also important to start this way of thinking in school children.

13.5 Indoor Environment and Productivity

Too often buildings are seen as costly static containers rather than an investment which if they are healthy and sustainable can add value. Boyden (1971) distinguished between needs for *survival* and those for *well-being*. Human beings have physiological, psychological and social needs. Heerwagen (1998) pinpointed those well-being needs relevant to building design as:

- Social milieu
- Freedom for solitary or group working
- Opportunities to develop self-expression

- An interesting visual scene
- Acceptable acoustic conditions
- Contrast and random changes for the senses to react to
- Opportunities to exercise or switch over from work to other stimulating activities.

To which one may add the need for clean fresh air. Stokols (1992) believed that physical, emotional and social conditions together are a requisite for good health. Buildings have a dynamic interaction with people, and this is the essence of this chapter.

13.6 Well-Being and Productivity

The question of the *well – being* of the employee is considered by Warr (1998a, b). Defining wellbeing is not easy because there are job specific issues and also people have feelings and concerns which are not related to a particular environment. Warr proposed a two-dimensional view of well – being, placing pleasure and arousal as the two main axes. In terms of measurement Warr also includes an anxiety comfort axis, and another one for depression-enthusiasm. Ten features of jobs are described by Warr (1998a, b) which have been found to be associated with well–being. He believes that stable personality characteristics as well as age and gender are also significant. Environmental determinants of well – being are described as: the opportunity for personal control; the opportunity for using ones skills; externally generated goals; variety; the environment; availability of money; physical security; supportive supervision; the opportunity for interpersonal contact and job status in society. Warr (1998a, b) reviews work that indicates that greater well – being is significantly associated with better job performance, lower absenteeism and reduced probability of leaving employee. The organisation as well as personal factors are also important.

Heerwagen (1998) draws attention to work in organizational psychology which shows the relationship between buildings and worker performance (P) is interrelated as shown:

$$P = \text{Motivation} \times \text{Ability} \times \text{Opportunity}$$

An individual has to *want* to do the task and then has to be *capable* of doing it; last but not least resources and amenities have to be available so that the task *can* be done. The built environment provides physical and social ambiance which affects motivation; the provision of individual control and a healthy environment can enable ability to flourish; communications systems, restaurants and other amenities aid motivation and ability even further by providing opportunity for task implementation.

Boyce (1997) shows the relationships between visual stimuli; the visual system; the cognitive, visual and motor components of task performance; the personality, motivation, management and cost factors which underlie output. This model can be repeated for the other human senses and then there is the complexity of the interactions between them.

Well-being reflects feelings about oneself in relation to the world. Earlier in the chapter, it was noted that Warr (1998a, b) has proposed a view of well-being which comprises three scales: pleasure to displeasure; comfort to anxiety; enthusiasm to depression. There are work and non-work attributes which characterize one's state of well-being at any time, and these can overlap with one another. Well-being is only one aspect of mental health; other factors include personal feelings about one's competence, aspirations and degree of personal control. Good architecture extends and enhances human capacities. Buildings moderate climates, which help to keep the body healthy and enhance well-being. Some buildings demand closely controlled environments, and various equipments can be installed in order to achieve this but many buildings can take advantage of the body's ability to adapt and interact in a compensatory way with other senses.

To understand how we can produce more productive environments means we have to understand more about the *nature of work* and how the human system deals with work. Quality, and hence productive, work means we need good concentration. When we are about to carry out a particular task we need to settle down, get in the mood and then concentrate. Our attention span usually lasts about 90–120 min and then natural fatigue comes into play and our concentration droops but with a creative break we pick up again, concentrate for another spell of time and this pattern repeats itself during the waking day. This is the so called *ultradian rhythm.* De Marco and Lister (1987) described this as a concept of *flow*. Mawson (2002) describes their work which claims that individuals take about 15 min to ramp up to their concentration level. When an individual is in a state of *flow* they then maybe distracted or may become naturally tired and the process repeats itself. Mawson (2002) believes that there is a significant loss of productivity from distraction which has been identified by the Harvard Business Review, for a well managed office as being approximately 70 min of lost productivity in a typical 8 h day. The distraction is mainly due to general conversation. In other words there is a waste of energy.

Barriers to effective work performance are distraction, boredom, poor support systems, unhelpful organisations, a lack of social ambience and a poor physical environment.

Davidson (2003) led a research study at University of Wisconsin-Madison which shows positive thinking (good moods, optimism) can promote good health because the body's defences (the immune system) are stronger. This suggests that the balance between the mind and the body is a sensitive one. So how relevant is this in the workplace? Various stressors can arise from conflicts in the physical, social organisational environments. People adapt to these in various ways but for some they will be weakened; if conditions are very stressful many will be affected.

There is substantial evidence described by Heerwagen (1998) showing that positive moods are associated with the physical environment and everyday events such as social interactions (Clark and Watson 1988). Even more telling is the research which showed that positive moods aid complex cognitive strategies (Isen 1990) whereas negative moods due to distractions, discomforts, health risks or irritants arising from the physical or social environments restrict attention and hence affect work performance. Because positive moods directly affect the brain processes (Le Doux 1996), it can be concluded that many aspects of building environmental design can aid task performance. Heerwagen (1998) distinguishes between direct effects such as overheating, noise or glare and indirect effects arising from mood and/or motivational factors. Several positive mood inducing factors have already been mentioned – aesthetics, freshness, daylight, view, colour, personal control, spatial aspects and Nature.

Mood, feelings and emotions affect people's decision-making. Mood can be influenced by several environmental factors such as Monday effect or weather conditions. A body of psychological literature shows that temperature is one of the important meteorological variables affecting people's mood, and this in turn influences behaviour. Cao and Wei (2005) stated that research to date has revealed that stock market returns are associated with nature-related variables such as the amount of sunshine, the daylight-savings time change, the length of the night, and the lunar phases of the moon.

Cao and Wei (2005) described evidence which suggests that low temperatures tend to cause aggression, and high temperatures tend to cause aggression, hysteria, and apathy. The question is then "Is does temperature variations cause investors to alter their investment behaviour?" They hypothesized that lower temperature leads to higher stock returns due to investors' aggressive risk-taking, and higher temperatures can lead to higher or lower stock returns since aggression and apathy have competing effects on risk-taking.

Based on an analysis of twenty international markets Cao and Wei (2005) concluded that the impact of apathy dominates that of aggression in the summer, leading to a statistically significant negative correlation across the whole temperature range. The correlation was robust to alternative tests (parametric, semi-parametric, and nonparametric) and remained present after controlling for such known anomalies as the Monday effect, the tax loss effect, the cloud cover effect, and the seasonal affective disorder syndrome. The difficulty with the word productivity is that in many places it is invisible. Time and motion studies can be used in factory conditions to some extent. There are measures that can be quite easy to employ for repetitive office work. In general however apart from the basic qualities like speed and accuracy, it is much more elusive to assess quality, because it involves some *objective* measures but it also introduces a high degree of *subjective* assessment. Table 13.1 shows some indicators of productivity.

The impacts of spatial design and sick building syndrome are discussed in Chap. 3 of Intelligent Buildings (Clements-Croome 2004).

Herzberg (1966) distinguished *hygienic* or *environmental factors* from the social needs of giving the worker more responsibility and recognition. The physical environment was one aspect of job satisfaction. In the Eden and Brown (2000) annual employment attitude survey of office workers in the UK, the following overall scores were achieved for various factors (Tables 13.2 and 13.3).

Table 13.1 Indicators of increased productivity (NEMA 1989)

Performing tasks more accurately
Performing faster without loss of accuracy
Capability to perform longer without tiring
Learning more effectively
Being more creative
Sustaining stress more effectively
Working together more harmoniously
Being more able to cope with unforeseen circumstances
Feeling healthier and so spending more time at work
Accepting more responsibility
Responding more positively to requests

Table 13.2 Achieving Maslow's Hierarchy of Needs in the Workplace (CIBSE 1999; Huczynski 1991)

Need	Achieved by
Physiological	Good working conditions, attractive salary, subsidised housing, free catering.
Safety	Private health care, pension, safe working conditions, job security.
Social esteem	Group relationships, team spirit company sports, office parties, informal activities, open communication.
	Regular positive feedback, prestige job titles, write-up in company news sheet, promotion and reward.
Self-actualisation	Challenging job, discretion over work activity, promotion opportunities, encouraging creativity, autonomy and responsibility

Table 13.3 Eden Brown (2000) employment attitude survey

Factor	Overall percentage vote
Nice people to work with	85
Job security	80
Money	77
Qualities of opportunity	74
Comfortable working condition	73
Career opportunities	65
Location	64
Company contributing to community/environment	63
Benefits	54
Flexi time	47

In general women scored all these factors higher than men, particularly on the issues of having nice people to work with, comfortable working conditions, qualities of opportunity, working for a company that was socially responsible to those in the community or a company that took sustainability seriously. We see that environmental conditions are rated almost as highly as money and opportunities.

To perceive the world around us in a holistic way the word environment has a broad meaning embracing how the organisation works and manages the staff; the physical factors such as lighting, noise and indoor air quality; space planning and layout; economic factors; general aesthetics; the amenities, facilities and support systems provided by the organisation; social ambience. If any one of these factors is particularly bad or particularly outstanding this tends to attract the attention of the human mind. In general however, the human sensory system is adaptable but people like to feel they have some degree of control over some of the factors. In other words people like to create their own environment to suit their work style. *Patterns of work* used to be rigid but are now much more flexible. A review of these factors is given in CIBSE (1999).

Fisk (2000a and b) reported that in the US respiratory illnesses cause the loss of about 176 million workdays and the equivalent of 121 million days of substantially restricted activity. Fisk (1999) and Clements-Croome (2000b) stated that in office buildings, the salaries of workers exceed the building energy and maintenance costs and the annual construction rental costs by a factor of at least 25. This means that small increases in productivity, of 1% or less, are sufficient to justify additional capital expenditure to improve the quality of the building's services. Ultimately, this will result in healthier working environments as well as reduced energy and maintenance costs.

Most people spend most of their lives in buildings, so the internal environment has to be designed to limit the possibilities of infectious disease; allergies and asthma; and building related health symptoms, referred to as sick building syndrome symptoms. Buildings should provide a multi-sensory experience, and therefore anything in the environment which blocks or disturbs the sensory systems in an unsatisfactory way will affect health and work performance. Thus, lighting, sound, air quality and thermal climate are all conditions around us that affect our overall perception of the environment. Air quality is a major issue because it only takes about 4 s for air to be inhaled and for its effect to be transmitted to the bloodstream and hence the brain. Clean, fresh air is vital for clear thinking, but it is not the only issue to be considered.

Fisk (1999) discussed linkages between infectious disease transmission, respiratory illnesses, allergies and asthma, sick building syndrome symptoms, thermal environment, lighting and odours. He concludes that in the USA the total annual cost of respiratory infections is about $70 bn, for allergies and asthma $15 bn, and reckons that a 20–50% reduction in sick building syndrome symptoms corresponds to an annual productivity increase of $15–38 bn. The linkage between odour and scents and work performance is less understood, but Fisk (1999) concluded that the literature provides substantial evidence that some odours can affect some aspects of cognitive performance. He referred to work by done by various researchers (Rotton 1983; Dember et al. 1995; Knasko 1993; Baron 1990b; Ludvigson and Rottman 1989). The application of scents has been used by the Kajima Corporation in their Tokyo office building, as reported by Takenoya in Clements-Croome (2000a).

Fisk goes on to consider the direct linkage between human performance and environmental conditions and writes that for US office workers there is a potential annual productivity gain of $20–$200 bn. His conclusions are that there is relatively strong evidence that characteristics of buildings and indoor environments significantly influence the occurrence of respiratory disease, allergy and asthma symptoms, sick building syndrome and worker performance. In 2002 the total sick leave due to stress related illnesses cost the UK £376 m; a significant part of this was due to the physical environment.

There are a number of interacting factors which affect productivity, including privacy, communications, social relationships, office system organisation, management, as well as environmental issues. It is a much higher cost to employ people who work than it is to maintain and operate the building, hence spending money on improving the work environment may be the most cost effective way of improving productivity. A seemingly small percentage increase in productivity of 0.1–2% can have dramatic effects on the profitability of a company because in a typical commercial organisation salaries amount to about 90% of the total costs. If more money is spent on design, construction and maintenance, and even if this, results in only small decreased absenteeism rates or increased concentration in the workplace, then the increase in investment is highly cost effective (Clements-Croome 2000a; Woods 1989). Measurement of productivity was discussed in Clements-Croome (2004).

Dobbelsteen (2004) made the point that productivity is difficult to measure but showed work by Kaczmarczyk and Morris (2002) presented in Table 13.4.

Eley Associates (2001) found that healthy buildings lead to better work performance and this is supported by other work such as (Mendell et al. 2002; Fanger 2002; Bell et al. 2003). The rapid development in technology is very helpful in some ways but there are negative issues and these are described by van der Voordt (2003) which include getting used to technology, concentration, ICT problems and time loss for logging onto computer systems and searching for information.

Table 13.4 Measures that lead to Productivity Improvement (Kaczmarczyk and Morris 2002)

Feature	Productivity improvement
Tele-work	22%
Quality of layout	15%
Renovation	25%
Ergonomic furniture	21%
Green surroundings	15%
Better lighting	12%
Noise reduction	20%
Better indoor climate	10%
Individual influence	16%

13.7 Evidence for Interaction Between Environment and Productivity

Oh (2005) conducted a questionnaire survey in Sabah, East Malaysia to find out the relationship between perceived IAQ and self-assessed productivity in offices. There were 127 respondents out of 180 questionnaires circulated. Little work concerning this issue has been carried out in Malaysia, thus the main objective of the survey was to find out the divergence of perception of IAQ in a hot humid climate which may yield different results to at European or American location. The relationship between perceived IAQ and self-assessed productivity was strong ($P < 0.001$) and similar to studies carried out in cooler climates. On the other hand, no correlation between temperature and self-assessed productivity was found. This may be because Malaysians have become acclimatized to a wider and higher range of temperatures so they can still perform well in temperatures which are often judged to be adverse.

Kosonen and Tan (2004) have studied the affect of indoor air quality on productivity and concluded that the loss in productivity is significant for thinking tasks than for typing ones. In general the percentage dissatisfied is a good indicator of the productivity loss. This is useful because the dissatisfied population can be estimated from pollution loads, fresh air flow-rate and ventilation efficiency; the latter will vary depending on the type of ventilation system installed. They conclude that in general the use of minimum air-flow rate design reduces productivity by 5–13%. Further, a 1% loss in productivity is equivalent to the annual total cost of operating an airconditioning system; it also represents an increase in dissatisfaction of 5%. Kosonen and Tan conclude that a productivity loss difference of 0.5–2% between mixing (100% in contaminant removal efficiency) and displacement systems (150% ventilation efficiency) could equate to \$3–\$12b. This shows the importance of selecting the right ventilation system to achieve high indoor air quality.

Federspiel et al. (2004) in studying worker performance and ventilation in a call centre made the point that the effect of ventilation is significant but factors such as understaffing and long shifts are even more significant. In terms of the environment temperatures above 25.4°C are detrimental to performance.

Gohara and Iwashita (2001) studied the perceived air quality, sick building syndrome (SBS) symptoms and performance of subjects in an office room that was renovated 1 year before this study. Thirty-one female college age subjects were exposed to the conditions in the same office with an outdoor airflow of 280 m^3/h and 45 m^3/h. The subjects were unaware of any intervention acoustically and visually since the ventilation fan was operated in both conditions. They assessed perceived air quality and SBS symptoms while performing simulated work. The measurements of formaldehyde and the volatile organic compounds showed much higher readings in the room with low ventilation than those in the room with high ventilation. However no significant difference was observed in the odour intensity, the acceptability and the SBS symptoms between overall average assessments of all subjects exposed to the room with either ventilation conditions. The air quality caused only 10% to be dissatisfied on entering the office with low ventilation; these dissatisfied subjects tended to claim more SBS symptoms than the others. It was found that there was significant difference in the performance of computer based proofreading task between the two ventilation conditions.

Gohara and Iwashita (2003) studied the influence of self-reported arousal caused by room temperature and scent on performance. Fifteen subjects performed proof reading work at three different levels of air temperatures and four different conditions of indoor air quality. Among the three levels of air temperatures, the subjects found air temperatures of 26.5–27.5°C, very acceptable. However, the highest performance occurred with cooler air temperatures of 22–24°C. For the evaluation test with pine scent, the subjects were divided into two groups; group A, found the pine scent not acceptable at higher odour intensity levels and group B, who found the pine scent acceptable even at high odour intensity levels. The conditions with the scent had more of an influence on the self-reported arousal and performance for the subjects of Group B, than for those of Group A.

Morita et al. (2003) used proof reading tasks to study the effect of the indoor thermal environment on task performance. A score of effective processing in the proof reading task was the highest and the low temperature condition (22–24 °C) but some subjects had high scores in high temperature conditions (30–32 °C) and it is thought that in this case performance was determined more by the arousal level of the occupants.

13.8 Economic Opportunities for Business

Evans et al. (1998) in a report entitled *The Long-term Costs of Owning and Using Buildings* for the Royal Academy of Engineering (RAE) made the point that the cost of ownership and maintenance of the building is typically about 3% of the overall cost of people working there. As a guide to the whole life cost of operation of office buildings the following ratios are proposed:

Design	0.1
Construction cost	1
Maintenance and building operating costs	5–9
Business operating costs	200

Oseland and Willis (2000) quote similar figures. Macmillan (2004) adds in design fees at 10% of total costs hence giving design a ratio of 0.1:1 for design: construction costs. Some buildings show different figures to these but the principal interest here is that business operating costs (mainly salaries) are much higher than design, construction and operating costs. Quoted from Wu and Clements-Croome (2005):

For a building as a whole, Evans et al. (1998) show a ratio of costs of 1:5:200, where for every one pound spent on construction cost, five are spent on maintenance and building operating costs and 200 on staffing and business operating costs. For HVAC systems in a building, Osso et al. (1996) shows that initial building costs account for approximately just 2% of the total, while operating and maintenance costs equal 6%, and personnel costs equal 92%. Modelling on a dataset including 20 costs of HVAC systems, Wu and Clements-Croome (2005) show that the ratios of operating and maintenance costs to initial costs range from 4.75 to 30, and the ratios of maintenance costs to initial costs range from 0.45 to 1.8. These results shows that the median of the ratio initial building costs to operating and maintenance costs is 1:7.77. Considering the medians of the ratios, and assuming that 90% of the total cost are on staffing and business operating costs, and 10% are on initial costs, operating and maintenance costs, then ratio of 1:7.77:78.93 results which can be approximated to 1:8:80.

The RAE report concludes that there is a good deal of evidence that the building itself if properly designed and managed can lead to significant improvements in productivity by as much as 17%.

Hodgett (1993) estimated that the annualized UK building cost including capital investment is about £200 m^2 p.a. of which energy and plant costs are about £10 m^2 p.a. Staff costs are about £15,000 m^2 per year. One can see immediately that any factor like increased productivity altering by only 1% can increase the value of the staff costs considerably for the organization. The USA has taken this relationship between the various costs seriously and examples are given in Clements-Croome (2000a). The conclusions from the work reviewed in CIBSE (1999) is that staff costs are 100–200 times the cost of energy and these costs can be off-set by a 0.5–1% reduction in staff costs. Staff costs are 20–44 times the HVAC running cost which indicates that an increase in productivity is required to off-set these costs by 2–5%. The costs are some 30 times the HVAC installation costs and any change in these costs are justified if the changes produce an increase in productivity of some 3½. Productivity of gain of just under 10% should off-set the full running and installation cost. Some US cost comparisons are given in Table 13.5.

Table 13.5 Comparison of energy and staff costs for North American Offices (CIBSE 1999)

Costs	Rosenfeld	Abdou and Lorsch	EPA	Woods	BOMA
Staff costs ($/ft^2/year)	300	218	200	237	130
HVAC running costs ($/ft^2/year)	–	2–10	6	12	2.9
Energy costs ($/ft^2/year)	1.5	1–2	2	2	1.5
Ratio of staff to energy costs	200	114–218	100	118	87
Productivity offset of energy (%)	0.5	0.5–0.9	1.0	0.9	1.2
Productivity offset (min/day per person)	2¼	2–3¾	4⅓	5	

13.9 Endnote

Productivity depends on four cardinal factors: *personal*, *social*, *organisational* and *environmental*. There are preferred environmental settings which decrease dissatisfaction and absenteeism, thus indirectly enhancing productivity. The assessment of problems at the workplace based on numbers of complaints is unreliable, because there is little mention of positive aspects and because complaints may be attributable to other, entirely different factors.

Kline (1999) believes it is important to design *thinking environments.* The most important aspect is to have places for work *where people feel that they matter*. When that becomes a guideline for architectural interior design she argues a very different place emerges, than when some abstract standard of opulence and furnishing for pure functionality is adopted as a guideline. Building regulations and codes to practice are only a basic foundation for providing health and safety in the workplace; they do not guarantee producing an environment which is conducive to well-being and this includes feelings and emotions. Froggatt (2001) enunciates eight principles for workplace design:

- the initiative to explore remote and mobile work strategies
- trust employers to work out of sight of management
- encourage joy in the workplace (Cabanac 2000)
- value individuality
- emphasise equality more than hierarchy
- engage in open honest dialogue
- epitomise cognitivity between all the stakeholders in the business
- provide access to a wide range of workplace options

Duffy (1997) and Worthington (1998) are two of several leading exponents on workplace design and they show many examples of diverse but successful internal environments. Offices of the future will be thought of as organisms which are developing in response to changes in technology and ways of working. It is important that office spaces allow people to work in teams, when necessary, but at the same time bond to individual needs for motivation and hence stimulate productivity.

Good environments can enrich the work experience. Stimulating environments can help people to think creatively and buildings have a role here because spaces have an emotional content (Farshchi and Fisher 2000). It is important that the built environment is designed to respect feelings of people as well as the functional aspects.

In response to the question about the principal shortcomings in the conventional public sector approach to design Hilary Cottam, nominee for UK Designer of the Year 2005, wrote:

Despite rhetoric to the contrary the public sector continues to be driven by short term calculations of cost. The failure to compute the emotional, social and therefore economic benefits that accrue from good design has led to procurement processes which exclude the real experiences and needs of the people who will use the buildings, objects and experiences that are designed.

For example, we are happy to continue building cheap, sub-standard housing to warehouse a population in need, while failing to connect the huge personal and social costs that result. Those responsible for commissioning design in the public sector largely fail to appreciate its potential. Briefs are issued which ask the wrong questions and thereby fail to capitalise on the wealth of design talent within the UK.

She gave the following solutions to how these problems could be addressed. Three things seem key. Firstly within my approach all briefs are developed in partnership with those who will work with and use whatever is to be the final product. This is not simply a consultation exercise or populism, but a rigorous design process whereby a range of professionals work with users to develop a solution. Secondly all projects develop practical, workable solutions for the users while also developing policy guidelines – a set of principles which could help to change the framework within which future designs will be commissioned. Thirdly we have an underlying principle of smart spending. All my projects are developed within the same budgets as traditional approaches. We do not need to spend more; we just need to spend differently. Sometimes this results in solutions which turn out to be cheaper than those developed through more traditional approaches. Hilary Cottam (Designer of the Year 2005)

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Chapter 14
Necessity of Counseling Institutions for Sick Building Syndrome Patients

Nami Imai and Yoshiharu Imai

14.1 Difficulty of Treating Sick Building Syndrome at General Hospitals

When we think about the prerequisites for hospitals that can treat sick building syndrome patients, the first is that there should be no toxic building materials that may volatilize toxic chemicals into the hospital because patients' conditions are influenced by indoor air quality. However, sick building syndrome patients cannot be treated in general hospitals where many patients with other illness visit even if there are no toxic materials in the building because modern people depend on many kinds of chemicals, and patients with other illness will bring these chemicals into hospitals by applying them to their clothing and body. Such chemicals are found in shampoo, hair conditioner, hair treatments, shaving cream, and the lingering scent of mothballs. Ordinary people may use all of these chemicals, but for sick building syndrome patients they can cause agony. It goes without saying that hospitals that are constructed with great care with regard to the toxic chemicals that they contain are necessary for sick building syndrome patients.

14.2 Reasons for the Insufficient Number of Special Hospitals for Sick Building Syndrome Patients

Unfortunately, even most medical staff is ignorant about the symptoms and treatment of sick building syndrome at the present time. Even worldwide, the number of medical staff and hospitals that can treat sick building syndrome patients is very small. In addition, there are few doctors who are clinically capable of treating sick building syndrome because the nature of the pathophysiology of sick building syndrome is still under investigation.

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For example, we heard of a doctor who was the head of the Department of Otorhinolaryngology at one of best hospitals in Japan. One day, a sick building syndrome patient suggested that his symptoms were due to sick building syndrome and showed him a measurement of the high formaldehyde density in his room, and the doctor replied “Sick building syndrome? What is that?” His attitude greatly disappointed the patient. At that time, WHO had already declared guideline values for toxic chemical densities in indoor air, and many newspapers and TV news programs were covering the sick building syndrome issue in Japan. Why did the doctor say what he did? It was not because he was lacking in ability or had a defect in his personality. Many patients respected the doctor, and his clinical skill was good. Rather, as a doctor of a private hospital, it was because he had never heard of sick building syndrome and could not write it on a medical chart before the term “sick building syndrome” was included on the list of illnesses eligible for governmental medical service fees from the governmental health insurance scheme.

Moreover, building a special hospital for sick building syndrome patients costs much more than a general hospital because such hospitals require special materials that do not emit toxic chemicals. Furthermore, they need special furniture made of steel or ceramic because normal furniture such as chairs, tables, and beds emit toxic chemicals. Interestingly, while there is a law that regulates the quantity of toxic chemicals emitted from building materials (especially formaldehyde) in Japan, there is no law that regulates the quantity of toxic chemicals emitted from furniture. Therefore, most furniture on the market is made from medium density fiberboard or plywood and emits lots of toxic chemicals because medium density fiberboard is made by mixing sawdust and glue, and plywood is made by pasting thin sheets of wood with glue. Thus, special hospitals require custom made furniture, which is very expensive. As a result, such expenses are a barrier to the number of special hospitals increasing.

14.3 Who Should Get Aid?

On a global scale, it is considered that the Environmental Health Center Dallas (EHCD) in the US and the Institute for Environmental Diseases in Germany are the best institutions at diagnosing and treating sick building syndrome and multiple chemical sensitivity. There also are a few special hospitals for sick building syndrome in Japan, where the author lives. Patients who can reach these hospitals are happy because they can stop seeking a correct diagnosis, learn appropriate countermeasures for their condition, and receive treatment. In fact, the true victims are the patients who cannot visit special hospitals. Maybe this is as same as the situation for cancer, autoimmune diseases, and other refractory conditions, and most patients who visited the author’s office did not know of the existence of such special hospitals. Some of them did know about them but worried whether their condition warranted treatment at such a hospital. The author runs a Nursing Counseling Room in Mie University. Some patients who visited the Nursing Counseling Room and underwent a screening test for sick building syndrome and multiple chemical sensitivity were instructed to go to a special hospital in Tokyo in order to prevent the aggravation of their symptoms and alleviate their agony (Imai and Imai 2009).

As described in Chap. 6, sick building syndrome and multiple chemical sensitivity patients should have a medical examination as soon as possible because their symptoms become worse with prolonged exposure. Therefore, counseling institutions that can refer such patients to special hospitals or doctors are necessary for patients who worried about whether their sickness requires treatment at a special hospital.

As mentioned above, the difference between sick building syndrome and multiple chemical sensitivity and other illness is that poor quality air can prevent patients from visiting hospitals. Seriously ill sick building syndrome or multiple chemical sensitivity patients cannot go to general hospitals safely because they could suffer a reaction to chemicals in the air on public transport or in stations or to exhaust fumes on the road. There are no relief measures for such patients, even though they need immediate medical support. In the author's opinion, we must make the solving of these problems a priority.

14.4 Who Should Help the Patients?

Who can give patients who are unsure whether they have sick building syndrome or multiple chemicals sensitivity appropriate advice? In the author's opinion, nurses are the best for this because they can assess a patient comprehensively and individually and can give them advice on how to improve their health by changing their lifestyle. In addition, the cost of building nursing counseling institutions for sick building syndrome patients is much lower than the cost of building special hospitals for sick building syndrome patients.

From 2006 to 2009, I interviewed 70 sick building syndrome patients and their families who visited my office in order to find out what sick building syndrome patients want nurses to do for them. According to the result, 46% of sick building syndrome patients and their families wanted information about their condition and how to treat it, 22% of them wanted information about how to make their daily life safe, 21% of them wanted mental support, and 11% wanted nurses to enlighten the public about sick building syndrome and multiple chemical sensitivity (Table 14.1). Therefore, the author hopes that many nurses will try to help sick building syndrome patients, but, unfortunately, few nurses have researched the subject and are able to help such patients. The reason why few nurses have studied the treatment of sick building syndrome is that they would have to stop or reduce as much as possible their use of chemicals in order to help these patients (Imai 2008).

People who are immersed in the use of chemicals in daily life associate them with convenience. They feel that treating sick building syndrome patients would mean throwing convenient life away and would cause them great stress because they would have no idea what they should eat, wear, and do. However, reducing the

Table 14.1 Users' demands to nurse (User: 70, code: 179)

Contents of demand to nursing in NCR	%
Information on the condition and treatment	46
Information that could improve the safety of daily living	22
Mental support	21
Action to promote social understanding of their situation	11

use of chemicals in daily life as much as possible is not only good and necessary for sick building syndrome or multiple chemical sensitivity patients but also for medical staff in order to live a healthy life.

Unfortunately, younger nurses in particular are displeased when they are told that they should reduce the amount of chemicals that they use in their daily life because they would not want to work without makeup. The author feels that support for sick building syndrome and multiple chemical sensitivity patients is not improving because of such trifling reasons. Younger nurses' desire to be beautiful should not be frowned upon, but the fact that cosmetics, which they feel forced to buy, contain many chemicals is a serious problem.

14.5 Effects of Nursing Intervention in the Nursing Counseling Room for Chemical Sensitivity

The author calls our support activities for sick building syndrome patients NCR-CS: Nursing Counseling Room for Chemical Sensitivity or just NCR. The effects of NCR-CS have already reported at scientific conferences (Imai and Imai 2009). Some examples of the NCR-CS's activities are given below.

Patient A was 29 years old and worked as a beautician. She got sick building syndrome when she moved to a new apartment after getting married. Her main symptoms were dyspnea and a feeling of worthlessness. She heard that her symptoms might be caused by sick building syndrome at an allergy clinic 2 months after she moved into her apartment. She heard about the NCR-CS accidentally, got advice from a nurse there, and her condition improved. Her worries at the time of her visit to NCR-CS were "No one understood her symptoms", "Which chemicals caused her symptoms?", and "She had no idea how to improve her symptoms". In response, a nurse at NCR-CS gave her counseling treatment, explained about sick building syndrome and how it is aggravated, and gave her advice on how to improve her symptoms. As a result, her condition improved dramatically with 5 months support from NCR-CS (Fig. 14.1). The NCR-CS support activities that she valued most were the peer counseling and advice about how to use a low-temperature sauna.

Patient B was 31 years old and was a vocational college student. She had symptoms suggestive of sick building syndrome. The origins of her symptoms were stressful childhood experiences involving repeated moves to newly refitted apartments. Her worries at the time of her visit to NCR-CS were "No one understood her

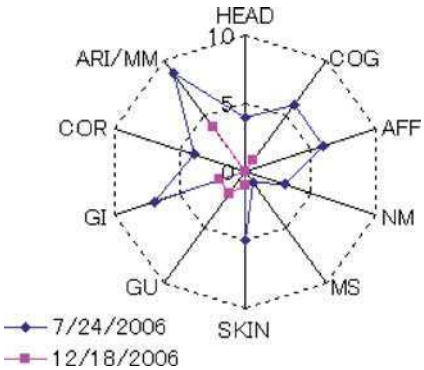


Fig. 14.1 Outcome of QEESI© symptom star and main intervention (Female, 29 years old, beautician, support method: peer counselling and sauna)

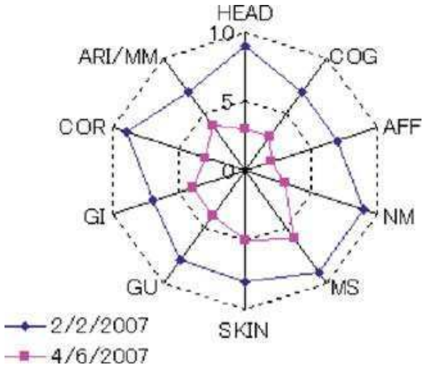
symptoms", "She could not find appropriate hospitals for her symptoms", and "She had no idea how to improve her symptoms".

It should be noted that QEESI© (Quick Environment Exposure Sensitivity Inventory) was developed by Miller and Prihoda (1999) and was designed to assist researchers and clinicians in evaluating patients for multiple chemical sensitivity. Symptom star is one of charts of QEESI© and it measures symptom severity scale by 10 items such as head-related (HEAD), cognitive (COG), affective (AFF), neuromuscular (NM), musculoskeletal (MS), skin (SKIN), genitourinary (GU), gastro internal (GI), heart/chest-related (COR) and airway or mucous membrane-related (ARI/MM). Each item uses 0–10 rating.

In response, a nurse at NCR-CS gave her counseling treatment, explained about sick building syndrome and how it is aggravated, told her about the special hospitals for the condition, explained how to use those hospitals (it is necessary to make a reservation at the hospital first, and patients must have accommodation near the hospital for the night before their treatment because the treatment starts at 8:00 am), and gave her advice about how to improve her symptoms by changing her daily life. After NCR-CS's advice, she went to a special hospital and got a correct diagnosis, and as a result, was able to dramatically improve her symptoms within 2 months (Fig. 14.2). The NCR-CS support activities that she valued most were the peer counseling, introduction to special hospitals, and advice about safe foods and safe water.

Patients C and D were a married couple. C was a 51-year-old housewife, and her husband D was a 55-year-old office worker. They had symptoms suggestive of sick building syndrome caused by disinfectants, which were used in a septic tank in front of their apartment. C was also a retired nurse, and she could not walk straight due to dizziness when she visited NCR-CS. Meanwhile, D had symptoms on his skin. They were at a loss because they had no information about sick building syndrome, ways to improve their condition, or any special hospitals for their disease. A nurse at NCR-CS gave them counseling treatment and introduced them to the special hospitals after explaining about sick building syndrome and how it is aggravated. Right after their visit to NCR-CS, they went a special hospital and got a correct diagnosis.

Fig. 14.2 Outcome of QEESI© symptom star and main intervention (Female, 31 years old, student, support method: peer counseling, introducing a special doctor and information of safe water and foods)



They were very glad because they finally had a name for their symptoms. After that, they visited NCR-CS regularly and learned how to improve their health condition from the nurse. As a result, their condition recovered dramatically with 10 months support from NCR-CS (Figs. 14.3 and 14.4). The NCR-CS support activities that they valued most were the peer counseling, introduction to special hospitals, and advice about safe foods and safe water.

According to these examples, sick building syndrome and multiple chemical sensitivity patients who visited NCR-CS were troubled by the fact that no one around them showed any understanding about their symptoms. Indeed, some people, including members of the patients' families, thought that the patients' symptoms were part of a mental disorder, which caused the patients to feel a deep sense of isolation.

Therefore, counseling treatment by nurses at NCR-CS is surely warranted to counter patients' feelings of loneliness. In the author's opinion, we medical staff must first ease patients' worries before starting counseling treatment in order to improve their health condition by fixing the problems with their daily life.

Medical staff must make patients visit special hospitals and get a correct diagnosis as soon as possible. As mentioned in Chap. 6, repetitively treating the symptoms

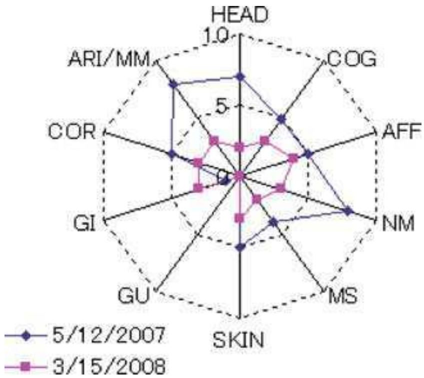


Fig. 14.3 Outcome of QEESI© symptom star and main intervention (Female, 51 years old, house wife, support method: peer counseling, introducing a special doctor and information of safe water and foods)

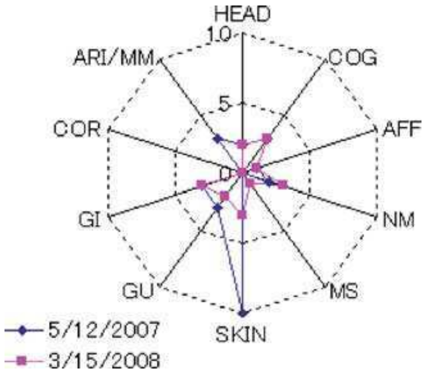


Fig. 14.4 Outcome of QEESI© symptom star and main intervention (Male, 55 years old, office worker, support method: peer counseling, introducing a special doctor and information of safe water and foods)

of sick building syndrome or taking useless treatment under a wrong self diagnosis prolong patients' exposure to toxic chemicals and aggravate their symptoms. Therefore, the existence of places where patients can talk about their condition such as NCR-CS and that provide appropriate advice about visiting special hospitals from educated medical staff are important for preventing the aggravation of the condition.

As mentioned above, sick building syndrome patients do not only have to pay attention to indoor air pollution, but also foods and goods such as soap, shampoo, cosmetics, and detergent because they may react to many kinds of chemicals after developing sick building syndrome. Moreover, their sick building syndrome may be aggravated and escalate to multiple chemical sensitivity, which is untreatable. Therefore, the staff of the NCR-CS suggest that patients should pay attention to indoor air quality, as well as the foods they consume and the goods they use and provide a chance for patients and their families to think seriously about their lifestyle.

Getting sick building syndrome and multiple chemical sensitivity is very unfortunate. However, patients' can recover from their condition if they realize they have sick building syndrome and take appropriate measures in the early stages of the condition. We should think about it as a chance to prevent other conditions by noticing chemical dangers and adjusting our lifestyle accordingly.

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Chapter 15
Investigation of Air Pollution in Large Public Buildings in Japan and of Employees' Personal Exposure Levels

Naoki Kunugita, Keiichi Arashidani, and Takahiko Katoh

15.1 Introduction

Approximately 80% of our lives are spent in indoor air environments such as homes or work places. The indoor air quality is often worse than that of the outdoor air, also it contains many pollutants. Jarke et al. (1981) identified 118 chemicals in the air inside new buildings and found that indoor pollutants probably arise from many components, such as the carpeting, clothing, and furniture. Many studies on indoor air pollution (Jia et al. 2008; Osawa and Hayashi 2009; Park and Ikeda 2006; Taneja et al. 2008) and its influence on health (Azuma et al. 2007; Ciencewicki and Jaspers 2007; Gomzi et al. 2007; Osman et al. 2007; Takigawa et al. 2010; Zuraimi et al. 2007) have been conducted.

In Japan, a major problematic change in indoor air environment has been recently recognized. This new problem is caused by highly air-tight houses incorporating adiabatic and other new building materials, and can lead to health problems. Residents in newly built homes complained of discomfort and illness related to this problem in the 1990s. These symptoms, called the sick house syndrome, have been studied in Japan. The symptoms are irregular and can not be distinguished from the sick building syndrome (SBS); socially, they have become a significant problem. The Ministry of Health, Labor, and Welfare (MHLW) of Japan, in cooperation with the Ministry of Land, Infrastructure, Transport, and Tourism (MLIT), Ministry of Economy, Trade, and Industry (METI), and Ministry of Agriculture, Forestry, and Fisheries (MAFF), have helped in controlling these sick house problems understanding the source and characteristics of indoor air pollution, indicating a concentration index (guideline) as a control policy, and developing methods for diagnosis and treatment. In addition, at the same time, the MLIT investigated pollution mechanisms and methods of calculating concentrations on the basis of the mechanisms, suggested designs

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Table 15.1 Japanese guidelines for acceptable levels of individual VOCs and aldehydes

Compound	Guideline value	Year of enforcement
Formaldehyde	100 μg/m^3 (80 ppb)	June, 1997
Toluene	260 μg/m^3 (70 ppb)	June, 2000
Xylene	870 μg/m^3 (200 ppb)	June, 2000
p-Dichlorobenzene	240 μg/m^3 (40 ppb)	June, 2000
Ethylbenzene	3,800 μg/m^3 (880 ppb)	Dec, 2000
Styrene	220 μg/m^3 (50 ppb)	Dec, 2000
Chlorpyrifos	1 μg/m^3 (0.07 ppb)	Dec, 2000
For children:	0.1 μg/m^3 (0.007 ppb)	
Di-n-butyl phthalate	220 μg/m^3 (20 ppb)	Dec, 2000
Tetradecan	330 μg/m^3 (40 ppb)	July, 2001
Di-(2-ethylhexyl) phthalate	120 μg/m^3 (7.6 ppb)	July, 2001
Diazinone	0.29 μg/m^3 (0.02 ppb)	July, 2001
Acetaldehyde	48 μg/m^3 (30 ppb)	
	(300 μg/m^3 (180 ppb), WHO)	Jan, 2002
Fenobucarb	33 μg/m^3 (3.8 ppb)	Jan, 2002
Total VOC	400 μg/m^3, advisable value	Dec, 2000

to meet the guidelines, while the developed ventilation control technology, and the METI and MAFF developed low-emissive materials and effective ventilation equipment and legislated standards, greatly contributing to the amendment of the Building Standards Law (BSL). The MHLW established the guideline level for formaldehyde (100 μg/m^3) in 1997 and then for 12 other chemicals, as shown in Table 15.1. Afterward, indoor air quality at individual houses improved rapidly, as shown in the discussion below.

On the other hand, air pollution in large buildings open to the public, such as museums, university buildings, department stores, and amusement facilities are not examined properly. However, it is necessary to investigate the indoor air quality of those buildings because many people visit them for the purpose of education, shopping, and entertainment. This study examined the air environment of various large buildings in Japan and the chemical exposure of employees in these buildings. Consequentially, the Act on Maintenance of Sanitation in Buildings, enforced by the MHLW, prevented the spread of SBS, which surfaced in developed countries due to policies to save energy by reducing the ventilation rate.

15.2 Methods

15.2.1 Buildings Studied

We investigated indoor and outdoor air quality at schools, book stores, hotels, a department store, a city hall, shopping malls, hotels, theaters, museums, and amusement facilities, including a pachinko parlor and a bowling alley in Japan. Brief

Table 15.2 Brief information on the buildings studied

Buildings	Purpose	Location	Year built	Floor area (m^2)
Amusement place A	Bowring alley	Kitakyushu	NA	NA
Amusement place B	Pachinko parlor	Miyazaki	NA	450
Beauty academy	School	Tokyo	2000	2,122
Bookstore A	Bookstore	Kitakyushu	1995	4,046
Bookstore B	Bookstore	Kitakyushu	1966	3,900
Bookstore C	Bookstore	Kitakyushu	NA	160
City hall	City hall	Kitakyushu	1959	4,577
Congress center	Congress	Kitakyushu	1991	8,997
Department store	Department store	Kitakyushu	NA	25,000
High school	High school	Kitakyushu	NA	15,348
Hotel A	Hotel	Kitakyushu	2002	NA
Hotel B	Hotel	Kitakyushu	1991	NA
Hotel C	Hotel	Akita	1988	3,287
Hotel D	Hotel	Tokyo	1981	84,774
Museum A	Art museum	Kitakyushu	1976	4,443
Museum B	Museum	Kitakyushu	2003	16,947
Shopping mall A	Shopping mall	Miyazaki	2005	28,631
Shopping mall B	Shopping mall	Kitakyushu	1981	7,000
Theater A	Art theater	Kitakyushu	2003	5,666
Theater B	Event hall	Kitakyushu	1994	3,584
University A	University	Kitakyushu	1978	NA
University B	University	Kitakyushu	1966	67,800

NA: not available.

information on these buildings is provided in Table 15.2. The survey was performed in 2004–2006. Some countermeasures were performed in Japan before SBS became a concern in developed countries. Administrators of buildings with 3,000 m^2 or more of architectural floor space have been obligated to observe ventilation standards by the Act on Maintenance of Sanitation in Buildings. Amusement place B (a pachinko parlor), a beauty academy, and bookstore C in Table 15.2 are outside the scope of this law because their floor space is less than 3,000 m^2.

15.2.2 Collection and Analysis of Chemicals

The concentrations of VOCs and aldehydes were measured. The chemicals were collected by a diffusive sampler in all the cases (personal exposure, indoor air, and outdoor air). A number of samplers for collecting the chemicals were set up at each sampling site so that the average indoor air condition of the area could be determined. To evaluate the personal exposure level of workers to chemicals, the personal sampler was attached to a worker's chest during working and non-working hours. After the collection, the VOC samples were stored in a freezer and the aldehyde samples were stored in a refrigerator until they were analyzed. The VOCs were analyzed as follows. An activated charcoal in a sampling tube (VOC-SD, Supelco, Sigma-Aldrich Japan) was moved to a test tube; 2 ml of carbon disulphide was added, and then VOCs were extracted. The VOCs in the extracted solution were analyzed by using a capillary gas chromatograph – mass spectrometer apparatus (Hewlett Packard, USA) with an auto sampler. The capillary column used was a 60 mm × 0.25 mm Aquatic (GL Sciences, Japan).

Aldehydes were collected by a diffusive sampler (DSD-DNPH, Supelco, Sigma-Aldrich Japan) silica gel impregnated with 2, 4-dinitrophenyl hydrazine. The aldehydes absorbed on the silica gel were extracted with 3 ml of acetonitrile. The separation and determination were performed by a high-performance liquid chromatography (HPLC) apparatus (Shimadzu LC-10 AD, Japan) using a column of Wakosil-II 5C18 HG, 250 mm × 4.0 mm (i.d.) (Wako Pure Chemical, Japan). The NO_2 absorbed by a filter (Toyo Roshi, Japan) was extracted in a solution of sulfanilic acid, phosphoric acid, and 0.1wt% N-(1-naphthyl) ethylenediamine dihydrochloride. The amount of NO_2 in the extracted solution was determined by using a UV-VIS spectrophotometer (Shimadzu UV-2200A, Japan).

15.2.3 Health Survey by Questionnaire

At the same time, as another indicator of the air quality in many of the buildings, a health survey for employees was used to investigate the incidence of multiple chemical sensitivity (MCS) and the effectiveness of the Quick Environment Exposure and Sensitivity Inventory (QEESI) (Miller and Prihoda 1999a, b) in Japanese workers. The QEESI (Japanese version) and a checklist for evaluation of fatigue were used to examine 410 workers in specific buildings.

15.3 Results

15.3.1 Indoor and Outdoor Air Quality and Personal Exposure

The characteristics of indoor and outdoor air quality in 22 public facilities are summarized in Table 15.3. To investigate the relationship between indoor and outdoor air quality, the ratio of indoor to outdoor concentrations of air pollutants were also calculated. Formaldehyde shows the highest concentration of 18.7 $\mu g/m^3$ at geometric mean (GM). Other chemicals, including acetaldehyde, toluene, xylene, ethylbenzene, decane, undecane, and limonene show relatively high concentrations of more than 5 $\mu g/m^3$ at GM. The maximum values of toluene, styrene, formaldehyde, and acetaldehyde exceed the guideline values of the MHLW, as shown in Table 15.1. However, only a few sampling points exceeded the guideline values, as shown in Figs. 15.1, 15.2, 15.3, 15.4, 15.5, 15.6, 15.7 and 15.8.

Table 15.3 Typical concentrations of air-polluting chemicals

	Compounds	[a]Indoor concentration ($\mu g/m^3$) (n = 759)			[b]Outdoor concentration ($\mu g/m^3$) (n = 30)				a/b	Personal exposure ($\mu g/m^3$) (n = 332)			
		minimum	maximum	GM	minimum	maximum	GM			minimum	maximum	GM	
Aromatic	Benzene	<1.43	78.79	1.89	<1.43	13.43	1.71		1.11	<1.43	71.58	1.78	
hydrocarbones	Toluene	<0.64	737.51	8.47	<0.64	33.50	5.13		1.65	<0.64	525.59	9.39	
	Ethylbenzene	<0.56	124.16	5.10	<0.56	20.18	2.10	***	2.43	<0.56	99.21	4.28	
	m/p-Xylene	<0.91	73.44	3.85	<0.91	18.36	1.62	***	2.38	<0.91	119.14	3.83	
	o-Xylene	<2.69	69.49	3.07	<2.69	14.37	1.56	***	1.97	<2.69	86.14	3.50	
	1,2,3-Trimethylbenzene	<4.17	142.18	2.58	<4.17	ND	ND			<4.17	177.66	2.58	
	1,2,4-Trimethylbenzene	<3.43	1322.35	3.51	<3.43	14.94	2.15		1.64	<3.43	1312.94	3.68	
	1,3,5-Trimethylbenzene	<2.74	370.96	2.31	<2.74	16.25	1.62		1.43	<2.74	416.62	2.20	
	Styrene	<4.25	369.29	3.06	<4.25	ND	ND			<4.25	123.91	2.66	*
Aliphatic	Heptane	<1.80	610.61	2.94	<1.80	20.14	1.60		1.83	<1.80	198.28	2.84	
hydrocarbones	Octane	<1.68	105.52	1.86	<1.68	10.36	1.31		1.42	<1.68	353.09	2.40	**
	Nonane	<2.09	299.12	3.05	<2.09	22.49	2.09		1.46	<2.09	268.30	2.32	**
	Decane	<2.03	1059.19	8.31	<2.03	175.86	4.76		1.74	<2.03	987.78	13.56	***
	Undecane	<8.03	298.67	10.43	<8.03	63.39	9.06		1.15	<8.03	1106.21	12.52	
	2,4-dimethylpentane	<1.02	54.12	0.98	<1.02	9.24	1.05		0.93	<1.02	149.26	0.99	
Terpenes	Alpha-pinene	<5.36	311.41	1.69	<5.36	18.44	1.32		1.27	<5.36	1262.47	2.40	**
	Limonene	<5.78	270.40	5.64	<5.78	7.00	3.05	**	1.85	<5.78	333.36	9.53	***
Alcohols	1-Butanol	<0.97	74.20	1.77	<0.97	10.58	1.09		1.62	<0.97	137.14	1.73	
	2-Ethyl-1-hexanol	<1.33	172.29	1.83	<1.33	7.13	0.78	**	2.34	<1.33	450.86	1.83	
Ketones	Methyl ethyl ketone	<1.29	103.14	1.94	<1.29	7.92	1.34		1.45	<1.29	39.53	2.16	

Table 15.3 (continued)

Compounds		[a]Indoor concentration ($\mu g/m^3$) (n = 759)			[b]Outdoor concentration ($\mu g/m^3$) (n = 30)					Personal exposure ($\mu g/m^3$) (n = 332)			
		minimum	maximum	GM	minimum	maximum	GM		a/b	minimum	maximum	GM	
	Methyl isobutyl ketone	<2.29	44.26	1.49	<2.29	12.27	1.29		1.16	<2.29	37.48	1.57	
Chlorinated	Carbon tetrachloride	<1.12	232.99	1.01	<1.12	13.08	1.04		0.98	<1.12	83.95	1.15	
organic	1,2-Dichloroethane	<0.84	17.11	0.49	<0.84	14.92	0.54		0.90	<0.84	131.43	0.50	
compounds	1,2-Dichloropropane	<0.87	9.54	0.45	<0.87	ND	ND			<0.87	ND	ND	
	p-Dichlorobenzene	<1.07	223.49	2.96	<1.07	54.22	1.65		1.79	<1.07	600.63	7.01	***
	Trichloroethylene	<1.38	11.15	0.82	<1.38	3.75	0.87		0.94	<1.38	4.56	0.74	
	Tetrachloroethylene	<1.47	83.25	1.13	<1.47	7.11	0.70		1.62	<1.47	78.32	0.75	
	1,1,1-Trichloroethan	<2.16	8.52	1.15	<2.16	ND	ND			<2.16	15.01	1.14	
	Dibromochloromethane	<0.84	40.03	0.45	<0.84	8.91	0.47		0.96	<0.84	158.00	0.48	
	Chloroform	<1.35	50.45	1.18	<1.35	8.86	1.10		1.08	<1.35	79.89	1.23	
Esters	Ethyl acetate	<2.16	491.98	2.62	<2.16	14.14	1.46		1.80	<2.16	1491.58	4.08	***
	Butyl ester acetic acid	<2.18	281.77	2.40	<2.18	9.68	1.79		1.34	<2.18	462.70	4.32	***
Aldehydes	Formaldehyde	<1.92	128.24	18.67	<1.92	38.18	9.16	***	2.04	<1.92	218.60	28.88	***
	Acetaldehyde	<1.42	134.79	9.45	<1.42	12.59	3.32	***	2.85	<1.42	128.40	15.29	***
Total VOCs		47.7	2686.44	214.43	39.07	300.42	101.19	***	2.12	54.32	3087.52	293.83	***

GM; Geometric mean. * $P<0.05$, ** $P<0.01$, *** $P<0.001$ compared to Indoor concentration.

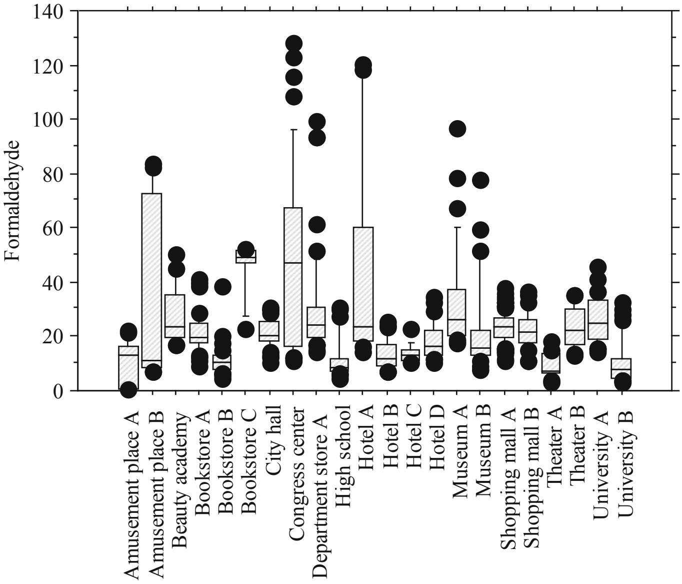

Fig. 15.1 Distribution of formaldehyde concentrations (μg/m^3) in various buildings

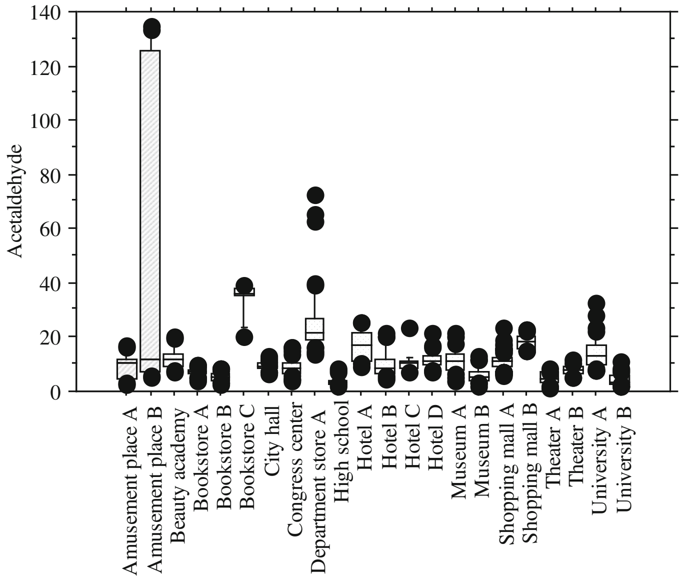

Fig. 15.2 Distribution of acetaldehyde concentrations (μg/m^3) in various buildings

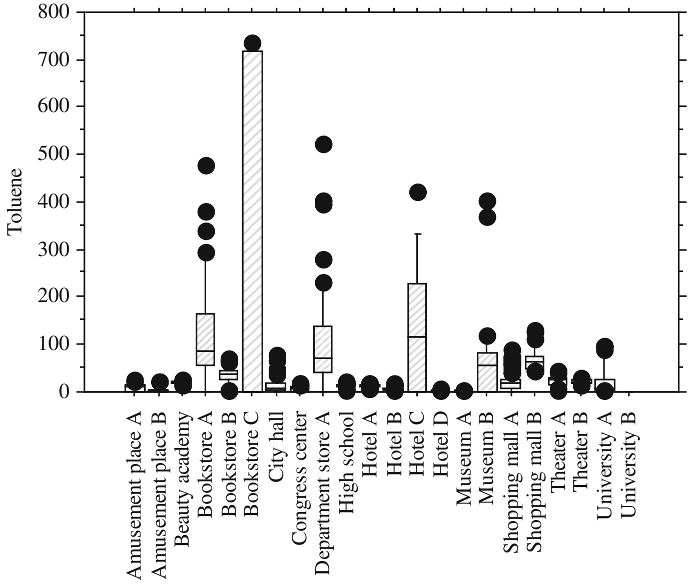

Fig. 15.3 Distribution of toluene concentrations ($\mu g/m^3$) in various buildings

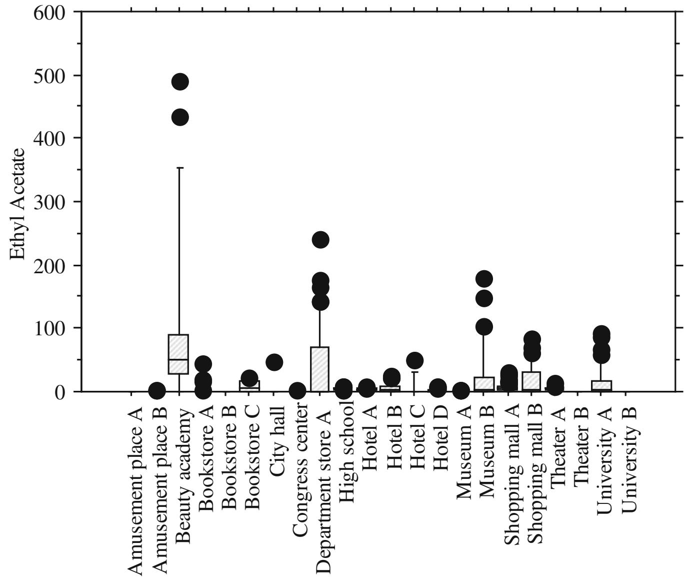

Fig. 15.4 Distribution of ethyl acetate concentrations ($\mu g/m^3$) in various buildings

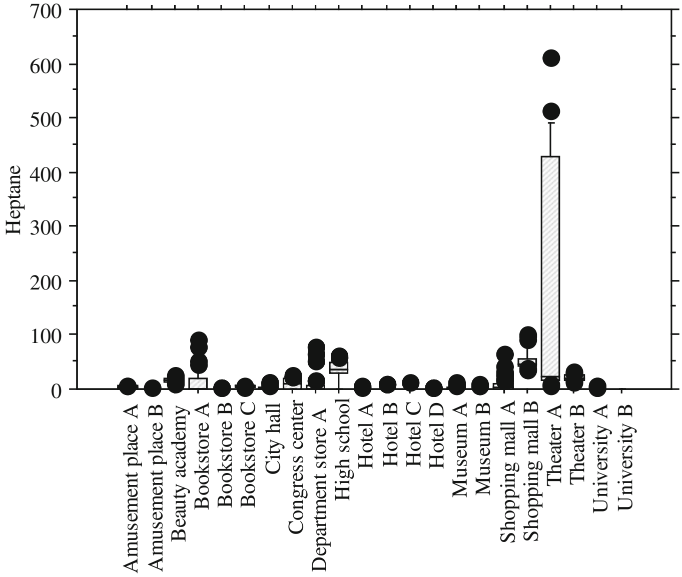

Fig. 15.5 Distribution of heptane concentrations (μg/m^3) in various buildings

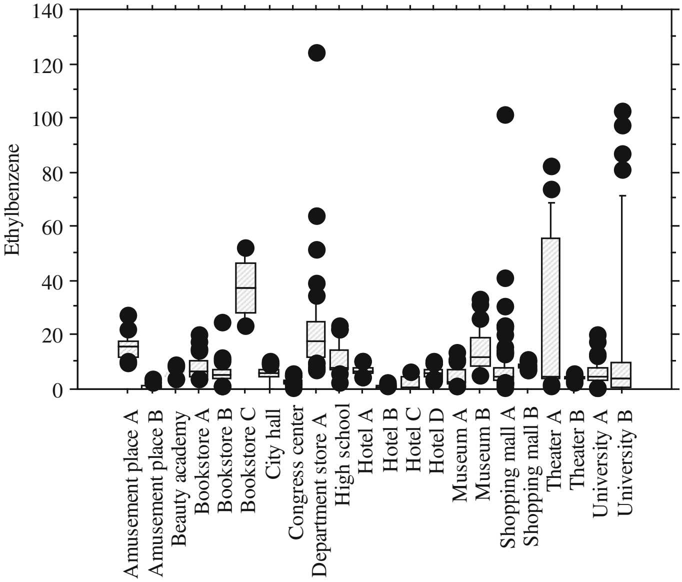

Fig. 15.6 Distribution of ethylbenzene concentrations (μg/m^3) in various buildings

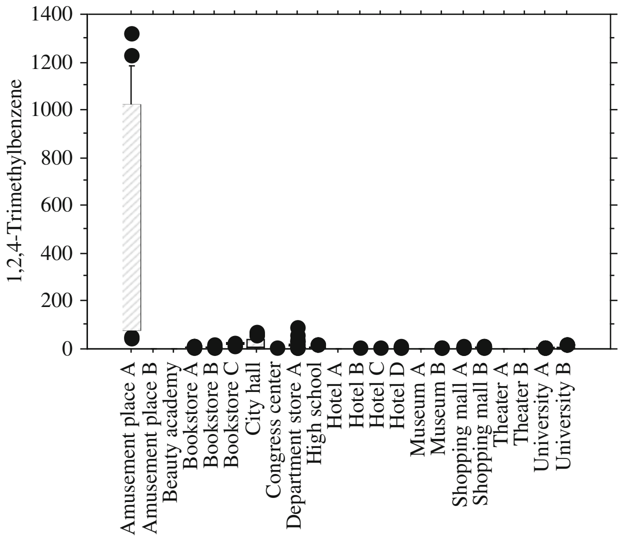

Fig. 15.7 Distribution of 1,2,4-trimethylbenzene concentrations (μg/m^3) in various buildings

Most of the chlorinated organic compounds show very low indoor concentrations. Excluding p-dichlorobenzene and tetrachloroethylene, the ratios of indoor to outdoor concentrations were almost all one or lower. On the other hand, other chemicals, especially aromatic hydrocarbons, showed a high indoor-to-outdoor ratio, suggesting indoor emission sources for these compounds.

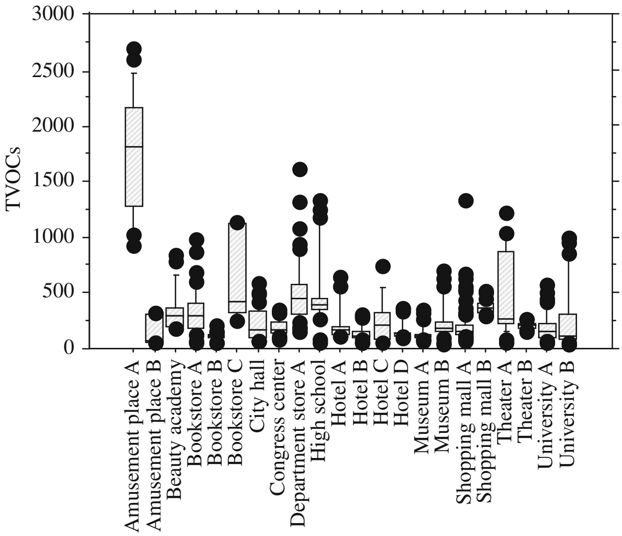

Fig. 15.8 Distribution of total VOC (TVOC) concentrations (μg/m^3) in various buildings

15.3.2 Characteristics of Air Quality and Specific Chemicals at Each Public Building

Distributions of the concentrations of specific chemicals and total VOCs (TVOCs) in various buildings are shown in Figs. 15.1, 15.2, 15.3, 15.4, 15.5, 15.6, 15.7 and 15.8 by box and whisker charts. The bottom, mid-line, and top of the box indicate the 25th percentile, median, and 75th percentile, respectively. The whiskers show the 10th and 90th percentiles.

In Figs. 15.1 and 15.2, amusement facility B showed relatively high indoor aldehyde concentrations during work hours, especially acetaldehyde, which was much higher than during non-work hours and in outdoor air (data not shown). Amusement facility B is a pachinko parlor that permitted guests to smoke. The parlor was 50% full when we investigated (about 150 customers were playing). Cigarette smoke may cause the high concentration of aldehyde in this location. Because this building has less than 3,000 m^2 of floor space, it is outside the scope of the Act on Maintenance of Sanitation in Buildings. Thus, ventilation standards are not enforced for this building. As shown in Fig. 15.1, few measurements at other buildings, including the Congress Center and hotel A, showed high concentrations (over 100 $\mu g/m^3$) of formaldehyde.

Figure 15.3 shows that the toluene concentration is high in some public buildings, especially in small bookstore C, which is also outside the scope of the Act on Maintenance of Sanitation in Buildings. The major source of toluene is considered to be printing inks used in books. Compared to other VOCs, toluene and ethylbenzene were generally detected in very high concentrations at bookstores. Large bookstores A and B also showed high concentrations of toluene, but these values are significantly less than the value of bookstore C. Because bookstores A and B have over 3,000 m^2 of floor space, ventilation standards are enforced in these buildings. In all the other buildings except department store A, hotel C, and museum B, all measurements were below the guideline values.

As shown in Fig. 15.4, ethyl acetate was detected in relatively high concentration in the beauty academy, and the concentration of butyl ester acetic acid was also relatively high. These tendencies were observed at the barber shop and beauty parlor in a university hospital, suggesting the influence of hair-dressing and cosmetic materials. At theater A, some sampling points show high concentrations of heptane (Fig. 15.5), ethylbenzene (Fig. 15.6), butanol, octane, tetrachloroethylene and methyl isobutyl ketone, these probably arise from many components, such as the carpeting, wall, and furniture.

The air quality of a bowling alley was measured (amusement place A). Of the VOCs, the concentrations of benzene (data not shown), toluene (Fig. 15.3), and xylene (data not shown) were all low, whereas those of nonane, decane, and undecane were relatively high (data not shown), and trimethylbenzene was found in very high concentration (Fig. 15.7). The personal exposure level showed the same trend as that of indoor air, and the level during work hours was higher than that during non-work hours. The high concentrations of some VOCs may come from wax on the alley and floor.

We measured air quality at department store A, a seven-story building with a total floor area of 25,000 m^2. Different VOCs were detected on each floor. Many kinds of VOCs, including toluene, ethyl acetate, ethylbenzene, methylethylketone, p-dichlorobenzene, styrene, limonene, and benzene, showed higher concentrations during work hours compared to other buildings. This may be due to the many kinds of merchandise sold at the department store.

The styrene concentration was less than the guideline value in almost all the places we investigated. Only two samples in the department store showed higher concentrations of p-dichlorobenzene than the guideline value. This may be due to the presence of moth repellents and air fresheners.

The Japanese government established a standard for NO_2 in the outdoor environment of 40–60 ppb for 1 day's average 1-h value. Only a few measurements showed a higher value than the environmental air quality standards. Specifically, NO_2 was observed at high concentrations in places where combustion tools were used, such as the restaurant in the department store (data not shown).

We also measured physical parameters (data not shown) such as temperature, relative humidity, noise, wind velocity, illumination, and particulate matter concentration in the buildings and found that those parameters were generally at an appropriate level except in the pachinko parlor. There, particulate matter exceeded the standard level, probably due to the smoking by customers, and the noise level was high, due to the nature of the gaming device.

15.3.3 Comparison of Indoor Air Quality and Personal Exposure

Of the aldehydes, the concentration of formaldehyde was twice as high as that of acetaldehyde in all measurements. The personal exposure level of about 80–90% for these aldehydes was parallel to that of indoor air. However, the personal exposure level of 10 ~ 20% for the remainder was obviously higher than the indoor concentration (Fig. 15.9). This is thought to reflect the influence of activities of individuals, including smoking, and factors in the working environment, such as working near emission sources.

Personal exposure to these two aldehydes in non-work hours (mostly spent at home) was higher than that in work hours (at the office), as shown in Fig. 15.10. These results suggest that there are more emission sources at home than at the office. Alternatively, the ventilation system required by the Act on Maintenance of Sanitation in Buildings has decreased the density of aldehyde concentrations in the office.

15.4 Discussion

15.4.1 Characteristics of Air Quality in Japanese Public Buildings

By using diffusive samplers, we were able to measure 32 kinds of VOCs, formaldehyde, and acetaldehyde. The indoor air quality in the large public buildings

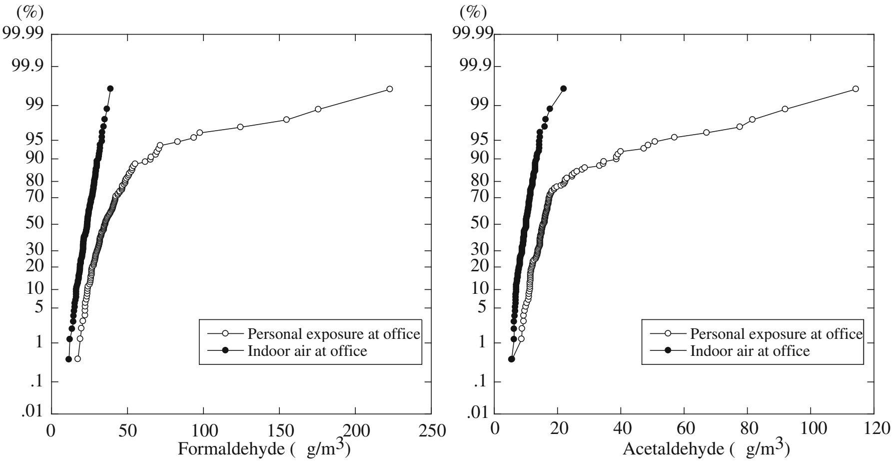

Fig. 15.9 Cumulative frequency distribution for formaldehyde (*left*) and acetaldehyde (*right*) concentrations. *Open and closed circles* show personal exposure during working hours and indoor air concentration at office, respectively

we investigated was maintained in good condition. This might be due to Japanese legal requirements that administrators of large buildings meet ventilation standards and regularly measure the indoor air environment in accordance with the Act on Maintenance of Sanitation in Buildings. Depending on the nature of the buildings, however, the kind and concentration of VOCs varied. Most sampling points in the buildings did not exceed the guideline values for formaldehyde (100 $\mu g/m^3$) and

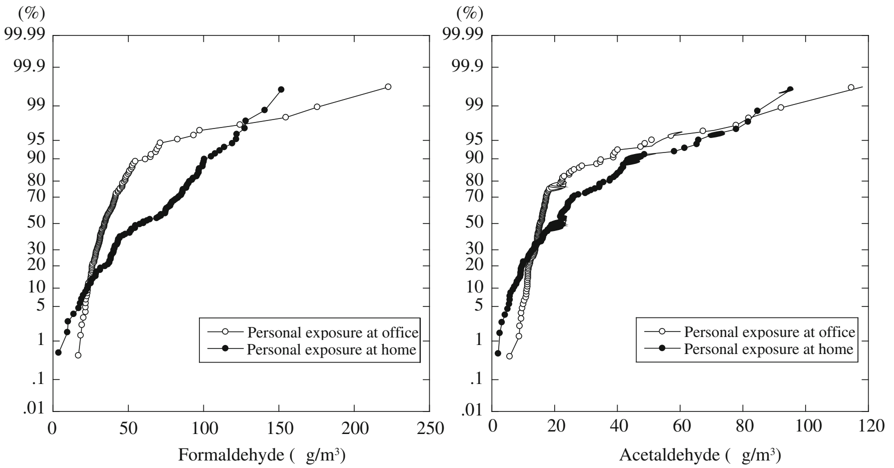

Fig. 15.10 Cumulative frequency distribution for formaldehyde (*left*) and acetaldehyde (*right*) concentrations. *Open and closed circles* show personal exposure during working hours (at office) and non-working hours (at home), respectively

acetaldehyde (48 μg/m^3), suggesting that the indoor air quality of all the buildings is good in terms of pollution by aldehydes.

The total VOCs in some buildings showed high concentrations (Fig. 15.8). The toluene in bookstores may come from printing ink used in books. The trimethylbenzne in the bowling alley (amusement place A) was considered to come from wax on the floor. The managers of these buildings may need to consider better ventilation.

Overall, air quality in various large buildings and employees' personal exposure levels were relatively good, especially for chemicals that have guideline levels set by the MHLW. However, we must note that there were some exceptional cases, such as toluene in bookstores and aldehyde and noise in the pachinko parlor.

15.4.2 Characteristics of Air Quality in Japanese Individual Houses

On the other hand, what is the indoor air quality in individual houses in Japan? Recently, Osawa and Hayashi reported the status of chemical pollution of indoor air in Japanese houses based on a nationwide field survey from 2000 to 2005 (Osawa and Hayashi 2009). A survey in 2000 revealed that the indoor concentrations of formaldehyde and toluene exceeded the guidelines shown in Table 15.1 in more than 27 and 12% of the houses surveyed, respectively. These results led to the development of various countermeasures for improving the indoor air environment, such as amending the Building Standard Law (BSL) to a performance-based regulation and enacting the Housing Quality Assurance Act, which provides a housing performance indication system. These countermeasures decreased the levels of indoor chemicals, especially formaldehyde and toluene, year by year, as shown in Fig. 15.11. In addition to improvements in building materials and the new installation of continuous ventilation systems under the amended BSL, these successes depend on many efforts for the improvement of indoor air quality by the

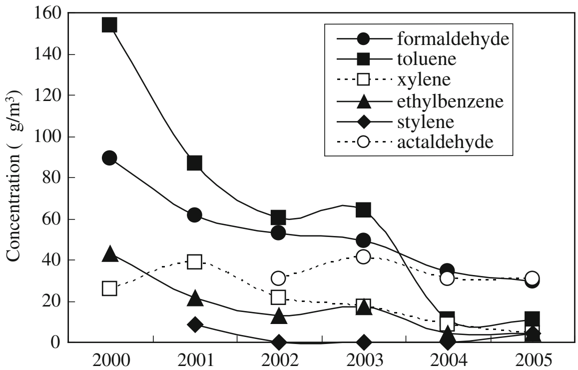

Fig. 15.11 Changes in the indoor concentration of VOCs in Japanese houses

government, private construction companies, manufacturers of building materials, and various other interested parties.

In addition, the countermeasures are ongoing, expanding the target from formaldehyde, a major pollutant at the time, to other VOCs and microbial volatile organic compounds (MVOCs) (Kilburn 2009; Kishi et al. 2009; WHO 2009).

While the changes in severe sick house problems in our country such as rapid air tightening, and heavy use of pollutant-emitting materials are not necessarily shared in other countries, changes in the residential environment are shared across hot and humid East Asia. Therefore, understanding and evaluation of housing conditions is expected to have considerable application in the future.

15.4.3 Questionnaire Survey of Workers by QEESI

Three criteria used in the QEESI (symptom severity, chemical intolerance, and other intolerance) were evaluated in this study (Hojo et al. 2009). Clinical histories were also surveyed. Responses were obtained from 368 (89.8%) of 410 workers (Manabe et al. 2008).

The results showed that 132 individuals (35.9%) have been diagnosed as having allergies. Only two individuals (0.5%) were found to be MCS patients, and none were SBS patients. Applying the "high" criteria of the QEESI to the standard of Miller and Prihoda (1999a, b), we determined that only four individuals (1.1%) met all three criteria, and 17 individuals (4.6%) met two of the three criteria, as shown in Fig. 15.12 . These values are the same as the values in previous Japanese reports (Hojo et al. 2008; Katoh et al. 2007) and less than those reported by Miller and Prihoda (1999a, b).

The QEESI score of allergic persons was higher than that of non-allergic persons (Fig. 15.13). Among non-allergic persons, those who scored high for accumulation

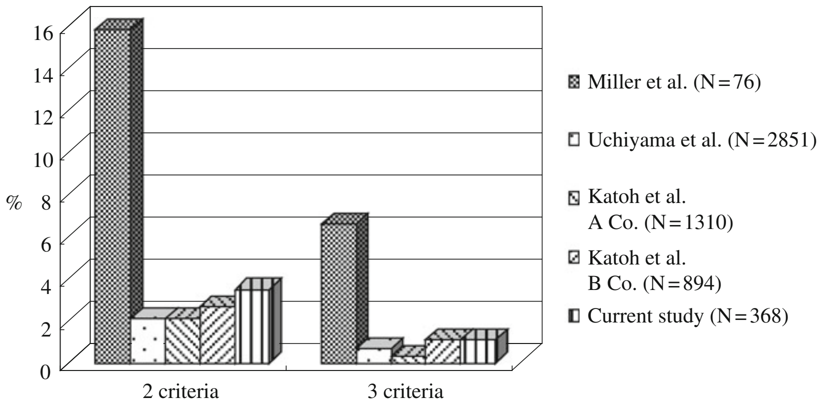

Fig. 15.12 Proportion of subjects who met two or three criteria (symptom score, chemical intolerance score, and other intolerance score) of the QEESI questionnaire

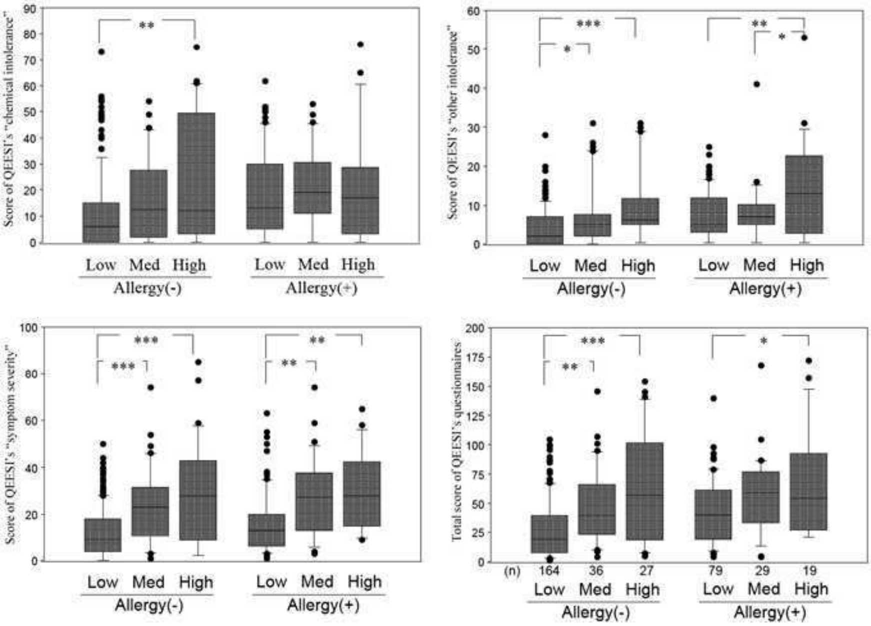

Fig. 15.13 Relationship of allergy and work load to QEESI score (chemical intolerance score, symptom score, and other intolerance score). *Low, Med* and *High* indicate the workload assessed by a checklist on the accumulation of fatigue developed by the Ministry of Health, Labor, and Welfare, Japan

of fatigue in the checklist showed a high score in the QEESI. These findings indicate that the QEESI score tends to increase with workload and to be high in individuals with allergies. Therefore, careful consideration is required when QEESI is used to screen MCS patients in Japan.

15.4.4 Aldehyde Concentration Under Specific Circumstances in Medical Laboratories

The concentration of formaldehyde is quite high under specific circumstances, including in medical laboratories. Formaldehyde is widely used during disinfection procedures or embalming of bodies in the medical field. Medical students are exposed to formaldehyde during their dissection course. First, we evaluated formaldehyde exposure that occurred in a gross anatomy laboratory with a general ventilation system. Formaldehyde in the air was sampled by an active 2,4-dinitrophenylhydrazine (DNPH)-silica gel cartridge, extracted with acetonitrile, and analyzed by HPLC. The GM formaldehyde concentration was 20–93 ppb in the anatomy laboratory before dissection began. After dissection began, the highest GM concentrations were 1,011–1,380 ppb (Kunugita et al. 2004). This suggests we should reduce formaldehyde exposure for medical students and lecturers during gross anatomy dissection courses. Next, we improved the ventilation by using a local ventilation system that included the existing ventilation assigned to the laboratory and a newly developed local ventilation apparatus for each dissection table. After these improvements, the GM concentrations were 100 ppb or less (Yamato et al. 2005). Significant decreases were also observed in symptoms of thirst, burning eyes, itchy eyes, feeling uncomfortable, and fatigue during exposure compared with the symptoms before the ventilation system was improved.

15.4.5 Biological Evaluation in Mice Exposed to Low Dose of Chemicals

To understand the effect of low dose exposure of VOCs on neuro-immuno-endocrine networks, we have studied many kinds of animal experiments (Ahmed et al. 2007a, b; Fujimaki et al. 2004a, b, 2007; Hayashi et al. 2004; Sari et al. 2004, 2005; Tsukahara et al. 2006; Win-Shwe et al. 2010a, b; Yamamoto et al. 2009). Our study showed that long-term exposure to low level of formaldehyde and the allergic condition induced by OVA sensitization may act to the hypothalamo-pituitary-adrenal gland (HPA)-axis as a stressor (Hayashi et al. 2004; Sari et al. 2004, 2005). Exposure to 80 and 400 ppb formaldehyde significantly increased the brain NGF levels in the OVA immunized mice (Fujimaki et al. 2004a). We have also demonstrated that low-level toluene and formaldehyde exposure affects memory function-related gene expression in the hippocampus of C3H/HeN mice (Ahmed et al. 2007a, b).

Long term exposure to low levels of VOCs including formaldehyde and toluene can disturb normal homeostatic response to enhance neural network, and coadministration with immunological stimuli can activate it abnormally, resulting in induction of neurogenic and immunogenic inflammation in the brain.

15.5 Conclusions

The indoor air quality in large public buildings we investigated was maintained in good condition. The level of personal exposure generally showed the same tendency as the indoor air pollution level. This might be due to the Japanese legal requirements that administrators of large-scale buildings meet ventilation standards and regularly measure the indoor air environment in accordance with the Act on Maintenance of Sanitation in Buildings. Although the lifestyle and engineering methods used in indoor and outdoor structures are not similar elsewhere, the living environment has changed in similar ways in many countries. Therefore, understanding and evaluating these conditions is expected to have considerable application in the future.

The basis of indoor air quality control is suppressing pollutants at the source by regulating materials and eliminating pollutants by securing ventilation. Neither of these measures alone is sufficient; both must be used in good balance within technological and economic restrictions.

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Chapter 16
Assessment of Chemical Hazards in Sick Building Syndrome Situations: Determination of Concentrations and Origin of VOCs in Indoor Air Environments by Dynamic Sampling and TD-GC/MS Analysis

Eva Gallego, Francisco Javier Roca, José Francisco Perales, and Xavier Guardino

16.1 Introduction

Nowadays, people spend approximately between 80 and 90% of the hours of the day indoors. So, the subgroup of population more sensitive to contaminants is at much greater risk of having adverse health effects deriving out of the chronic exposition to low levels of indoor air pollutants (Bernstein et al. 2008; Ashmore and Dimitroulopoulou 2009; Jo and Sohn 2009; Xu et al. 2010). Volatile organic compounds (VOCs), defined as having a boiling point that ranges between 50 and 260°C (WHO 1989), are a highly diverse class of chemical contaminants; and between 50 and 300 compounds may be found in non-industrial indoor air environments (Mølhave 1992; Johansson 1999; Gallego et al. 2008a; 2009a). Due to their low boiling point, VOCs pass to indoor air in vapour form.

High levels of VOCs may be found indoors due to several causes, e.g. type of building materials, poor function of the ventilating system, recirculation of ventilation air, moisture damage of building materials or the development in the building of not advisable activities (Lundgren et al. 1999). VOC have been generally less studied than other indoor air contaminants, and the knowledge of the adverse effects on health associated to indoor air VOCs concentrations is nowadays limited (Edwards et al. 2001; Venn et al. 2003; Järnström et al. 2006; Liang and Liao 2007; Bernstein et al. 2008; Rios et al. 2009; Yu et al. 2009). On the other hand, the different exposition locations to VOCs (e.g. homes, work environment, public buildings, vehicles, outdoor air) and their different pollution loads lead to uncertainties when an evaluation of personal exposure is to be done (Sexton et al. 2004; Peng and Lin 2007; Ashmore and Dimitroulopoulou 2009).

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Therefore, concentration controls are important in air quality determination, and VOCs levels in indoor air should be legislated and maintained as low as reasonably achievable (ALARA), to diminish the organic pollution load in these environments (EC 1997a; Hodgson et al. 2000; Righi et al. 2002; Mølhave 2003). In addition to that, accurate pollution controls would improve health risk assessments and the risk management decisions taken in relation to indoor contamination (Sexton et al. 2004). In this way, the procedure for sampling and analysis low concentrations of VOCs in indoor air building samples has been standardized (Gallego et al. 2009a).

16.2 Health Effects and Reactions Caused by Exposition to Low Levels of VOCs

Several human VOCs exposure studies have been carried out to determine possible health effects (Wolkoff 1995; Andersson et al. 1997; Pappas et al. 2000; Mølhave 2001; Zeliger 2003; Hey et al. 2009), as well as in-vitro experiments to determine the role of VOCs in inflammatory and immuno-modulatory effects in human tissues (Wichmann et al. 2005; Lehmann et al. 2008; Pariselli et al. 2009). However, the VOCs concentrations experimented are relatively high and far from the usual dwelling concentrations, making difficult the extrapolation between the results obtained and the real effects of indoor air VOCs concentrations (Holcomb and Seabrook 1995; Wolkoff et al. 1997).

In addition to that, VOCs concentrations that trigger adverse reactions in target population (e.g. sick building syndrome and multiple chemical sensitivity affected people), are generally tolerated by the general population (Zeliger 2008). On the other hand, the evaluation of health issues caused by complex VOCs mixtures is also difficult because their effects may be additive, synergistic, antagonist or even independent for each other, making hardly predictable the toxicological consequences of VOCs exposition to human wellness (Mølhave et al. 1997). However, a daily exposure to multiple chemicals (e.g. VOCs) could contribute to an increasing prevalence of several illnesses (Pappas et al. 2000; Bernstein et al. 2008; Rios et al. 2009), such as asthma, medically unexplained symptoms and childhood cancer (Zhang and Smith 2003).

16.2.1 Sensory Irritation and Odour

Environmental pollutants can act as irritants to the human organism. Pollutants can cause biological responses from the different components that comprise the human defense system, being the responses different depending on the susceptibility of each individual (Bascom et al. 1995). Poor indoor air quality has been strongly associated to both irritation and odour nuisances (Pappas et al. 2000; Mølhave 2001; Wolkoff et al. 2006). On the other hand, in relation to outdoor air quality, the exposure to traffic-related VOCs has been linked to respiratory tract irritation (phlegm and chest tightness), as well as to sore throat, cough and asthma (Kongtip et al. 2006; Ana et al. 2009). In addition to that, a 45% of the compounds determined in a dwelling where complaints were related to industrial activities, presented combined R-phrases associated to irritation of the eyes, skin and respiratory system (Gallego et al. 2009a).

16.2.2 Sick Building Syndrome

The term sick building syndrome (SBS) describes the reduction of comfort and health status of the occupants of a whole building or a part of it, where the residents have complaints with the perceived indoor air quality and relate them to possible health effects (Maroni et al. 1995). The symptomatology of SBS is varied and complex, but nasal, ocular, oropharyngeal, cutaneous and general (tiredness, headache, etc.) manifestations are the five most common symptoms (Guo et al. 2004). The causes of SBS remain unknown and further investigations have to be done (Eberlein-Königa et al. 2002; Dalton 2003) but some factors have been described to contribute in SBS, such as outdoor and indoor chemical contaminants (e.g. VOCs), biological contaminants and inadequate ventilation (WHO 1982; WHO 1986; EC 1989; Wang et al. 2008).

16.2.3 Multiple Chemical Sensitivity

People repetitively exposed to long-term relatively high levels of VOCs, specially the subgroup of population more sensitive to VOCs concentrations found indoors, can modulate their physiological response to a given VOC (Hummel et al. 1999; Wolkoff and Nielsen 2001; Chun et al. 2010), and achieve multiple chemical sensitivity (MCS) (Levy 1997; Shorter 1997; Zeliger 2008). Multiple symptoms (e.g. chest pain, dry eyes, anxiety, headache, nausea) can appear to affected people when they are exposed to low levels of VOCs, generally tolerated by healthy population (Zeliger 2008). MCS can implicate disruptions in immunological and/or allergy processes, alterations in nervous system functions, changes in biochemical or biotransformation capacities and changes in psychological and/or neurobehavioral functions in human organisms (Winder 2002).

16.3 Sources of VOCs in Indoor Air

Most indoor air pollution comes from sources inside the building, such as adhesives, carpeting, building materials, tobacco smoke, wood products or cleaning products, which may emit VOCs (Knöppel and Schauenburg 1989; Seltzer 1995; Salthammer 1997; Jones 1999; Hodgson et al. 2000; Jensen et al. 2001; Reiser et al. 2002;

Zhang and Xu 2002; Jia et al. 2008a; Katsoyiannis et al. 2008). However, the building design and the ventilation applied to indoor environments (both natural and/or mechanical) would also be a determinant in the ingress of outdoor pollution indoors (Seltzer 1995; Olson and Corsi 2002; Ashmore and Dimitroulopoulou 2009).

Outdoor air that enters the building through poorly located air intake vents, windows and other openings can also be the main source of indoor air pollution for some contaminants, for example, pollutants form motor vehicle exhausts, plumbing vents, building exhausts (kitchen and bathroom exhausts) and combustion products from a nearby garage (EC 1989; Mølhave 1991a; EC 1997b; Mølhave 1999; Weschler and Shields 2000; Zuraimi et al. 2003; Weisel et al. 2005; Batterman et al. 2007). In addition to that, emission of odorous VOCs from heating, ventilating and air conditioning (HVAC) HVAC filters have been observed, being these compounds associated to the dust layer in the filter and the microbial growth (Seppänen and Fisk 2002; Fisk et al. 2002; Hummelgaard et al. 2007; Hyttinen et al. 2007; Yu et al. 2009).

Nevertheless, it has to be taken into account that the entrance of outdoor air indoors due to its infiltration through the building fabric has decreased in the last decades. Improvements in buildings airtightness (better building techniques and new materials) have been applied to reduce energy costs and maintain comfortable temperatures indoors (Yu et al. 2009), as well as to maintain good levels or indoor air quality (Ashmore and Dimitroulopoulou 2009). However, an increase in artightness can also decrease natural ventilation rates in dwellings not provided with HVAC systems, leading to an increase of pollution indoors due to the emission of VOCs from building materials (Hodgson et al. 2000; Jia et al. 2008a; Kim et al. 2008; Yu et al. 2009).

The knowledge of VOCs concentrations and its sources in buildings is a key parameter to regulate indoor air quality and establish effective pollution source control strategies and energy-efficient ventilation guidelines (Zuraimi et al. 2003). Consequently, chemical control based in VOCs adsorption onto solid sorbents followed by thermal desorption coupled to gas chromatography/mass spectrometry is a reliable methodology to identify and quantify VOCs concentrations indoors (Ribes et al. 2007; Gallego et al. 2008a; b; Gallego et al. 2009a; b).

16.3.1 Indoor Sources

Building materials are among the most important VOCs emitters in indoor environments (EC 1992; Maroni et al. 1995). Furniture and furniture coatings have been found to cause an increase of the levels of VOCs indoors, especially when low air exchange rates are applied to the building (e.g. the absence of HVAC systems) (Salthammer 1997; Chan et al. 2009). In addition to that, household products (e.g. detergents and waxes) are also an important source of VOCs indoors. It has been observed that the absence/presence of water in its composition is an important trigger of VOCs emissions (Knöppel and Schauenburg 1989).

On the other hand, human activity related processes (e.g. cleaning and cooking) can also be important sources of VOCs in indoor air (Wolkoff et al. 2006). Hence, due to the differences existing in heating and cooking, indoor VOCs sources derived from these activities would be different in developed and in developing countries, as well as between people from different socio-economic conditions (Godish 2001; Rehfuess et al. 2006; Ashmore and Dimitroulopoulou 2009). The use of biomass fuels inside the building to cook and/or to heat the dwelling is one of the main causes of bad indoor air quality and poor health worldwide (WHO 2002; Prüs-Üstüm and Corvalán 2006; WHO 2006).

In addition to that, a garage directly connected to the house has been identified as one of the most influential factors in indoor air pollution (Duarte-Davidson et al. 2001; Ilgen et al. 2001a; Emmerich et al. 2003; Batterman et al. 2006; 2007; Gallego et al. 2008b; Jia et al. 2008a). Apart from the VOCs released from gas-fired engines, other products present in garages (e.g. paints, varnishes, solvents) can also emit pollution into the indoor environment of the garage and consequently to the attached house (Emmerich et al. 2003). Tobacco smoke is another important source of VOCs indoors, which can increase benzene concentration in indoor air (Edwards and Jantunen 2001; Schlink et al. 2004; Gallego et al. 2008c; Jia et al. 2008a).

Moreover, the professional activities developed in buildings (e.g. offices, libraries) are also noteworthy to the burden of VOCs found in these indoor environments (Zuraimi et al. 2004). Desktop and notebook computers, monitors, printers and copiers are VOCs emitters (Destaillats et al. 2008).

16.3.2 Outdoor Sources

Outdoor air is also a known cause of indoor air pollution (Seltzer 1995; Saarela et al. 2003; Jia et al. 2008a; Chan et al. 2009). Industries, power plants, refineries, gas stations and major roads would be potential VOCs sources for indoor air (Seltzer 1995; Chan et al. 2009). However, the proximity to these sources is not always translated into higher levels of VOCs indoors (Jia et al. 2008a), as other factors such as environmental variables (e.g. temperature, humidity, wind direction and wind speed) can alter VOCs concentrations as well as carry them farther from the nearest place, creating annoyance in locations far away from the original source (Gallego et al. 2008a; b). Nevertheless, traffic density is an important source of benzene, toluene and xylenes (BTX) indoors, as generally higher concentrations of BTX and other VOCs are found in indoor environments in dwellings located in high traffic density areas (Baek et al. 1997; Mohamed et al. 2002; Zuraimi et al. 2003; Gallego et al. 2008c; Jia et al. 2008a).

16.3.3 Seasonal Variations

Seasonal patterns in indoor air VOCs concentrations have been observed in several studies (Baek et al. 1997; Ilgen et al. 2001b; Schlink et al. 2004; Gallego et al. 2008c; Jia et al. 2008a). Generally, winter time present higher VOCs concentrations than summer time (Jia et al. 2008b), mainly owing to higher ventilation rates during summer (Schneider et al. 2001), and being the observed summer concentrations up to three to four times higher. However, the type of the room evaluated and the individual VOC considered could vary this seasonal pattern (Schlink et al. 2004).

16.3.4 New and Established Buildings Differences

An important percentage of the complaints related to indoor air nuisance and odours are correlated to new buildings or the use of new building materials (Mølhave et al. 1991b; Kim et al. 2008; Jo and Sohn 2009). Generally, VOCs concentrations related to building materials decrease in several factors since the building or the renovation of the dwelling, nevertheless, the decrease would depend on the kind of compound and the material characteristics (e.g. material thickness) (Lundgren et al. 1999; Hodgson et al. 2000; Huang and Haghighat 2003; Tuomainen et al. 2003; Zuraimi et al. 2004; Järnström et al. 2006; Jo and Sohn 2009).

In addition to that, VOCs emitted by building materials tend to be replaced by other VOCs, related to the activities developed in the building, as the occupancy period broadens (Järnström et al. 2006). On the other hand, it has been observed that some of the building materials can behave as VOCs reservoirs, emitting VOCs under diffusion or reactions with air during longer periods of time (Reiser et al. 2002; Zuraimi et al. 2004). Hence, the concentration of individual VOCs would be different between dwellings depending on the presence or absence of potential emission sources of each kind of compound.

Several countries, e.g. North European, Asian and the United States of America, have developed labelling schemes to regulate the maximum permissible emissions of VOCs from building materials, especially carpets and flooring materials (Järnström et al. 2006; Katsoyiannis et al. 2008), and have established recommended guidelines for VOCs concentration levels in new buildings (Kim et al. 2008; Jo and Sohn 2009). However, these labelling are generally country-specific and the test experiments to determine VOCs emissions are not standardized. In this line, the European Union underlined in 1997 the necessity of an extensive applicable validated methodology for the evaluation of VOCs emissions from building materials (EC 1997b). Hence, more demanding and systematized methods to determine VOCs emissions for all building and furnishing products should be established worldwide (Reiser et al. 2002; Katsoyiannis et al. 2008).

16.4 Indoor (IAQ) Determination

Air quality can be defined in a variety of ways, but the most realistic form to define it would be in terms of a measurable condition of the atmosphere. Generally, specific atmospheric pollutants are established and measured, physically or chemically, in real-time or average concentrations (Godish 1997; Johansson 1999; Mølhave 2003;

Monks et al. 2009). Outdoor air quality in a specific place and period of time would depend on several variables, such as the chemical emissions to the atmosphere, the source emission density, the topography and orography of the area, the meteorological conditions and the territorial planning (in many occasions industrial facilities are located very close to inhabited areas).

Due to the specific meteorology of the area, changes in the wind regimes can cause variability in air quality over the course of the year, over 24 h periods and from one location to another (Godish 1997; Gallego et al. 2008b). On the other hand, indoor air quality (residential, commercial, office and public buildings) would depend mainly on the emissions from a variety of sources, including building materials and appliances of various types and consumer products, environmental tobacco smoke, outdoor air entrance and ventilation rates (Maroni et al. 1995; Godish 2001).

Varied types of VOCs and in variable concentrations, as it has been said previously, can be found in non-industrial indoor air environments (Gallego et al. 2008a; 2009a). Hence, the interest in determining air quality in reference to VOCs concentrations in both indoor and outdoor air has increased over the last several decades (EC 1997a; Atkinson 2000; Wolkoff and Nielsen 2001; Zuraimi et al. 2006; Liang and Liao 2007; Peng and Lin 2007; Vautard et al. 2007; Jia et al. 2008b; Gallego et al. 2009a), mainly due to their association with odorous annoyance and SBS symptoms (Hutter et al. 2006; Gallego et al. 2008a; Wang et al. 2008; Peng et al. 2009).

Environmental analysis means in many cases the analysis of pollutants in trace and ultra-trace quantities (Ras 2008). The complexity of pollutants occurrence in the atmosphere, in terms of composition (polar to non-polar compounds, very volatile and semi-volatile compounds) and abundance (below detection limit (ppbv to pptv) to over detectors saturation limit), points out the necessity to develop versatile analytical methods (Desauziers 2004; Ribes et al. 2007). Consequently, sensitive, selective, fast and reliable methodologies are needed to detect pollutants in ambient air to determine air quality, and concentration techniques have often to be applied prior to the analysis (Harper 2000; Dettmer and Engewald 2002; Desauziers 2004; Demeestere et al. 2007; Ulman and Chilmonczyk 2007; Barro et al. 2009).

In this line, chemical control, based in the adsorption of pollutants in solid sorbents and their posterior analysis by TD-GC/MS, is used for the individual determination of a wide range of odorous and nuisance VOCs present in air samples (Ribes et al. 2007; Demeestere et al. 2008a; Gallego et al. 2008a), and has been successfully used in the determination of air quality (Dettmer and Engewald 2003; Donaldson et al. 2003; Kuntasal et al. 2005; Ribes et al. 2007; Ras 2008). However, when an analytical methodology is developed to study air quality, several terms have to be taken into account such as the pollutant state (gaseous or particulate matter), compound type or family, compound concentration, period of measurement (short- or long-term, e.g. instantaneous, 24-h, monthly or yearly concentrations), the measurement site (in situ or in the laboratory) and the principal aim of the study (qualitative, estimation of a emission, punctual or long-term concentrations, main, minor or trace components study).

Thus, the application of solid sorbent chemical control methodologies to pollution and air quality determination is an essential parameter to establish exactly the type and kind of compounds that are present in the atmosphere (Dettmer and Engewald 2003). The sampling enriches the analytes in the adsorbent, removing selectively form the matrix the target compounds by adsorption with the sorbent surface (Harper 2000). Target compounds are further analyzed using generally chromatographic techniques (Camel and Caude, 1995; Demeestere et al. 2008a; Woolfenden 2010a), as the single component analysis of the constituents of the atmosphere is preferred to the sum of pollutants in the case of VOCs (Dettmer and Engewald 2002; Ras 2008).

In addition to that, with the implementation of a methodology based on the simultaneous application of social participation and chemical control it is possible to identify and evaluate air quality in different environments. Social participation makes it possible to create databases of odour episodes, obtain sensory measurements (by determining the annoyance index) and obtain samples during odour episodes (through the activation of VOCs samplers) (Gallego et al. 2008b).

When we are faced with an indoor air quality problem, three different steps should be taken. First of all, a record of sensory and occurrence data (through social participation) should be done to determine the type of annoyance episodes and the timing incidence of the events. Secondly, a survey of an adequate ventilation of the dwelling might be performed to discard possible bad ventilation causes. And thirdly, a chemical control strategy should be established to determine exactly the kind of compounds that are causing the discomfort and the SBS symptoms, and verify their possible sources in order to diminish their emissions into the indoor air atmosphere.

16.4.1 Sensory and Occurrence Data

A model of social participation that records data about the frequency and duration of odour episodes and annoyance symptoms using sensory data that meet a number of criteria in terms of participation levels, discernment and representation is an exceptional tool in the process of odour/nuisance episode evaluation. Besides, sensory databases can be built to measure the scale of annoyance, the effects detected, and the potential sources of emissions. In the same way, questionnaires can be conducted in which odour/nuisance can be correlated with hourly meteorological data (Nicolas et al. 2007) in cases of outdoor pollution entering indoors (Gallego et al. 2008a).

In order to obtain significant data about the origin of episodes over regular 24-h periods, social participation must be defined. In this case, it consists in obtaining sensory and occurrence data, and in activating a VOCs sampler during odour episodes when medium and high odour intensity and nuisance are perceived by the inhabitants of the dwelling (Sect. 16.4.3).

The database can be built using questionnaires (Aitken and Okun 1992; Roca et al. 2005), ranging from the most simple (Fig. 16.1) to the most complex (Fig. 16.2), whose data is related to effects that have been detected, such as

Questionnaire model to register odour episodes

Personal data
Name:
Address:
Telephone:
Annoyance data
Date of the odour episode
Hour of beginning of the odour episode
Hour of finishing of odour episode
Location of odour
Odour description
Odour intensity each half-hour according to the next scale:

1 No odour
2 Lightly perceptible odour
3 Clearly perceptible odour
4 Strong odour
5 Very strong odour

Fig. 16.1 Simplified method of an odour episode form

MONTH

ODOR FORMULARY (UPC)

CODE

First Name-Surname ______________________ Address ______________________

1 : NO ODOR 2 : LIGHTLY PERCEPTIBLE ODOR 3: CLEARLY PERCEPTIBLE ODOR 4: STRONG ODOR 5: VERY STRONG ODOR

HOUR	00:00 - 08:00								08:00 - 16:00								16:00 - 24:00							
DAY	00-01	01-02	02-03	03-04	04-05	05-06	06-07	07-08	08-09	09-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23	23-24
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Fig. 16.2 Odour formulary prepared for social participation in odour assessment studies. Hour and intensity of odour are annotated

headaches, nausea and irritation of the respiratory system, and to personal circumstances (time of presence in the place, type of work, etc.). Standard questionnaires should include the date of the odour episode, the time the odour episode began, the time the odour episode ended, the location of the odour, a description of the odour and its intensity, which should be recorded every 30 min using the following scale: 1, no odour; 2, slight odour; 3, clearly perceptible odour; 4, strong odour; and 5, very strong odour (Gallego et al. 2008a; b).

The assignment of specific values for odour intensity (Aitken and Okun 1992; McKenzie and Mann 2004) is one way to quantify to what extent odours annoy people over time. As several factors, such as differences in sensitivity to odours, can influence the participants' responses, these control processes are not considered very objective. Nevertheless, citizen participation can provide a great deal of very important information about episodes of low air quality and aid in the identification of the chemical compounds responsible for odour episodes (Gallego et al. 2008a). Before filling out these forms, participants should take part in preparatory sessions in order to explain them the rules for recording odours and common problems. Integration in a continuous information process helps to maintain a high ongoing participation level throughout a control process.

Questionnaires that record data on a quarter-hourly basis produce an ample database (60,000 data over a 6-month period) (Roca et al. 2005), which, in cases of outdoor air being the main source of indoor pollution, can be used to map episode roses (frequency of episodes graphed along the 16 cardinal directions, like wind roses) and annoyance indices that make it possible to determine the contributions of the known emission sources and to identify initially unknown or unconsidered sources in the group of VOCs emitters (Roca et al. 2006). The final identification of unknown emission sources would be determined by using additional data from the chemical analysis of air samples and mathematical modelling (Gallego et al. 2008b).

16.4.2 Annoyance Index

The obtention of the annoyance index (AI) is done according to the following validation criteria (Aitken and Okun 1992; Roca 2006):

a. Participation level: The participant is eliminated if his/her response is lower than 70% (fewer than 456 annotations in a 6-month period).
b. The participant is eliminated if the discernment coefficient (CD) is smaller than 0.3 and F(1) = 0 or F(2)+F(3) = 0.

$$\mathbf{CD = \sigma_{2-5}/\sigma_{max}}$$

Where:

σ_{2-5}: Standard deviation of the number of responses in the different ranges comprised between 2 (light annoyance) and 5 (very high annoyance).

σ_{max}: Maximum possible standard deviation for the total number of responses with an annoyance level between 2 and 5.

F(1): Number of annotations for annoyance index 1 (no annoyance).
F(2): Number of annotations for annoyance index 2 (light annoyance).
F(3): Number of annotations for annoyance index 3 (moderate annoyance).

c. The participant is eliminated for the month if:

$$X_i \notin [X - S, X + S] \ or \ S_i > 2S$$

Where:

X_i: Average value of the participant's sensory annotations for the range 1–5.
X: Average value for all participants in the area for the range 1–5.
S: Standard deviation of the annotations of all participants in the area.

Based on the resulting data after the aforementioned criteria have been applied, the AI is calculated by applying a weighted value for each annoyance value: 0 for value 1, 25 for value 2, 50 for value 3, 75 for value 4 and, finally, 100 for value 5. The final result, expressed as an annoyance percentage (scale: 0–100) is calculated using the following expression:

$$AI(\%) = (1/N_k)\, \Sigma_i\, (W_i N_{ik})$$

Where:

AI: Annoyance index for the period under study
N_k: Total number of annotations
I: Annoyance value (1–5)
W_I: Weighting factor
N_{iK}: Number of annotations for each annoyance value

The AI values can be calculated for daily, hourly or monthly intervals for each of the affected locations.

16.4.3 Survey of Adequate Ventilation/Comfort

Mechanical ventilation has to assure the renovation of indoor air, removing indoor-generated air pollutants, and provide thermal comfort and good indoor air quality in a building (EC 1992; TIP-VENT 2001; ASHRAE 2007; Yu et al. 2009). The applied ventilation rates have to be in accordance with indoor emissions from building occupants (e.g. bioeffluents), emissions from the developed activities, and building materials emissions (EC 1992; Zuraimi et al. 2003). In addition to that, adequate ventilation has to avoid the formation of irritant and annoying compounds through potential chemical reactions among indoor air VOCs. Suitable ventilation rates have to warrant low residence times of VOCs indoors as well as decrease their concentrations, limiting the possibility of VOCs reactions (Weschler and Shields 2000; Peng et al. 2009; Yu et al. 2009).

On the other hand, outdoor incoming fresh air can also introduce pollution indoors (EC 1992; Seppänen and Fisk 2002; ASHRAE 2007). It has been observed that the location of the air gathering of the HVAC system can be an important factor in areas with remarkable traffic. In public buildings, mechanical ventilation is generally inoperative during non-working hours. Due to this fact, indoor VOCs emitted levels increase during these periods, mainly because there is no removal through ventilation (Cheong and Chong 2001). Nonetheless, VOCs that enter the building through the ventilation system (e.g. traffic-related), tend to decrease (Zuraimi et al. 2003).

The most internationally used ventilation standardized methodologies and guidelines for suitable indoor air quality are ASHRAE standard 62 for indoor air quality and ventilation (ASHRAE 2007), and the CR 1752 technical report "Ventilation for Buildings: Design Criteria for the Indoor Environment" from the European standard organization (CEN) (Olesen 2004).

When complaints related to bad indoor air quality are stated in a building, a survey for satisfactory ventilation has to be done to dismiss inadequate ventilation as the cause of the annoyance, as deficiencies in HVAC design, construction, operation and maintenance can cause pollutant emissions from the system (Cheong and Chong 2001; Seppänen and Fisk 2002; Zuraimi et al. 2004). First of all, a thorough visual survey searching for evidence of poor indoor and/or outdoor HVAC hygiene (e.g. water intrusion, mould, dust/particles) is advised. HVAC systems are complex and buildings provided with them have usually little natural ventilation, being the airtightness of the building an important key (Yu et al. 2009). Intake fresh air grilles, pipes, coils and filters have to be checked to ensure their cleanliness and assure that they provide outdoor air indoors without contaminating it during the process (Seltzer 1995).

On the other hand, carbon dioxide is often used as a direct indicator of acceptable ventilation due to its relationship with the occupancy level of the place (EC 1992; TIP-VENT 2001; Clements-Croome et al. 2008; Wong et al. 2008), however, this approach ignores the ventilation needs related to other pollutants (Baek et al. 1997; Olesen 2004; Lin et al. 2005), such as VOCs, which its main indoor sources would be building materials and the activities developed in the building. In addition to that, a direct measurement of air velocity in the air suppliers and gatherers is also suggested. Knowing this value, the airflow (volume/time) can be established (Seltzer 1995) and the correct flow of air through the room ensured, as well as the ventilation effectiveness and the age of air.

16.4.4 VOCs Sampling and Analysis Protocol

The procedure for sampling and analysis of low concentrations of VOCs in indoor air has been standardized in three sampling steps (Gallego et al. 2009a). The design aims to determine the type of VOCs present in indoor air in a first step, through 24 h samplings. The second control step is based on integrated odour episodes sampling in several points of the dwelling, mainly where more incidences have been detected, when medium or high odour intensity is percept by the inhabitants. The odour episodes are characterised (type of VOCs found and at which time of the day the episodes occur) and the concentrations of VOCs are determined. The third and last step implies taking samples following the usual working timetable (e.g. from 8 am to 5 pm).

16.4.4.1 Air Sampler

A collector pump sampler has been specially designed in our laboratory (LCMA-UPC) to collect dynamically air samples in solid sorbent tubes (Fig. 16.3). The VOCs sampler is equipped with inert sampling line and high precision total volume measurement. On the other hand, other sampler characteristics include 10 calibration flow levels, high flow stability, very low breakthrough values and inexistent tube contamination during pre-activation processes. The airtihghtness of the system was evaluated coupling a sorbent tube to the collector pump sampler during a month. The analysis of the sorbent tube revealed no VOCs contamination. The operating flow can range between 40 and 200 ml min^{-1}.

By means of a remote control (both radio frequency and mobile phone), the air sampler can be activated by the potentially affected people when medium or high odour intensity and nuisance is percept (Roca 2006; Gallego et al. 2008a). Hence, the remote-controlled LCMA-UPC pump sampler allows the dwelling occupants to turn on and turn off the sampler when an odorous and/or discomfort episode occurs. Sampling flows applied are generally of 90 ml min^{-1} for control periods higher than 6 h and 120 ml min^{-1} for episodic controls (Gallego et al. 2009a).

A minimisation of sampling costs is achieved with this control program, as the activation of the remote-controlled sampler by the inhabitants of the building in the very moment of the occurrence of odorous episodes diminishes the number of samples necessary to obtain reliable data for the study.

Fig. 16.3 LCMA-UPC collector VOCs sampler

16.4.4.2 Analytical Instrumentation

Custom packed glass multi-sorbent cartridge tubes (Carbotrap 20/40, 70 mg, weak sorption strength, hydrophobic; Carbopack X 40/60, 100 mg, medium sorption strength, and Carboxen-569 20/45, 90 mg, high sorption strength) have been optimized for the retention of VOCs in air samples (Ribes et al. 2007) (Fig. 16.4).

Different air sampling strategies have been described in the literature (Godish 1997; Dąbrowski 2001; Kim et al. 2004), however, sorbent based methods permit a high sampling versatility (compatible with both apolar and semi-volatile compounds, active and passive sampling), high concentration power, easy portability, low cost and easy storage of sorbent tubes (Volden et al. 2005; Prado et al. 2006; Ribes et al. 2007). Ambient air is a very complex mixture of compounds, and has a very variable composition and concentration of pollutants. On the other hand, sorbents have variable selectivity towards different types of compounds; hence, according to the characteristics of the sampled components, different combinations of sorbents are often used in multi-bed arrangements (combination of various sorbents) to achieve the determination of a wide range of target trace compounds present in air samples.

Therefore, a good combination of different sorbents may allow the determination of a wide range of desired compounds (Harper 2000; Donaldson et al. 2003; Wu et al. 2004; Demeestere et al. 2007; Ribes et al. 2007; Barro et al. 2009; Gallego et al. 2009b; Woolfenden 2010b). Nowadays, multi-sorbent beds are used in a high amount of validated methods for determining volatile toxic organic compounds in ambient air (e.g. NIOSH 2549 and EPA TO-17). Consequently, the designed multi-sorbent bed tube is suitable for the retention of a wide range of VOCs, both polar and non-polar compounds (Ribes et al. 2007; Gallego et al. 2008a).

In multi-sorbent beds, sorbents have to be placed in tubes ordered from weak to strong sorption strength in the air stream introduction way. Moreover, desorption has to be done in the direction from strong to weak sorption strength adsorbent (Harper 2000; Ribes et al. 2007). This aspect has to be taken into account to avoid irreversible sorption of high volatile compounds in strong adsorbents (Ras 2008; Ras et al. 2009). In order to take the samples, the tube cartridges are connected to the above mentioned LCMA-UPC pump samplers (Roca 2006) (Sect. 16.4.3.1).

The analysis of VOCs is performed by Automatic Thermal Desorption coupled with capillary Gas Chromatography/Mass Spectrometry Detector (Fig. 16.5).

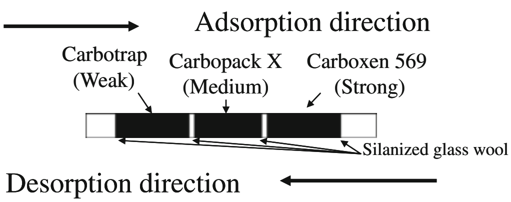

Fig. 16.4 Optimized multi-sorbent bed tube

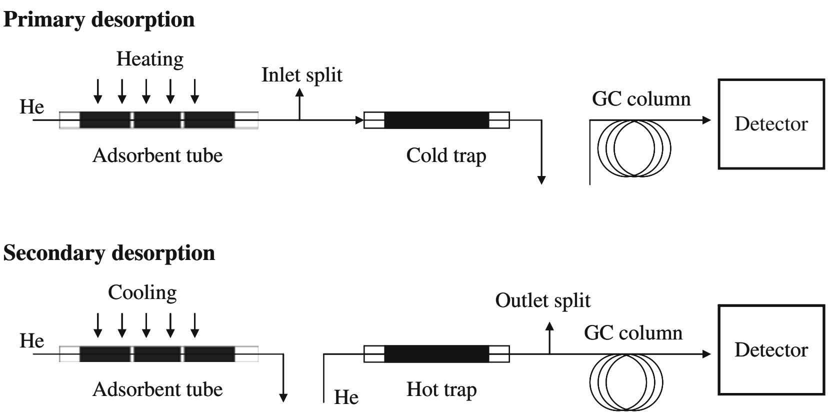

Fig. 16.5 Scheme of a thermal desorber coupled with gas chromatography/mass spectrometry. Two stages of thermal desorption. Primary desorption: the analytes are transferred from the adsorbent tube to the cold trap through heating. Secondary desorption: The cold trap is rapidly heated and the analytes are transferred to the chromatographic system

Thermal desorption is one of the most widespread techniques used (Demeestere et al. 2007; Ulman and Chilmonczyk 2007), as it is precise, has high sensitivity, low detection limits, and it is automatic (Desauziers 2004). Besides, all trapped pollutants can be chromatographed and directed to the detector in only one run, avoiding sample manipulation and dilution (Dettmer and Engewald 2002; Sunesson 2007; Barro et al. 2009; Woolfenden 2010a). In addition to that, solvent use is eliminated (Batterman et al. 2002).

The thermal desorption of the sampling tubes is carried out at 300°C with a flow rate of 50 ml min^{-1} for 10 min (primary desorption), during that time the eluted compounds are swept from the tube to a cryofocusing trap (containing approximately 15 mg of Tenax TA and 15 mg of Carbotrap) maintained at –30°C, applying a flow split of 4 ml min^{-1}. After the primary desorption, the cold trap is rapidly heated from –30°C to 300°C (secondary desorption) and then maintained at this temperature for 10 min. During the secondary desorption, the compounds are submitted to a flow split of 7 ml min^{-1} and are injected onto the capillary column (DB-624, 60 m × 0.25 mm × 1.4 μm) via a transfer line heated at 200°C. The column oven temperature starts at 40°C for 1 min, increases to 230°C at a rate of 6°C min^{-1} and then it is maintained at 230°C for 5 min. Helium (99.999%) carrier gas flow in the analytical column is approximately 1 ml min^{-1} (1.4 bar) (Ribes et al. 2007; Gallego et al. 2008a).

Mass spectral data are acquired over a mass range of 20–300 amu. A 6 min solvent delay time is applied for standards analysis to avoid saturation of mass spectrometer detector.

16.4.4.3 Qualitative and Quantitative Determination of Individual VOCs

Qualitative identification of target compounds is based on the match of the retention times and the ion ratios of the target quantification ions and the qualifier ions (Xcalibur 1.2 validated software package). Quantification of field samples is conducted by the external standard method. Standards are prepared in methanol and injected at 30°C on the multisorbent-tubes under an inert Helium gas flow (100 ml min^{-1}) using a conventional gas chromatograph packed column injector. Tube loading lasts not less than 5 min. The large variability of VOCs occurrence in air samples, in terms of abundance, lets to the necessity of working with two different concentration ranges. Hence, the quantification method is validated for two different quantification ions for each VOC to allow a reliable quantification in both very diluted (major characteristic ion in the VOCs spectra) and very concentrated samples (minor characteristic ion, normally the molecular ion) (Ribes et al. 2007).

The chromatographic separation is satisfactory for most of VOCs (Fig. 16.6, Table 16.1). Mainly all co-eluting VOCs are satisfactory quantified using characteristic ions. Only *m*-xylene and *p*-xylene are quantified together as they exhibit identical mass spectra. Limits of detection (LOD), determined applying a signal-to-noise ratio of 3, range from 0.001 to 10 ng. However, *NN*-Dimethylformamide and *N*-Methylformamide present values of 14 and 97 ng, respectively. The studied compounds exhibit linearity ranges (ng) from 3 to 4 orders of magnitude. Nonetheless, ethanol, carbon disulfide, methylethylketone and benzene exhibit the wider linear dynamic ranges (around 10^6 ng).

Most of the VOCs show repeatabilities (% relative standard deviation values) lower than 25%, accomplishing the EPA performance criteria (US EPA 1999).

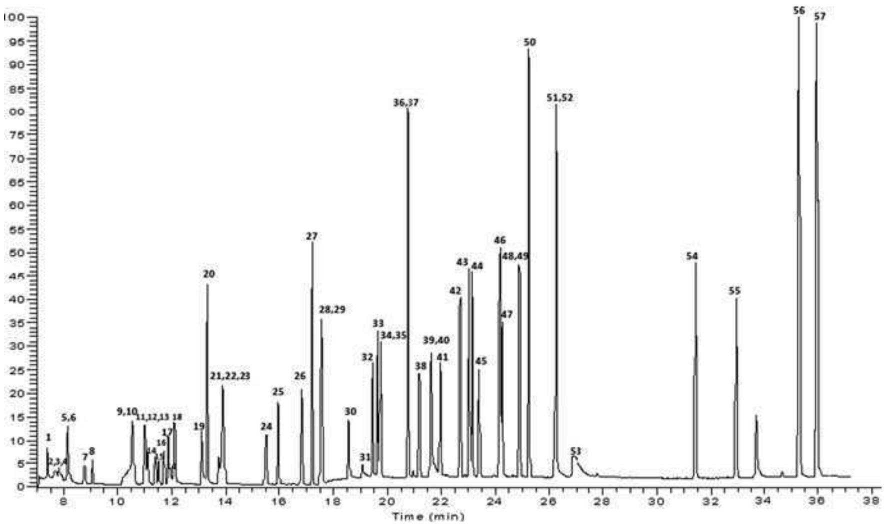

Fig. 16.6 GC chromatogram for stock standard solution. Correspondent VOCs reference numbers are listed in Table 16.1

Table 16.1 Method target VOCs analytes. CAS number (CAS No.), molecular weight (MW, g mol^{-1}), boiling point (BP, ºC, at 760 mmHg), retention time (RT, min) and quantification ions m/z 1 (low concentration range) and m/z 2 (high concentration range)

Target VOCs	VOC ref. no.	CAS no.	MW (g mol^{-1})	BP (°C)	RT (min)	Quantification ions	
						m/z 1	m/z 2
Ethanol	1	64-17-5	46	79	7.4	45	46
Propanal	2	123-38-6	58	49	7.5	58	58
Acetone	3	67-64-1	58	56	7.56	43	44
Carbon disulfide	4	75-15-0	76	46	7.84	76[a]	76
Methyl acetate	5	79-20-9	74	57	8.14	74[a]	74
Isopropanol	6	67-63-0	60	82	8.16	45	59
Tert-butylmethylether	7	1,634-04-4	88	55	8.81	73	57
n-Hexane	8	110-54-3	86	69	9.11	57	86
Butanal	9	123-72-8	72	75	10.16	44	72
Ethyl acetate	10	141-78-6	88	77	10.48	61	88
Chloroform	11	67-66-3	117	61	11.02	83	87
Methylethylketone	12	78-93-3	72	80	11.12	72	57
Tetrahydrofuran	13	109-99-9	72	66	11.12	42	72
1,1,1-Trichloroethane	14	71-55-6	131	74	11.42	97	117
Cyclohexane	15	110-82-7	84	81	11.54	56	84
Carbon tetrachloride	16	56-23-5	151	77	11.74	117	121
Isobutanol	17	78-83-1	74	108	11.9	43	74
Benzene	18	71-43-2	78	80	12.12	78	51
1-Butanol	19	71-36-3	74	118	13.11	56	31
Trichloroethylene	20	79-01-6	129	87	13.13	130	134
Methylcyclohexane	21	108-87-2	98	101	13.77	55	98
Pentanal	22	110-62-3	86	103	13.78	44	86
Methyl methacrylate	23	80-62-6	46	100	13.83	100[a]	100
Methylisobutylketone	24	108-10-1	100	117	15.53	43	100
Toluene	25	108-88-3	92	111	15.97	92	65
1,1,2-Trichloroethane	26	79-00-5	132	114	16.83	166	168
Tetrachloroethylene	27	127-18-4	163	121	17.22	166	168
Butyl acetate	28	123-86-4	116	126	17.55	73[a]	73
Hexanal	29	66-25-1	100	131	17.59	44	72
N,N-Dimethylformamide	30	68-12-2	73	153	18.56	73	58
N-Methylformamide	31	123-39-7	59	183	19.06	59	30
Ethylbenzene	32	100-41-4	106	137	19.45	106	65
n-Nonane	33	111-84-2	128	150	19.63	57	128
m-Xylene	34	108-38-3	106	139	19.73	106	77
p-Xylene	35	106-42-3	106	138	19.73	106	77
o-Xylene	36	95-47-6	106	145	20.75	91[a]	91
Styrene	37	100-42-5	104	145	20.75	104[a]	104
Heptanal	38	111-71-7	114	150	21.2	44	86
2-Butoxyethanol	39	111-76-2	118	171	21.64	57	87
α-Pinene	40	7,785-70-8	136	157	21.65	93	136
Cyclohexanone	41	108-94-1	98	155	21.97	98	83
Propylbenzene	42	103-65-1	120	159	22.71	91	120
n-Decane	43	124-18-5	142	174	23.04	71	142
1,3,5-Trimethylbenzene	44	108-67-8	120	165	23.15	105	120
β-Pinene	45	127-91-3	136	167	23.4	93	136

Table 16.1 (continued)

Target VOCs	VOC ref. no.	CAS no.	MW (g mol^{-1})	BP (°C)	RT (min)	Quantification ions	
						m/z 1	m/z 2
1,2,4-Trimethylbenzene	46	95-63-6	120	168	24.16	105	120
Benzaldehyde	47	100-52-7	106	178	24.25	77	106
Isocyanatocyclohexane	48	3,173-53-3	125	169	24.88	82	125
Limonene	49	5,989-27-5	176	177	24.88	93	136
p-Dichlorobenzene	50	106-46-7	147	174	25.24	146	75
n-Undecane	51	1,120-21-4	156	195	26.22	57	156
Phenol	52	108-95-2	94	182	26.32	94	66
1-Octanol	53	111-87-5	130	194	26.88	41	84
Naphthalene	54	91-20-3	128	218	31.4	128	102
Isothiocyanatocyclohexane	55	1,122-82-3	141	219	32.9	55	141
2-Methylnaphthalene	56	91-57-6	142	242	35.34	142	115
1-Methylnaphthalene	57	90-12-0	142	245	35.9	142	115

[a]Compound with only one characteristic quantification ion.

Multi-sorbent bed tubes do not exhibit significant breakthrough values for the studied VOCs (sampling volumes up to 90 l), except the VVOCs ethanol (for sampling volumes over 10 l), and acetone, dichloromethane and isopropanol (for sampling volumes over 40 l) (Gallego et al. 2010). Extreme precautions are established for quality assurance, injecting periodically blank samples and known concentrations of chosen standards (Ribes et al. 2007; Gallego et al. 2008a).

The majority of the identified VOCs are quantified, establishing as a criterion their abundance in indoor air, toxicity or request in TVOC analysis (WHO 1989; EC 1997a; Mølhave et al. 1997; ISO 16000-6).

16.4.4.4 Total VOCs (TVOC) Determination

Wide ranges of sampling strategies and Total VOCs (TVOC) concentration calculation methods have been used in the literature to evaluate VOCs concentrations. Differences observed between calculated TVOC values in the literature can be related to the differences in the analytical systems used, the type of sampling adsorbents, sampling rate, sampling volume, the chromatographic separation and the detection system used. Hence, these aspects often make TVOC published data not comparable (EC 1997a; Andersson et al. 1997; Mølhave et al. 1997; Wolkoff et al. 1997; Johansson 1999; Hodgson et al. 2000).

The European Commission recommended a definition of TVOC and a procedure for its sampling and analysis (EC 1997a), focusing in the main indoor VOCs families, such as aliphatic hydrocarbons, aromatic hydrocarbons, terpenes, alcohols, aldehydes, ketones, halocarbons and esters (Table 16.2).

In the same way, the international standard ISO 16000-6 describes a way of measuring TVOC. Generally, TVOC calculated values do not include very volatile

Table 16.2 Minimum number of compounds to be quantified in a TVOC analysis

Aromatic Hydrocarbons	*Aliphatic Hydrocarbons*	*Cycloalkanes*	*Terpenes*
Benzene	*n*-hexane	Methylcyclopentane	3-carene
Toluene	*n*-heptane	Cyclohexane	α-pinene
Ethylbenzene	*n*-octane	Methylcyclohexane	β-pinene
m+p-xylenes	*n*-nonane	*Alcohols*	Limonene
o-xylene	*n*-decane	2-propanol	*Aldehydes*
n-propylbenzene	*n*-undecane	1-butanol	Butanal
1,2,4-trimethylbenzene	*n*-dodecane	2-ethyl-1-hexanol	Pentanal
1,3,5-trimethylbenzene	*n*-tridecane	*Glycols/Glycolethers*	Hexanal
2-ethyltoluene	*n*-tetradecane	2-methoxyethanol	Nonanal
Styrene	*n*-pentadecane	2-ethoxyethanol	Benzaldehyde
Naphthalene	*n*-hexadecane	2-butoxyethanol	*Ketones*
4-phenylcyclohexene	2-methylpentane	1-methoxy-2-propanol	Methylethylketone
Esters	3-methylpentane	2-butoxyethoxyethanol	Methylisobutylketone
Ethylacetate	1-octene	*Halocarbons*	Cyclohexanone
Buthylacetate	1-decene	Trichloroethylene	Acetophenone
Isopropylacetate	*Others*	Tetrachloroethylene	*Acids*
2-ethoxyethylacetate	2-pentylfuran	1,1,1-trichloroethane	Hexanoic acid
Texanolisobutyrate (TXIB)	Tetrahydrofuran	1,4-dichlorobenzene	

Source: EC (1997a).

organic compounds (0ºC < Boiling point <50ºC), and only include the range of compounds obtained in the analytical window between hexane and hexadecane on a non-polar column (ISO 16000-6; Zuraimi et al. 2003).

The standardized procedure for sampling and analysing low concentrations of VOCs in indoor air building samples (Gallego et al. 2009a) proposes the evaluation of the TVOC value following the European Union recommended procedure (EC 1997a) and Mølhave et al. (1997) recommended method. The main and more toxic compounds found in the studies and the minimum number of compounds to be analysed suggested by the methods above mentioned (Table 16.2) are quantified individually. The rest of compounds are quantified by the response factor of toluene. The summation of all that values gives us the TVOC value.

A selection of recent (2000–2010) TVOC concentrations in worldwide private and public dwellings is shown in Table 16.3. TVOC concentrations would mainly be influenced by the age of the dwelling (building materials and furniture emissions), the use of low emitting materials, the presence or absence of forced ventilation and the activities developed (e.g. cooking, printing, use of glue and painters) (Tham et al. 2004; Zuraimi et al. 2004).

Table 16.3 Selected TVOC concentrations in worldwide dwellings

TVOC ($\mu g\ m^{-3}$)	Dwelling type	Dwelling age	Ventilation	Country	Date	References
85–1,050	Residential	Used	Natural ventilation and with HVAC	Sweden	2000	Bornehag and Stridh (2000)
1,520 ± 1,400	Residential[a]	New	HVAC	USA	2000	Hodgson et al. (2000)
2,720 ± 1,500	Residential[b]	New	HVAC	USA	2000	Hodgson et al. (2000)
203–749	Library	Used	Natural ventilation	Italy	2002	Righi et al. (2002)
70 ± 28	Residential[c]	1 year old	HVAC	Finland	2003	Tuomainen et al. (2003)
45 ± 27	Residential[c]	2 years old	HVAC	Finland	2003	Tuomainen et al. (2003)
28 ± 9	Residential[c]	3 years old	HVAC	Finland	2003	Tuomainen et al. (2003)
931 ± 1,068	Residential	1 year old	HVAC	Finland	2003	Tuomainen et al. (2003)
330 ± 234	Residential	2 years old	HVAC	Finland	2003	Tuomainen et al. (2003)
265 ± 340	Residential	3 years old	HVAC	Finland	2003	Tuomainen et al. (2003)
782–868	Office	New	HVAC	Singapore	2003	Zuraimi et al. (2003)
257–366	Office	6 years old	HVAC	Singapore	2003	Zuraimi et al. (2003)
916–1,801	Office	New	HVAC off	Singapore	2003	Zuraimi et al. (2003)
261–570	Office	6 years old	HVAC off	Singapore	2003	Zuraimi et al. (2003)
373	Residential	Used	Not ventilated[d]	Germany	2004	Hippelein (2004)
7,084	Office	6 months old	HVAC	Singapore	2004	Tham et al. (2004)
1,068–1,121	Museum (zoology)	Used	HVAC	Germany	2006	Schieweck et al. (2005)
973–1,252	Museum (prehistory)	Used	HVAC	Germany	2006	Schieweck et al. (2005)
4,680	Museum (art gallery)	Used	HVAC	Germany	2006	Schieweck et al. (2005)
780	Residential[c]	New	Not ventilated[d]	Finland	2006	Järnström et al. (2006)
329	Residential[c]	6 months old	Not ventilated[d]	Finland	2006	Järnström et al. (2006)
247	Residential[c]	1 year old	Not ventilated[d]	Finland	2006	Järnström et al. (2006)
82–192	Residential	Used	–	USA	2008	Jia et al. (2008b)
23–3,144	Office	Used	HVAC	China	2006	Wong et al. (2006)
584	Residential	New	Not ventilated[d]	South Korea	2008	Kim et al. (2008)
517	Residential	New	Natural ventilation	South Korea	2008	Kim et al. (2008)

Table 16.3 (continued)

TVOC (μg m^{-3})	Dwelling type	Dwelling age	Ventilation	Country	Date	References
851–1,920	Residential	New	Use of decomposing agents	South Korea	2008	Kim et al. (2008)
33–59	Office	Used	HVAC	Taiwan	2009	Peng et al. (2009)
73–187	Office	Used	HVAC off	Taiwan	2009	Peng et al. (2009)
540–3,632	Residential	Used	Natural ventilation	Spain	2009	Gallego et al. (2009a)
468 ± 391	Residential	Used	HVAC	USA	2010	Xu et al. (2010)
612 ± 232	Classroom	New	Not ventilated	South Korea	2009	Yang et al. (2009)
603 ± 270	Classroom	1–3 years old	Not ventilated	South Korea	2009	Yang et al. (2009)
507 ± 175	Classroom	3–5 years old	Not ventilated	South Korea	2009	Yang et al. (2009)
512 ± 192	Classroom	>10 years old	Not ventilated	South Korea	2009	Yang et al. (2009)
176 ± 136	Laboratory	Used	Not ventilated	South Korea	2009	Yang et al. (2009)
186 ± 208	Computer room	Used	Not ventilated	South Korea	2009	Yang et al. (2009)
416–2,900	Hotel room	< 6 months old	HVAC	China	2009	Chan et al. (2009)
478	Hotel room	< 6 months old	Not ventilated	China	2009	Chan et al. (2009)
1,135 ± 907	Residential	Used	HVAC off	USA	2010	Xu et al. (2010)

[a]Manufactured house.
[b]Site-built house.
[c]Built with low emitting materials.
[d]Not ventilated during sampling.

16.4.5 Indoor/Outdoor Ratios

Generally, indoor VOCs concentrations are higher than outdoor concentrations (Saarela et al. 2003; Zuraimi et al. 2003; Sexton et al. 2004; Edwards et al. 2005; Jia et al. 2008b) for several reasons, but VOCs emissions from building materials and furniture, and underventilation of the buildings, mainly in cold climate locations, are among the most important factors (Ashmore and Dimitroulopoulou 2009).

The indoor/outdoor (I/O) ratio determines the main contributor to VOCs in indoor air, and can be used as an indicator of the relative share of indoor and outdoor sources to the total VOCs burden (Baek et al. 1997; Freijer and Bloemen 2000). I/O values above 1 would indicate that indoor VOCs concentrations are higher than outdoor concentrations; hence, indoor sources are more important to the load of VOCs indoors than outdoor sources (Peng et al. 2009; Chan et al. 2009). Besides, I/O ratios exceeding 10 expose that indoor sources are mainly the unique sources of these compounds indoors (Jia et al. 2008b). However, an increase of the airtightness of the buildings would decrease the infiltration of outdoor air, decreasing also the contribution of outdoor air indoors and consequently increasing the I/O ratio (Ashmore and Dimitroulopoulou 2009).

16.5 Air Quality and Toxicity of VOCs in Indoor Air

Several criterions, based on guides and quality standards, have been established to determine air quality. Some of them, proposed by the US Environmental Protection Agency (US EPA), are referred to indoor and outdoor air and are established to protect the population from adverse health effects caused by their exposition to toxic substances. In addition to that, other types of standards, such as the threshold limit values (TLV) from the American Conference of Governmental Industrial Hygienists (ACGIH), are used as professional exposure limits, for both outdoor and indoor air pollutant concentrations, applicable to the working population. These values are not advisable to be used directly on general population, as they have been established with specific exposition conditions, however, they can be useful as indicators.

Nowadays, different quality criteria for individual compounds exist worldwide, as no international guidelines have been established. However, the most commonly used are the Threshold Limit Values in working ambient (TLV) divided by a factor that ranges from 30 to 1,000. The value obtained depends on the toxic potential of the compound. The value TLV/420 is commonly used to establish maximum concentration limits in urban outdoor air in a 24-h period for non-carcinogenic compounds. The factor 420 is an uncertainty factor that takes into account the varied physiological status of people (Repetto 1997).

All the identified VOCs in a qualitative analysis in a residential flat and in two offices (in a Research Building and in a University building) located in Barcelona city (Spain) are shown in Table 16.4. More than one hundred compounds were detected in these indoor environments. Odour thresholds, TLV/420, associated

Table 16.4 Residential flat, Research building and University building (Offices). Identified VOCs, Odour Thresholds ($\mu g\ m^{-3}$), TLV/420 ($\mu g\ m^{-3}$), relevant associated R-phrases, relevant associated new H labelling, Cancer Risk Concentrations ($\mu g\ m^{-3}$), and IARC cancer classification

Compound	CAS#	Residential flat	Research building (offices)	University building (offices)	Odour threshold[b] ($\mu g\ m^{-3}$)	TLV/420[c] ($\mu g\ m^{-3}$)	R-phrases	H labelling	Concentration for cancer risk[d] ($\mu g/m^3$)	IARC cancer classification[e]
α-Pinene[a]	80-56-8	x	x	x	230	267	36-37-38			
β-Pinene[a]	127-91-3	x	x	x	8,900	267	36-37-38			
1,1-Dimethylcyclopropane	1,630-94-0		x							
1,1,1-Trichloroethane[a]	71-55-6			x	5,300	4,548	20	H332		
1,1,2-Trimethylcyclohexane	7,094-26-0	x								
1,1,3-Trimethylcyclohexane	3,073-66-3	x								
1,2-Diethylbenzene	135-01-3									
1,2,3-Trimethylbenzene[a]	526-73-8		x			293	36-37-38			
1,2,4-Trimethylbenzene[a]	95-63-6	x	x	x	140	293	20-36/37/38	H332-H319-H335-H315		
1,3,5-Trimethylbenzene[a]	108-67-8	x	x		180	293	37	H335		
1,3-Pentadiene	504-60-9	x	x	x						
1-Butanol[a]	71-36-3	x	x	x	10	145	37/38-67	H335-H315-H336		
1-Heptene	592-76-7	x			37,000					
1-Hexene	592-41-6	x				410				
1-Methoxy-2-propanol	107-98-2	x	x		37,000	879	36-37-38			
1-Propanol	71-23-8		x		5,900	586	67	H336		
2,2,4,4,6,8,8-Heptamethylnonane	4,390-04-9	x								
2,2,4,6,6-Pentamethylheptane	13,475-82-6	x								

Table 16.4 (continued)

Compound	CAS#	Residential flat	Research building (offices)	University building (offices)	Odour threshold[b] ($\mu g\ m^{-3}$)	TLV/420[c] ($\mu g\ m^{-3}$)	R-phrases	H labelling	Concentration for cancer risk[d] ($\mu g/m^3$)	IARC cancer classification[e]
2,2,5,5-Tetramethylhexane	1,071-81-4	x								
2,3-Dimethylhexane	584-94-1									
2,4-Dimethylheptane	2,213-23-2	x								
2,6-Dimethyloctane	2,051-30-1	x								
2-Bromoheptane	1,974-04-5	x								
2-Butanol	78-92-2			x	285,000	714	36/37-67	H319-H335-H336		
2-Butene	107-01-7		x		4,800	1,366				
2-Butoxyethanol[a]	111-76-2	x	x		500	231	20/21/22-36/38	H332-H319-H315		
2-Ethyl-1-butanol	97-95-0	x			300					
2-Ethyl-1-hexanol	104-76-7		x		400		36-37-38			
2-Hexene	592-43-8	x								
2-Methyl-1-butene	563-46-2	x								
2-Methyl-1-heptene	15,870-10-7									
2-Methyl-1-pentene	763-29-1	x								
2-Methyl-2-butene	513-35-9	x								
2-Methyl-2-pentanol	590-36-3			x						
2-Methylheptane	592-27-8		x				38-67	H315-H336		
2-Methylhexane[a]	591-76-4	x	x	x			38-67	H315-H336		
2-Methylnonane	871-83-0		x							
2-Methylpentane	107-83-5	x				4,191				
2-Methylpentanol	105-30-6	x			100					
2-Pentene	109-68-2		x				36-37-38			
3,5-Dimethyloctane	15,869-93-9									
3-Ethylhexane	619-99-8	x								
3-Methylheptane	589-81-1	x	x							
3-Methylhexane	589-34-4	x	x							

Table 16.4 (continued)

Compound	CAS#	Residential flat	Research building (offices)	University building (offices)	Odour threshold[b] (μg m^{-3})	TLV/420[c] (μg m^{-3})	R-phrases	H labelling	Concentration for cancer risk[d] (μg/m^3)	IARC cancer classification[e]
3-Methylpentane	96-14-0	x	x	x		4.191				
4,5-Dimethylnonane	17,302-23-7									
4-Methyl-2-pentanone[a]	108-10-1	x	x		140	195	20-36/37-66	H332-H319-H335		
4-Methyl-2-pentene	4,461-48-7									
Acetaldehyde	75-07-0		x		2.7		36/37-40	H351-H319-H335	3.7[f]5[g]	2B
Acetic acid	64-19-7	x	x	x	90	60				
Acetone[a]	67-64-1	x	x	x	11,000	2,829	36-66-67	H319-H336		
Acetonitrile	75-05-8	x	x		285,000	81	20/21/22-36	H332-H319		
Acetophenone	98-86-2		x		1.2	117	36	H319		
Benzaldehyde	100-52-7	x	x		100					
Benzene[a]	71-43-2	x	x	x	28,000	4	45-46-36/38-48/23/24/25	H350-H340-H372-H319-H315	1.3–4.5[g,h] 0.4[f]	1A
Benzoic acid, 2-[(trimethylsilyl)oxy]-, trimethylsilyl esther	3,789-85-3	x								
Benzothiazole	95-16-9	x	x				20–36			
Bromoform	75-25-2		x		2,200	12	23-36/38	H331-H319-H315		
Butanoic acid	107-92-6	x			0.35					
Butyl acetate[a]	123-86-4	x	x	x	7,700	1,698	66–67	H336		
Camphene[a]	79-92-5		x		26,000		36/37/38			

Table 16.4 (continued)

Compound	CAS#	Residential flat	Research building (offices)	University building (offices)	Odour threshold[b] (μg m^{-3})	TLV/420[c] (μg m^{-3})	R-phrases	H labelling	Concentration for cancer risk[d] (μg/m^3)	Compound
Carbon disulfide[a]	75-15-0	x	x	x	180	7	36/38-48/23-62-63	H361-H372-H319-H315		
Carbon tetrachloride[a]	56-23-5		x	x	260,000	74	23/24/25-40-48/23	H351-H331-H372	0.2[f]0.7[h]	2B
Chloroform[a]	67-66-3	x	x	x	650,000	117	38-40-48/20/22	H351-H373-H315	0.4[h]1.9[f]	2B
Cyclobutane	287-23-0		x				38–67			
Cyclohexane[a]	110-82-7	x	x	x	35,600	819	38–67	H315-H336		
Cyclohexanone	108-94-1	x	x		480	119	67–68			
Cyclopentane	287-92-3					4,095				
Dichloromethane[a]	75-09-2	x	x	x	4,100	415	40-48/20	H351	20[g]	2B
DL-Limonene[a]	7,705-14-8	x	x	x	10		38–43	H315		
Ethanol	64-17-5	x	x	x	260	4,476	20-36-37-38-40			
Ethyl acetate[a]	141-78-6	x	x	x	2,200	3,429	36-66-67	H319-H336		
Ethylbenzene[a]	100-41-4	x	x	x	10,000	1,033	20	H332	4[f]	2B
Ethylcyclobutane	4,806-61-5	x								
Ethylcyclohexane	1,678-91-7	x								
Ethylhexanoic acid	149-57-5	x				12	63	H361		
Ethylisobutylketone	623-56-3		x				20			
Formic acid	64-18-6		x		2,000	22				
Furan	110-00-9		x				26–45			2B
Heptanoic acid	111-14-8		x		50		20			
Hexamethylethane	594-82-1	x								
Hexanmethylcyclotrisiloxane	541-05-9	x	x	x						
Hexanoic acid	142-62-1	x			20		20			
Isobutyl isobutyrate	97-85-8	x								
Isocyanato cyclohexane	3,173-53-3		x				23			

Table 16.4 (continued)

Compound	CAS#	Residential flat	Research building (offices)	University building (offices)	Odour threshold[b] ($\mu g\ m^{-3}$)	TLV/420[c] ($\mu g\ m^{-3}$)	R-phrases	H labelling	Concentration for cancer risk[d] ($\mu g/m^3$)	Compound
Isooctane	540-84-1	x					38–67	H315-H336		
Isopentane	78-78-4		x			4,214	66–67	H336		
Isopropanol[a]	67-63-0	x	x	x	800	1,172	36–67	H319-H336		
Isopropylbenzene[a]	98-82-8	x			650	586	37	H335		
Isothiocyanato cyclohexane	1,122-82-3		x							
Methyl acetate	79-20-9	x	x	x	22,000	1,443	36-66-67	H319-H336		
Methylcyclobutane	598-61-8	x								
Methylcycloheptane	4,126-78-7	x								
Methylcyclohexane[a]	108-87-2	x	x	x		3,833	38–67	H315-H336		
Methylcyclopentane[a]	96-37-7			x						
Methylethylketone[a]	78-93-3	x	x	x	2,900	1,405	36-66-67	H319-H336		
m-Ethyltoluene[a]	620-14-4	x		x						
m-Xylene[a]	108-38-3	x	x	x	700	1,033	20/21-38	H332-H315		
N,N-Dimethylformamide	68-12-2	x	x		140	71	61-20/21-36	H360-H319		
N-Nitrosodimethylamine	62-75-9				24		26-45-61	H350-H330-H372	0.002[f]	2A
Naphthalene[a]	91-20-3	x	x	x	7	124	40	H351	0.3[f]	2B
n-Decane[a]	124-18-5	x	x	x	11,300		36-37-38			
n-Dodecane[a]	112-40-3	x		x	11,800					
n-Heptanal	111-71-7	x	x		14		36-37-38			
n-Heptane[a]	142-82-5	x	x	x	930,000	3,905	38–67	H315-H336		
n-Hexadecane[a]	544-76-3	x			500		38			
n-Hexanal	66-25-1		x	x	25					
n-Hexane[a]	110-54-3	x	x	x	107,000	419	38-48/20-62-67	H361-H373-H315-H336		
n-Nonanal[a]	124-19-6	x		x	20		36–38			

Table 16.4 (continued)

Compound	CAS#	Residential flat	Research building (offices)	University building (offices)	Odour threshold[b] (µg m^{-3})	TLV/420[c] (µg m^{-3})	R-phrases	H labelling	Concentration for cancer risk[d] (µg/m^3)	Compound
n-Nonane[a]	111-84-2	x	x		60,000	2,500				
n-Octanal	124-13-0	x	x		7,8		20-23-36-37			
n-Octane[a]	111-65-9	x		x	710,000	3,357	38–67	H315-H336		
n-Pentadecane[a]	629-62-9	x								
n-Pentanal	110-62-3	x			19	419	20			
n-Pentane	109-66-0	x	x	x	92	4,215	66–67	H336		
n-Propylbenzene[a]	103-65-1	x	x		14,400		37	H335		
n-Tetradecane[a]	629-59-4	x		x	5,000		36-37-38			
n-Tridecane[a]	629-50-5	x		x	42,000		36-37-38			
n-Undecane[a]	1,120-21-4	x	x	x	9,600		36-37-38			
Octamethylcyclotetrasiloxane	556-67-2	x	x	x			36–62	H361		
Octanoic acid	124-07-2	x	x		0.3					
o-Ethyltoluene[a]	611-14-3	x					36-37-35			
o-Xylene[a]	95-47-6	x	x	x	770	1,033	20/21-38	H332-H315		
p-Cymene	99-87-6		x		196					
p-Dichlorobenzene[a]	106-46-7	x	x		1,100	143	36–40	H351-H319	0.9[f]	2B
p-Diethylbenzene	25,340-17-4	x								
Pentanoic acid	109-52-4	x	x	x	0.15					
p-Ethyltoluene	622-96-8	x	x	x						
Pivalic acid	75-98-9		x							
Propyl acetate	109-60-4	x			600	1,988	36-66-67	H319-H336		
Propylcyclohexane			x							
p-Xylene[a]	106-42-3	x	x	x	700	1,033	20/21-38	H332- H315		
Styrene[a]	100-42-5	x		x	12	202	20-36/38	H332-H319-H315		2B
tert-Butylethylether	637-92-3	x	x			50				
tert-Butylmethylether[a]	1,634-04-4	x				429	38	H315	39[f]	
Tetrachloroethylene[a]	127-18-4	x	x	x	8,300	405	40	H351	1.7[f]	2A
Tetrahydrofuran	632-22-4		x		270	350	36–37			

Table 16.4 (continued)

Compound	CAS#	Residential flat	Research building (offices)	University building (offices)	Odour threshold[b] ($\mu g\ m^{-3}$)	TLV/420[c] ($\mu g\ m^{-3}$)	R-phrases	H labelling	Concentration for cancer risk[d] ($\mu g/m^3$)	Compound
Tetramethylurea	108-88-3		x							
Toluene[a]	108-88-3	x	x	x	600	179	38-48/20-63-65-67	H361-H373-H315-H336		
Trichloroethylene[a]	79-01-6	x	x	x	3,900	129	45-36/38-67	H350-H341-H319-H315-H336	5[f]	2A
Trichlorofluoromethane[a]	75-69-4	x	x	x	28,000	13,381	36-37-38			

[a]VOC identified in several worldwide indoor air studies (Holcomb and Seabrook 1995).
[b]Odour thresholds obtained from: Compilations of odour threshold values in air and water. L.J.van Gemert (TNO Nutrition and Food Research Institute). Boelens Aroma Chemicals Information Service (BACIS), The Netherlands, 2003, and Odor Thresholds for Chemicals with Established Occupational Health Standards. American Industrial Hygiene Association. USA, 1989.
[c]TLV = Threshold limit values, www.acgih.org (Accessed May 2010).
[d]Estimated lifetime excess cancer risk (95th percentile upper-bound) of $1 \times 10–5$ (1 in 100,000) for an individual exposed to this concentration for a 70-year lifetime.
[e]IARC (International Agency for Research on Cancer) Classification: 1A: Carcinogenic to humans, 2A: Probably carcinogenic to humans, 2B: Possibly carcinogenic to humans.
[f]California Environmental Protection Agency Value (2010).
[g]Minnesota Health Risk Value (HRV).
[h]US Environmental Protection Agency IRIS (Integrated Risk Information System).

Table 16.5 R-phrases meaning

R-phrase	
R-20	Harmful by inhalation
R-23	Toxic by inhalation
R-26	Very toxic by inhalation
R-36	Irritating to eyes
R-37	Irritating to respiratory system
R-38	Irritating to skin
R-40	Possible risk of cancer
R-45	May cause cancer
R-46	May cause heritable genetic damage
R-48	Danger of serious damage to health by prolonged exposure
R-61	May cause harm to the unborn child
R-62	Possible risk of impaired fertility
R-63	Possible risk of harm to the unborn child
R-66	Repeated exposure may cause skin dryness or cracking
R-67	Vapours may cause drowsiness and dizziness

R-phrases and H labelling, concentration for cancer risk, and the IARC cancer classifications are also shown.

R-phrases (short for Risk phrases) (Directive 2001/59/EC) describe the nature of special risks attributed to dangerous substances and preparations. These risk phrases, nonetheless, are used in an international context, not just in the European Communities. At the moment, however, the new Regulation of the European Communities (EC) 1272/2008 on classification, labelling and packaging of substances and mixtures transposes the Globally Harmonised System (GHS), which is expected to facilitate global trade and the harmonised communication of hazard information of chemicals and to promote regulatory efficiency. With this new regulation the R-phrases are being replaced by the Hazard labelling (H). The meanings for the simple and combined R-phrases and the H labelling are described in Tables 16.5, 16.6 and 16.7.

A great number of the indoor detected compounds (both in the private dwelling and the offices) (Table 16.4) present irritation potential (skin, eyes and respiratory system), as well as some of them are possibly, probably or assured carcinogens.

On the other hand, several compounds can threaten the unborn child in addition to reproduction. A complete evaluation of all VOCs present indoors is a useful tool when assessing indoor air quality. Their associated R-phrases and H labelling and their TLV/420 value are helpful data when no other reference recommended values or guidelines are published.

16.5.1 Indoor Air Quality Regulations, Guidelines and Recommendations

Different health organizations have established exposure limits/guidelines for certain chemical compounds found in indoor environments. A few examples are described below (EC 2004; EC 2005).

Table 16.6 Combined R-phrases meaning

Combined R-phrase	
R20/21	Harmful by inhalation and in contact with skin
R20/21/22	Harmful by inhalation, in contact with skin and if swallowed
R23/24/25	Toxic by inhalation, in contact with skin and if swallowed
R36/37	Irritating to eyes and respiratory system
R36/37/38	Irritating to eyes, respiratory system and skin
R36/38	Irritating to eyes and skin
R37/38	Irritating to respiratory system and skin
R48/20	Harmful: danger of serious damage to health by prolonged exposure through inhalation
R48/20/22	Harmful: danger of serious damage to health by prolonged exposure through inhalation and if swallowed
R48/23	Toxic: danger of serious damage to health by prolonged exposure through inhalation
R48/23/24/25	Toxic: danger of serious damage to health by prolonged exposure through inhalation, in contact with skin and if swallowed

Table 16.7 H labelling meaning

H-phrase	
H315	Causes skin irritation
H319	Causes serious eye irritation
H330	Fatal if inhaled
H331	Toxic if inhaled
H332	Harmful if inhaled
H335	May cause respiratory irritation
H336	May cause drowsiness or dizziness
H340	May cause genetic defects
H341	Suspected of causing genetic defects
H350	May cause cancer
H351	Suspected of causing cancer
H360	May damage fertility or the unborn child
H361fd	Suspected of damaging fertility or the unborn child
H372	Causes damage to organs through prolonged or repeated exposure
H373	May cause damage to organs through prolonged or repeated exposure

The World Health Organization has developed the Air Quality Guidelines for Europe. For several compounds the guidelines establish certain recommendations to reduce human exposure to harmful levels of air pollutants. For some compounds, tough, there are no guideline values recommended, however their estimated risk is indicated. Besides, guidelines based on carcinogenic effects have also been established for those carcinogens that are considered to be genotoxic (WHO 2005). See: www.who.int

The Agency for Toxic Substances and Disease Registry (ATSDR), a federal public health agency of the US Department of Health and Human Services, has established the Minimal Risk Levels (MRLs). MRLs are estimations of the daily human exposure to hazardous substances that are plausible to be without observable risk of adverse noncancer health effects over a specified duration of exposure. See: www.atsdr.cdc.gov

The Integrated Risk Information System (IRIS), from the US Environmental Protection Agency, has developed the inhalation Reference Concentration (RfC). The RfC is analogous to the oral RfD (Reference Dose) in respect to breathed air. The inhalation RfC considers toxic effects for both the respiratory system (portal-of-entry) and for effects peripheral to the respiratory system (extrarespiratory effects). In general, the RfC is an estimate of a daily inhalation exposure of the human population that is plausible to be without an observable risk of harmful effects during a life period. See: www.epa.gov/iris

The Office of Environmental Health Hazard Assessment of the Californian Environmental Protection Agency (OEHHA) has developed the Reference Exposure Levels (RELs), the concentrations at or below which no adverse health effects are predictable in the general human population. RELs are based on the most sensitive relevant adverse health effects reported in the literature (medical and toxicological). RELs are designed to protect the most sensitive individuals in the population by the inclusion of margins of safety. REL values are subdivided in acute and chronic exposures to pollutants. See: www.oehha.org

The Massachusetts Department of Environmental Protection provides the TELs (Threshold Effects Exposure Limits), the NTELs (Non-threshold Effects Exposure Limits) and the AALs (Allowable Ambient Limits). TELs determine the compound air concentration that is allowable based on protection against threshold health effects (e.g. acute and chronic toxicity, developmental and reproductive toxicity). NTELs are designed to provide protection against nonthreshold effects based on estimates of potential risks to humans from carcinogenicity and mutagenicity. AALs are the lowest of the values obtained for TELs and NTELs for each compound, and cover all types of effects, including the most sensitive effect. See: www.mass.gov/dep

The Minnesota Pollution Control Agency has developed the Health Risk Values (HRVs) for chemicals or chemical mixtures emitted to ambient air. HRVs are referred to the concentration of a chemical or defined mixture of chemicals in ambient air, at or below which the chemical or defined mixture of chemicals is improvable to cause an adverse health effect to the general public. See: www.pca.state.mn.us

The Federal Environmental Agency of Germany (Umweltbundesamt – UBA) has established two Guideline Values. Guideline Value I (GV I) is the concentration level at which a compound does not induce negative health effects even at a lifetime exposure period. On the other hand, Guideline Value II (GV II) settles the limit concentration for a given compound. If this concentration is reached or exceeded in a concrete place, immediate actions have to be conducted due to continuous exposure at this concentration level can represent a threat to health, especially for sensitive people. See: www.Umweltbundesamt.de

Environment Canada – Health Canada (EC-HC) has established the Tolerable Concentrations (TCs) and the Tumorigenic Concentrations 05 (TC05). TCs are the air pollution concentrations to which it is believed that a human being can be exposed continuously over a lifetime without observed harmful effects. On the other hand, the TC05 is the air pollution concentration correlated with a 5% increase in incidence of deaths or tumours associated with pollution exposure to concrete pollutants. See: www.hc-sc.gr.ca

In addition to that, during the last 20 years both the European Commission and the United States have developed several studies related to human exposure to chosen gaseous pollutants and particles (e.g. EU-EXPOLIS project, US-TEAM project, US-NHEXAS project) (Saarela et al. 2003; Ahsmore and Dimitroulopoulou 2009). Recently, in the year 2002, the Joint Research Centre of the European Commission started a project called "Critical Appraisal of the Setting and Implementation of Indoor Exposure Limits in the EU" (INDEX) to assess the health risks of indoor air pollutants. The main objectives of the project were to determine health risks of indoor-originated chemical pollutants and to provide suggestions and recommendations on potential exposure limits or other risk management measures. The INDEX project established high priority compounds to be regulated in indoor air due to their health impact on human beings as well as their presence in indoor sources (Table 16.8). Benzene, toluene, xylenes, naphthalene, styrene, formaldehyde, and the terpenes α-pinene and limonene were among the selected compounds (EC 2005; Koistinen et al. 2008; Ashmore and Dimitroulopoulou 2009). A summary of recommendations and management options were published (EC 2004).

16.5.2 TVOC Classification

TVOC has been recommended to be used as a screening tool, due to it does not have biological relevance, and is not recommended for making definitive conclusions

Table 16.8 Indoor pollutants that were assessed and considered the most hazardous in the identification process of hazardous compounds in the INDEX project

1-Butanol	Benzene[a]	Hexaldehyde	Phenol
2-Buthoxyethanol	Benzo[a]pyrene	Lead	Propionaldehyde
2-Ethyl-1-hexanol	Cadmium	*m*+*p*-Xylene	Propylbenzene
2-Methyl-1-propanol	Carbon monoxide[a]	Mercury	Styrene
3-Carene	Decane	Methyl-ethyl-ketone	Tetrachloroethylene
Acetaldehyde	Dichloromethane	Naphtalene[a]	Toluene
Acetone	Diisocyanate	Nitrogen dioxide[a]	Trichloroethylene
Ammonia	d-Limonene	Nonane	Trimethylbenzenes
α-Pinene	Ethylbenzene	o-Xylene	Tris-(2-chloroethyl) phosphate
Benzaldehyde	Formaldehyde[a]	Pentachlorophenol	Undecane

[a]Priority pollutants.

about indoor air quality (Andersson et al. 1997). However, it has some useful applications as an indicator of the presence of VOCs indoors and for identifying their possible sources (Mølhave 2000; Wolkoff and Nielsen 2001; Mølhave 2003; Hippelein 2004; Wong et al. 2006; Gallego et al. 2009a).

Seifert (1990) estimated a target TVOC indoor air quality guideline value based on two empirical field studies in German and Dutch homes (Seifert and Abraham 1982; WHO 1989; Lebret et al. 1986; Krause et al. 1987), suggesting that TVOC concentrations in indoor air should not exceed 300 μg m^{-3}. On the basis of the above mentioned empirical field studies, a standard classification of the dwelling indoor air VOCs concentrations was proposed depending on the different chemical families present indoors. Alkanes, aromatic hydrocarbons, terpenes, halocarbons, esters, aldehydes (except formaldehyde) and ketones and other compounds, should contribute with 33, 17, 10, 10, 7, 7 and 16% of the TVOC, respectively.

In addition to that, two indoor air quality criterions were established. Criterion 1: no individual compound should exceed 50% of the average value of its class and Criterion 2: no individual compound should exceed 10% of the TVOC value. Moreover, Mølhave (1991a) suggested four exposure ranges of TVOC: comfort range (<0.2 mg m^{-3}), multifactorial exposure range (0.2–3 mg m^{-3}), discomfort range (3–25 mg m^{-3}) and toxic range (>25 mg m^{-3}).

16.6 Solutions for Poor IAQ

The concern related to bad indoor air quality has increased in the past years, mainly due to the fact that people spend around 90% of their time indoors. Buildings provided with HVAC systems are not an exception, and sometimes they present high levels of prevalence of nuisance problems associated with poor indoor air quality (Seppänen and Fisk 2002). As building materials and indoor developed activities are two of the main sources of indoor air pollution, a control over them should be advised in a first instance (EC 1992; Tuomainen et al. 2003). However, if these aspects cannot be controlled, indoor air purification could be a valuable methodology to improve IAQ (Yu et al. 2009).

16.6.1 Source Identification Through Detected Compounds

The type of compounds determined in indoor air analysis would be indicative of their sources. Depending on the kind of compounds found, their source would be indoors or outdoors, indicating that their emission comes from building materials or the activities developed inside the dwelling or, on the other hand, that the compounds found indoors come from outdoors (e.g. nearby industries, traffic, power plants) entering the building through intake vents, the HVAC system or by means of the open doors and windows.

16.6.1.1 Indoor Sources

In new built homes, the best way to provide adequate indoor air quality would be the application of adequate ventilation and the use of building and furnishing materials with low VOCs emission rates (Hodgson et al. 2000; Guo et al. 2003; Wolkoff 2003; EC 2004; Chan et al. 2009; Yang et al. 2009; Yu et al. 2009).

Guo et al. (2003) developed a methodology to select low emitting building materials to create a low VOCs emission house. Their methodology is divided in three stages. The first stage is based in the evaluation of the products to be used in the house through the information that can be obtained from manufacturers or from the literature. The second stage is based in a TVOC analysis through GC-FID. And the third and last stage is based on the occupant exposure to indoor air VOCs during the occupation of the building (e.g. identification of specific VOCs by GC/MS, chemical/toxicological evaluation, health risks evaluation).

16.6.1.2 Outdoor Sources

Several studies in different worldwide established dwellings expose that the most abundant VOCs found in residential and public buildings are toluene, benzene, ethylbenzene, *m*+*p*-xylenes, 1,2,4-trimethylbenzene, 1,3,5-trimethylbenzene, DL-limonene, α-pinene, *p*-dichlorobenzene, trichloroethylene, tetrachloroethylene, *n*-decane, 2-buthoxyethanol, chloroform, *n*-hexanal and *n*-nonanal (Godish 2001; Lee et al. 2002; Saarela et al. 2003; Sexton et al. 2004; Schlink et al. 2004; Wolkoff et al. 2006; Jia et al. 2008b). In addition to that, in American office buildings, acetone and 2-buthoxyethanol also have been detected in relevant abundance (Griman et al. 1999).

On the other hand, terpenes have strong sources indoors, as their I/O ratio values tend to be higher than the observed for other compounds (Saarela et al. 2003). However, if the compounds found in highest concentrations in the studied buildings are not the expected, that can mean that their release is not originated by the common sources of VOCs indoors (Jones 1999; Gallego et al. 2008b), like cleaning products, floor waxes, paints or vehicle exhausts (Weschler et al. 1990; Godish 2001; Reiser et al. 2002; Zhang and Xu 2002; Jia et al. 2008a; Katsoyiannis et al. 2008), and that their origin may come from polluted outdoor air entering indoors (Gallego et al. 2009a).

An exhaustive revision of the activities realized in the adjacent buildings of the studied dwelling has to be done in order to find the possible sources of the unexpected detected VOCs. In previous studies, these kind of surveys have allowed the finding of not declared activities (e.g. manipulation and storage facilities of industrial solvents) that caused the annoying episodes indoors, as the polluted outdoor air entered the dwelling through the windows and interior patios (Gallego et al. 2009a).

In addition to that, remote outdoor sources such as transportation (motor vehicle exhausts), fossil-fuel-burning power plants, chemical plants, petroleum refineries, construction work, and solid waste and sewage facilities (Baek et al. 1997; Godish

1997; Mohamed et al. 2002; Brown et al. 2007; Gallego et al. 2007; Khoder 2007) can also contribute to poor indoor air quality generating annoying odour episodes. In this case, a combination of social participation (Sect. 16.4.1), chemical control (Sect. 16.4.3) and back-trajectory modelling is used to determine the origin of odour episodes, as well as the exact VOCs that generate them (Gallego et al. 2008a; b).

16.6.2 Application of Corrective Measures

When an appropriate ventilation rate, with good quality outdoor air, is applied to a dwelling, VOCs concentrations should be maintained in an acceptable level (Holcomb and Seabrook 1995; Weschler and Shields 2000; Zuraimi et al. 2003; Kim et al. 2008). However, if adequate ventilation is applied and VOCs values continue high, probably strong local sources of these compounds are located inside or near the building (Weschler et al. 1990). In these cases, when the control of pollution sources is not possible, indoor air purification is an important methodology to improve IAQ removing indoor air contaminants (Godish 2001; Fisk et al. 2002; Yu et al. 2009; Xu et al. 2010). Five methods of indoor air purification are the most common: filtration, adsorption, photocatalytic oxidation (PCO), negative air ions (NAIs) and non-thermal plasma (NTP).

Filtration methodologies are economical and efficient, however, drawbacks derived from micro-organisms contamination, mainly due to their growth in the particulate matter deposited in the filters, can be problematic. Adsorption methods, based in activated carbon, activated carbon fibres, zeolites, porous clay ore, activated alumina, silica gel and/or molecular sieves adsorbents, are highly used mechanisms. Nonetheless, the adsorptive capacity of the filters is limited and generally family/compound specific (Tham et al. 2004), and their replacement is often expensive. In addition to that, secondary pollution can be derived from the filters (Chan et al. 2009).

PCO techniques degrade indoor pollutants and transform them into final compounds such as CO_2, water and mineral inorganic substances less harmful to human health than VOCs. Pollutants removing efficiencies are relatively high (Demeestere et al. 2008b), however, more research has to be done to apply PCO in an efficient way as most applications are still limited to ambient air conditions (Chan et al. 2009).

NAIs procedures remove aerosol particles from air through particle charging. The reactions produced between VOCs and NAIs are slow and complicated, and they are also affected by temperature and relative humidity. Hence, more research has to be done to develop more adequate NAIs methodologies.

NTP approaches produce chemically active species (e.g. atomic oxygen, hydroxyl radicals, ozone) that are able to remove indoor air pollutants. Nevertheless, NTP efficiency is low at the present time, and the formation of several by-products during air purification can also be a negative aspect of this concrete metrology. A combination of several of the above mentioned techniques can be more useful tool for indoor air purification than the use of a unique methodology (Yu et al. 2009).

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Chapter 17
Is it Safe Enough to Depend on Ventilation? Recommendation of Radical Measures for Addressing Sick Building Syndrome

Yoshiharu Imai and Nami Imai

17.1 Sick Building Syndrome (SBS) from An Architectural Perspective

Reduction of energy use is an important mitigation measure against global warming. However, in order to reduce energy consumption, developers construct airtight buildings and use a variety of methods to help keep the air inside buildings cool in summer and warm in winter. In addition, earthquake resistance has increased in importance in recent years, and building materials are now also selected for their ability to withstand earthquakes. Unfortunately however, the desire for materials that have the desired characteristics of strength and airtightness often outweighs considerations of the health and safety of the inhabitants of these buildings.

Materials such as medium-density fiber (MDF) board are designed to resist deformation and maintain airtightness. These MDF boards are produced using a variety of organic solvents to glue the wood fiber material derived from wood chips. In high temperature and high humidity environments, the synthetic compounds in these boards can volatilize harmful chemical substances like formaldehyde.

These toxic chemical compounds that are volatilized from building materials become trapped inside energy efficient buildings where they are inhaled by people and cause health problems. This process of volatilization is the mechanism responsible for the onset of sick building syndrome (SBS). In this chapter, we describe the countermeasures that need to be implemented against SBS caused by toxic chemicals in the living environment.

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17.2 Are Ventilation and/or Adsorption Sufficient for Solving the SBS Problem?

Despite the common belief in Japan that ventilation and/or the adsorption of the toxic compounds responsible for SBS will resolve the problem, such countermeasures are often insufficient for addressing indoor air pollution problems.

The initial response of most people who detect indoor air pollution is to disperse the agent using a ventilation fan. Next, they place adsorbent materials, such as active charcoal, in the room, or they employ air purifiers. These measures are intended to reduce the concentration of the toxic chemicals contaminating the indoor air, and while they are not entirely ineffective, they are often insufficient. This is because many people believe that only a limited quantity of toxic chemicals will be volatilized and, consequently, that indoor air quality can be restored after a several days or weeks of ventilation or adsorption. However, this misunderstanding actually prolongs the problem and aggravates the symptoms. To explain how such a situation may arise, we examine a case in which formaldehyde, a known carcinogen, was the primary pollutant in a new apartment.

17.2.1 Example of Health Problems Caused by Formaldehyde

Formaldehyde (systematic name: methanal) is an organic compound with the formula CH_2O. It is a colorless gas at room temperature. Formalin is an aqueous solution that contains 37% formaldehyde by mass. Formaldehyde is the simplest aldehyde and is an important precursor to many other chemical compounds, including urea, melamine, phenolic and resorcinol resin adhesives. These compounds are used the manufacture plywood and particle board and as glue for wallpaper. In the home environment, these compounds can volatilize formaldehyde into the indoor air, causing mucosal damage or skin lesions.

The production of most of these adhesive resins is achieved through a polycondensation reaction between formaldehyde and another monomer. The result is the formation of a polymer macromolecule and a small molecule byproduct, such as water. Importantly however, these polycondensation reactions are reversible. For example, with the chemical equilibrium of the polycondensation reaction driven in the reverse direction, urea resin adhesives will hydrolyze at high temperatures and humidities causing the volatilization of formaldehyde (Fig. 17.1). This change in chemical equilibrium due to changes in environmental conditions means that the quantity of formaldehyde volatilized increases at high temperatures and humidities and decreases at low temperatures and humidities. Consequently, the quantity of formaldehyde volatilized from building materials and furniture containing formaldehyde-based resins is greater at higher temperatures and humidities. The influence of temperature and humidity on formaldehyde volatilization is also the reason why the number of SBS patients increases from the rainy season to summer and decreases from autumn to winter. In theory, this reversible reaction will continue

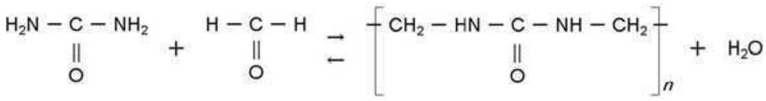

Fig. 17.1 Reaction scheme showing the chemical equilibrium of urea resin adhesives; the chemical equilibrium moves to the left by hydrolytic cleavage at high humidities and to the right by polycondensation at low humidities

until formaldehyde is no longer present in the adhesive, at which time the adhesive will no longer be effective.

Thus, in cases where the concentration of formaldehyde in a newly constructed building is high, the concentration of formaldehyde in a room is likely to increase and reach dangerous levels repeatedly over time, even though the concentration may decrease to safe levels immediately after ventilation.

Moreover, because people misunderstand this process, they believe that their SBS problem will be resolved by ventilation, when in fact it is not, and their symptoms often become prolonged as a result.

In one example of the SBS problem in Japan, a couple moved into a newly constructed apartment in 2001. They were both in their 1930s and in good health. Shortly after moving in, both experienced onset of nasal mucosal damage, cutaneous symptoms, and central nervous system damage. After an agonizing search for the cause of their ailments and numerous visits to different hospitals, they were eventually correctly diagnosed as suffering from SBS caused by formaldehyde exposure.

After the diagnosis, the couple attempted to reduce the concentration of formaldehyde by fully opening all of the windows to ventilate their apartment, placing activated charcoal throughout their apartment, and operating air purifiers all day, even during the winter. Nonetheless, because the building materials used in the construction of their apartment contained significantly high concentrations of formaldehyde, their symptoms were not alleviated.

Specifically, when measured immediately after 5 h of ventilation, the concentration of formaldehyde in the air of their apartment was 60 $\mu g/m^3$, which is lower than the 100 $\mu g/m^3$ recommended by the World Health Organization (WHO). However, the formaldehyde concentrations in the air of the apartment returned to 420 $\mu g/m^3$ after 5 h of not ventilating the apartment.

Detailed investigation of the apartment revealed that building materials containing high levels of formaldehyde had been used in the floor, wallpaper, doors, curtain pelmets, and the doors and shelves of closets. The couple had to move out of their apartment in the rainy season because the concentration of formaldehyde increased to very high levels due to the increase in temperature and humidity. They eventually experienced financial difficulties as they were forced to pay their mortgage as well as the rent for their temporary accommodations while suffering from SBS.

In countries such as in Japan, where housing costs account for a high proportion of a family's budget, falling ill with SBS after moving into a newly purchased home is like falling into the pit of an ant lion.

17.2.2 *Examples of Countermeasures for Reducing Formaldehyde Concentrations*

To address the problems encountered in the apartment described above, the owners implemented several countermeasures. Since the combined effect of ventilation, air purifiers, potted ornamental plants, and activated charcoal was ineffectual, the first measure we employed was the application of a paint sealer. Even though the concentration of formaldehyde decreased by 50% after implementing this countermeasure, the concentrations remained higher than the recommended guidelines (Imai and Imai 2006).

This result was not surprising because, although paint sealers are applied to the visible surfaces from which volatilized toxic chemicals are released, such sealers cannot be applied to surfaces that are not visible. Consequently, since toxic air containing high densities of formaldehyde can still leak from apertures in the wall, the concentration of toxic substances in the air will gradually increase.

We then attempted to completely remove the formaldehyde from the apartment by removing all of the hazardous materials and replacing them with safer ones. The process involved the following steps:

Step 1: Identification of hazardous materials through the analysis of the materials used in the apartment. Fresh material samples were obtained, including the glue used to manufacture them, and the quantity of volatized toxic chemicals were measured in a chamber.

Step 2: All of the non-structural building materials used in the apartment were removed.

Step 3: Antioxidation paint was applied to exposed surfaces in order to convert formaldehyde into H_2O and CO_2. The concentrations of formaldehyde and total volatile organic compounds (TVOC) in the indoor air of the apartment were measured.

Step 4: All of the new building materials used to refurbish the apartment were placed inside and the doors and windows were sealed. The concentration of formaldehyde and the TVOC in the air of the apartment were then measured to confirm that no toxic substances were being released from the new materials.

Step 5: Upon completion of refurbishing the house, the air inside the apartment was chemically analyzed to identify which chemicals were present after the apartment was refurbished.

Qualitative chemical analysis of the indoor air of the apartment was not performed before refurbishing because, with the exception of formaldehyde, we already knew that there were no toxic chemicals in the apartment. In addition, to avoid prolonging the construction schedule and increasing refurbishing costs, we did not measure the concentrations of chemicals by qualitative chemical analysis at each step.

Since the TVOC concentrations in the apartment were high after completing step 4, we qualitatively analyzed the chemicals in the air. The results showed that the high TVOC levels were due to constituents of the natural wood in the building materials. This same result was obtained after the final step, but the concentration of formaldehyde decreased to levels below that measured outdoors (Imai et al. 2007).

These results revealed that ventilation, adsorption and sealing are not effective for eliminating indoor air pollution completely. Removal of all hazardous materials and the use of safe alternatives is the only way to solve the SBS problem.

17.3 Are the Safety Guidelines for Formaldehyde Truly Safe?

Concerns have recently been raised regarding whether the current safety guidelines recommended for formaldehyde are appropriate. For example, exposure to formaldehyde at a concentration of 100 $\mu g/m^3$ in the air over a lifetime is not considered harmful to human health. However, in this case, "human" refers to an adult and does not include children or the elderly. Furthermore, since these safety guidelines were not developed after long-term exposure experiments involving human subjects, the author doubts whether the 100 $\mu g/m^3$ limit stipulated in the safety guidelines for formaldehyde is truly safe.

Moreover, while the Japanese government considers the standard of 100 $\mu g/m^3$ formaldehyde in the air to be sufficient, this recommendation is not based on formaldehyde concentrations in a sealed room. Rather, this standard assumes that the air of the room is circulated once every 2 h by ventilation. The Japanese guidelines incorporate ventilation because lobby groups affiliated to the construction industry petitioned the government, insisting that constructing a building that satisfied the recommended guidelines was not possible. However, as described above, we demonstrated that it was indeed possible to construct the interior of an apartment and meet the recommended standards using only commercially available products and no ventilation (Imai et al. 2007). Therefore, wherever possible, home environments should be constructed using building materials that have low levels of toxic chemicals and which do not need to be used in conjunction with ventilation.

17.4 Difficulties Associated with Resolving the SBS Problem in Public Buildings

The same approach cannot always be adopted when developing countermeasures for SBS. For example, a different set of countermeasures needs to be employed when dealing with SBS in public buildings, primarily because the convenience of the various people using the building need to be considered.

In the case of a private building, the number of people affected is usually limited, the scale of the mitigation measures is relatively small, and the problem can be resolved privately. On the other hand, if SBS occurs in a public building, the source of harmful chemicals may not necessarily be the building materials, but chemicals that are carried into the building by an unspecified number of people.

The possible causes of air contamination in public buildings are varied and can include furniture, printing ink, chemicals used on electrical appliances, floor wax, perfume, cosmetics, shampoos or skin creams, and synthetic detergents, among others. Consequently, identifying the cause of SBS under these circumstances is extremely difficult.

Also, if SBS occurs in a private building and the cause of the problem is determined to be the building materials, then countermeasures can be implemented relatively easily because the building is usually owned by a single entity.

However, the implementation of countermeasures in public buildings is often delayed, or is insufficient, because building managers typically know very little about SBS, or they try to hide the problem to avoid incurring the repair costs or being prosecuted for violating public health standards.

As mentioned in Chap. 6, many of the students and staff at a nursing school developed SBS symptoms, such as cephalgia, mucosal damage and mental disorders in a newly constructed teaching facility at the school. The headmistress of the school refused further inspections by a specialist and ordered the staff to keep quiet about the matter out of concern that the number of applicants to the school would decline if it was discovered that the school had an SBS problem.

As a result of the delay in implementing appropriate countermeasures, the magnitude of the health hazard increased and a teacher who consulted the author had to resign from the school due to ill health (q.v. Chap. 6). In this way, the ignorance of management regarding SBS, combined with the fear of SBS becoming a public health problem, prolonged exposure to hazardous materials in this public building and prevented the resolution of the issue.

17.5 Conclusions

Radical measures are required to adequately reduce the levels of toxic chemicals in the home environment to affect both prevention and recovery from SBS without the use of ventilation. Instead of relying on countermeasures such as ventilation to mitigate the dangers of contaminated air, the use of building materials that release toxic substances should be avoided. Furthermore, increased attention should be focused on preventing the use of potentially hazardous materials in the construction of public buildings. This is because identifying the origin of SBS in public facilities is more difficult than it is in private buildings, particularly since the visitors to these facilities may bring a wide variety of chemical contaminants into these buildings.

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Chapter 18
Building Related Illnesses

Gustavo Silveira Graudenz

18.1 Introduction

The first reports of health and comfort complains among building occupants of artificially ventilated buildings started to pop up in the literature during the seventies (Ricks 1982). A significant robust prevalence study was published by Finnegan et al. (1984), on work-related complains as headache, lethargy, mucosal symptoms (nasal congestion, nasal discharge, eye-tearing and ocular itching) and chest tightness from workers from office buildings. These complaints were two fold higher in buildings with artificial ventilation when compared to naturally ventilated buildings. A longitudinal study by Sterling and Sterling (1983) demonstrated an increased rate of absenteeism in employees transferred from one building with natural ventilation to another with air conditioning system.

In the early 1980s, around 5,000 studies reporting the existence of "sick building syndrome" were published (Stolwijk 1984). The World Health Organization defined the sick building syndrome in 1983 as a high prevalence of symptoms in the occupants of these buildings. These symptoms include headaches, eye problems (irritation, pain, dryness, itching, and tearing), nasal symptoms (obstruction, rhinorrhea and irritation), oropharyngeal symptoms (irritation, dryness or pain) and problems to keep the concentration at work (WHO 1983).

Also during the 1980s some studies stressed the role of Heating, Ventilation and Air Conditioning (HVAC) systems as risk factor for building related complains. Danish Indoor Climate Study Group evaluated 4,369 employees from municipalities, showing a higher prevalence of symptoms of mucous membrane irritation, headache and asthenia strongly associated with the indoor environment conditions (Skov et al. 1989; Skov 1992). A third large European study was conducted by Burge et al. (1987), with 4,373 employees in 42 office buildings, showing a

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prevalence of 80% of workplace-related complaints. Employees working with air-cooling system had the highest rate of symptoms. The most common symptoms observed were lethargy (57%), nasal obstruction (47%), pharyngeal irritation (46%) and chest tightness (9%). Mendell and Smith (1990) published a meta-analysis of epidemiological studies showing a consistent pattern of increased risk of reporting work-related headache, lethargy, and upper respiratory/mucus membrane symptoms in office buildings with air conditioning, when compared to buildings with natural ventilation.

Since the arrival of 1990s, changes in lifestyle of the urban population were consolidated and large cities inhabitants spend about 90% of their time indoors making indoor environment and air quality a matter of global importance. At the same time, there was a generalized awareness that close contact with indoor environment contaminants and increased susceptibility of the population from industrialized world are associated with an epidemic increase of allergic diseases in industrialized countries (Bousquet et al. 2008), and indoor environment quality problems affecting human health were considered the most common environmental problems of clinical practice (Ledford 1994).

During the past 10 years there was an increase in attention to indoor air quality (IAQ) problems in developing regions of the world due to burning of biomass (especially for cooking) that produces a deadly mixture of pollutants that results in more than 2,000,000 people, mainly women, elderly and children, that die because of this exposure yearly (Smith and Sundell 2002). This is the present priority of World Health Organization in matters related to indoor air pollution.

In the developed world studies on radon and environmental tobacco smoke as causes of cancer of the lungs, and studies on volatile organic compounds, particles, allergens, and agents of microbial origin and their relation to the increasing prevalence of allergies in the industrialized world are matter of debate (Kim and Bernstein 2009).

18.2 Definitions

In this chapter the term building-related illnesses will be used for diseases or symptoms that occur in non-industrial and non-residential buildings, which are in vast majority, office buildings. The term “specific diseases building related illnesses” refers to a group of diseases with fairly homogeneous clinical presentations, objective laboratory abnormalities, and one or more identifiable causes or agents known to be capable of carrying infectious diseases, immunological or allergic reactions. The term “nonspecific diseases related to buildings” refers to a heterogeneous group of work-related symptoms that include irritation of skin and mucous membranes (eyes, nose and throat), headache, fatigue and difficulty concentrating. These symptoms may be considered based on disease incidence or prevalence of these, even in the absence of objective clinical and laboratory abnormalities or causing agents, according to the classification proposed by Menzies and Bourbeau (1997).

18.2.1 Specific Building-Related Illnesses

A single causative can result in outbreaks of diseases related to buildings with many manifestations due complex interaction of a biological agent and the immunological system. Let us use the *Legionella pneumophila* as an example. This gram-negative bacteria, depending on the virulence of the strain and individual susceptibility, can result in Legionnaires' disease, a type of pneumonia with fatality rates up to 16% of cases, or may manifest as a milder form, called Pontiac fever, with only symptoms of fever and muscle pain and no lung symptoms (Seltzer 1994a).

Similarly, diseases such as humidifier fever (HF) and hypersensitivity pneumonitis (HP) will generate a clinical spectrum resulting from the interaction between the host immune system and inhaled airborne bacteria, fungi or protozoa that can be tracked to contaminated humidifiers, air conditioners systems or other sources. The clinical picture of PH is presented as recurrent pneumonia with pulmonary infiltrates visible at the chest images, associated with muscle aches, fever, cough and chest tightness. The causative agents of PH are particles measuring 1–5 μm of diameter that are deposited in the terminal alveoli. Once sensitized, individuals exposed again to tiny amounts of the same agent can produce an immunological reaction mediated by antibodies and pro-inflammatory cytokines that will lead to symptoms. The diagnosis of PH is classically described with the association of high levels of antibodies against biological contaminants responsible for the clinical picture that are found in the indoor environment (Laukova et al. 2009). However about 50% of individuals without symptoms may have demonstrable immunity (IgG), which reduces the specificity of the research (Seltzer 1994b). Careful medical history together with quantitative and qualitative approach to antibodies directed against environmental contaminants normally help confirm the diagnosis.

The HF is presented as a flu-like illness with fever, chills, muscle aches and weakness. Lung images are normal and pulmonary symptoms can be absent, differently from HP. This two diseases are much related, both result from exposure to biological contaminants in indoor environments and the clinical presentation will depend on the type and amount of biologically active contents and their interaction with the host immune system. The most important problems related to buildings are presented in Table 18.1.

18.2.2 Nonspecific Building-Related Diseases

This category is not related to diseases, but rather nonspecific symptoms that occur in a particular building and not in the home environment, without objective findings that can convincingly explain its cause. The prototype is sick building syndrome (SBS). "Sick Buildings" are identified by prevalence among occupants of non-industrial buildings above 20% of the symptoms described in the Table 18.2. There is no universally accepted definition for this entity because the clinical spectrum is variable, and environmental findings are inconclusive.

Table 18.1 Specific diseases related to buildings

Disease	Causative agent	Physiopathology	Clinical presentation	Diagnosis
Legionelosis	Gram negative bacteria *Legionella pneumofillia*.	Respiratory infection due to inhalation of viable airborne bacteria.	Dry cough, fever, muscle aches, chills, and breathlessness. Outcome can reach up to 10–15% of fatalities.	Identification of focus and document increased IgG serum antibodies to the same serotype of the bacteria outbreak in the environment.
Hypersensitivity pneumonitis	Antigens associated with fungi, bacteria, protozoa, insects and endotoxin.	Inflammatory reaction with granulomas and pulmonary fibrosis caused by delayed type-hypersensitivity reactions.	Acute: fever, myalgia, cough and recurrent inflammatory lung inflammation. Chronic: pulmonary fibrosis.	Medical history, radiographic studies, spirometry, pulmonary diffusion studies, antibodies titers and bronchial challenge.
Humidifier fever pneumonitis	Same as hyper sensitivity pneumonitis.	Transient inflammatory response with no granuloma formation.	Virus-like with fever, myalgia and asthenia, less pulmonary symptoms or sequelae.	Clinical presentation associated with environmental findings.
Rhinitis and Asthma	Mites, fungi, allergens from animals, bacterial toxins, temperature changes.	Nonspecific mucosal irritation or exacerbation of pre-existing allergic inflammation.	Nasal itching and obstruction, nasal drip and sneezing. Coughing, wheezing and breathlessness.	Spirometry, positive bronquial or nasal challenges, skin prick-testing or specific IgE for occupational allergens associated with occupational allergen exposure.
Eczema or contact dermatitis	Exposure to irritants products such glass fibers, cleaning and paper products, irritative substances, unknown.	Irritant contact dermatitis (the majority) or allergic contact dermatitis mediated by memory T cells.	Skin itching, scaling, redness, papules or vesicles on the exposed skin.	Medical history, physical examination, patch tests and environmental analysis.

Table 18.2 Clinical presentation of sick building syndrome (SBS)

No.	Most common symptoms in SBS
1.	Mucosal symptoms: nasal obstruction and/or nasal itching, irritation, pain, dryness, affecting also the lining of the eye, nose and pharynx.
2.	Asthma-like symptoms: chest tightness, cough, dyspnea (breathlessness) and chest wheezing.
3.	Neuro-toxic symptoms: headache, lethargy, difficult concentration, memory loss, depression and irritability.
4.	Skin symptoms: xeroderma (dry skin), irritation and erythema (redness).
5.	Other symptoms: fatigue, nausea, general aching, neck/back pain, numb hands, increased awareness to smells, and visual changes.

The prevalence of buildings-related health complains is still largely unknown. The prevalence of different symptoms can vary greatly, even within the same microenvironment, depending on environmental exposure and individual susceptibility.

In cross-sectional studies, up to 60% of occupants report at least one work-related symptom and 10–20% reported it to occur at least twice a week, according to meta-analysis (Mendell and Smith 1990). Although not considered serious, symptoms can be very uncomfortable and can lead to a considerable work-loss, productivity and quality of life. The intensity of symptoms generally decreases over time, but they may persist up to 50% of the affect individuals after 7 years of onset, despite the actions taken (Edvardsson et al. 2008). The concern with a more severe disease is common and can become obsessive in susceptible personalities (Bardana 1997).

18.3 Triggering Events

There is no single causal agent in SBS and it is much related to the altered perception of indoor environment quality. The causes of altered perception of indoor quality environments are many and have complex interactions. They include temperature, relative humidity, air exchange rates, odor, indoor air speed, exposure to biological contaminants (fungi, algae, bacteria, protozoa, allergens and their derivatives), volatile organic compounds, organizational and psychosocial factors described in review by Burge (2004). Some of the most common contributing events in SBS are listed below:

18.3.1 Climatic and Geographical Variations

Complaints about air quality may be substantially different in different locations related to their respective climates. Populations living in places with more adverse outdoor conditions tend to spend more time indoors and are more dependent on artificial ventilation, but relevant prevalence's of IAQ problems are reported in locations with milder climates. Some studies in tropical and sub-tropical climate also demonstrated increased risk for mucosal and neuro-toxic symptoms in populations working with air conditioning when compared to natural ventilation (Ooi and Goh 1996; Graudenz et al. 2005). Buildings located in humid climates tend to have problems with mould and biological contamination in indoor environment and they require special maintenance precautions (Spaul 1994). Exposure to low humidity conditions can lead to respiratory symptoms due to mucosal dehydration and shredding. In addition, air conditioning systems using humidification systems that might get biological contamination in dry climates. The buildings must be adapted regional climate, which is not always the case, for example, in companies that have branches in different locations and want to have the same building pattern resulting in thermal discomfort among the occupants.

18.3.2 Artificial Ventilation

The prevalence of mucosal symptoms reported in meta-analysis covering US and European cross-sectional studies show an excess of 50% of symptoms of mucosal irritation in buildings with air conditioning systems when compared to natural ventilation (Mendell and Smith 1990). The prevalence of symptoms is higher in buildings with a renewal rate of air less than 10 l/s/per, described by Menzies and Bourbeau (1997), probably due to the difficulty of removing indoor pollutants.

18.3.3 Age of Building and Maintenance of Air Conditioning System

In this aspect, the buildings are similar to humans; some problems are more common with certain ages. The newer buildings tend to have problems related to the exposure to chemicals as volatile organic compounds (VOCs) or due to initial testing and evaluation of air-conditioning system. The older buildings are more prone to biological contamination by fungi, bacteria, algae, protozoa and other biological contaminants (Spaul 1994). The degradation and lack of maintenance of the HVAC system can lead to improper air quality due to contamination by biological agents, inadequate air exchange and filtration rates and loss of indoor thermal control parameters (Oliver and Shackleton 1998). Symptoms of nasal and eye irritation had a positive association ageing of the HVAC system without adequate maintenance (Graudenz et al. 2002a). In such circumstances remediation procedures can decrease significantly the building related symptoms (Graudenz et al. 2004). On the other hand, non-regulated air conditioning systems or indoor environmental exposure to sudden indoor temperature changes has been showed to induce nasal inflammation in both normal but more pronounced and long lasting in the allergic individuals (Graudenz et al. 2006a).

18.3.4 Renovations

Air quality complaints often occur after renovations of buildings. This may be due to exposure to bioaerossols, dust particles or volatile organic compounds used in building renovations (Kilburn 2000). The time required to reduce emission of pollutants from glues, paints and coatings, is rarely observed in situations of re-occupation of the workplace. The use of low emission materials are recommended to diminish this problem although their safety is still not adequately confirmed. Renovations in hospitals with immunocompromissed patients can lead to a serious fungi infectious disease named invasive aspergilosis (Pini et al. 2008), demanding careful precaution measures to avoid dust exposure to inpatients during hospitals renovations.

18.3.5 Bioaerossol Exposure

Situations of flooding and dampness are often the triggering events of indoor air quality problems. Although subsequent proliferation of fungi or bacteria is expected, is not systematically demonstrated (Bornehag et al. 2004). The exposure of fungi can affect individuals in various ways, depending on the degree of exposure and individual susceptibility:

A- Sensitization: Exposure to fungi and other microorganisms can lead to conditions of sensitization after initial contact to *Cladosporium, Penicillium, Aspergillus* and other fungi characterized by the induction of immunoglobulin E antibodies (IgE) that mediate diseases as asthma, and rhinitis in individuals predisposed to allergic diseases (atopic). It is possible that higher exposure to these contaminants could lead to lung inflammatory conditions as pneumonitis (inflammation of the lung) or hypersensitivity (allergic alveolitis) in special situations. Diagnosis is done through tests of hypersensitivity (skin prick tests) and antibodies detection formed against to the suspicious fungi present in the indoor environment. If the environmental analysis comes up with the presence of a large number of dispersed viable fungal spores in the air, it corroborates to the diagnosis. This association can be difficult to establish in retrospective studies due to the impossibility of establishing either the time or exposure situation able to cause sensitization to fungi to characterize sensitizing exposure.

B- Irritation of mucous membranes: Considerable exposure to bioaerosols as fungi or bacteria, either as viable or non-viable particles can cause nonspecific irritation of the airways, which presents with cough, wheezing, sneezing, nasal stuffiness, breathlessness, eyes and throat irritations. It can also present with fever, chills, muscle aches and joint pain, like a flu-like condition. Normally there is a degree of adaptation with reduction of symptoms during the normal working days and recurrence during the re-exposure after long weekends and public holidays (Monday-fever). In this case, is better known as humidifier fever, toxic pneumonitis or organic dust toxic syndrome (Bardana 1997). Among the bioaerosols, endotoxins from gram-negative bacteria are most commonly incriminated. Skin tests and specific antibodies do not help in diagnosis. Presumptive diagnosis is with environmental evidence and clinical findings.

C- Mycotoxicosis: is the health effect resulting from exposure to a secondary toxic metabolite produced by fungi. Mycotoxicosis can have a clinical presentation with generalized headaches, fatigue, joint pain and vague neurological symptoms. These symptoms are transient and may be caused by fungi like *Stachybotrys* and *Aspergillus*. The environmental and clinical diagnosis is difficult to establish due to neither the possibility of any demonstrable allergic mechanisms in clinical research or an increase of viable fungal spores exposure in environmental reserch.

18.3.6 Work Stress

Personal factors are of great importance due to diversity and intensity that individuals perceive and react to same external stimuli. Although some studies demonstrate associations between work stress and SBS symptoms, no feature of the organizational system of work or types of personalities prone to develop symptoms have been identified so far (Skov et al. 1989; Kjaergaard et al. 1992; Ooi and Goh 1997).

18.3.7 Interaction of Multiple Factors

The cases of dampness infiltration and building renovations are described as the major risk factors for the onset of nonspecific diseases related to Buildings (Pejtersen et al. 2001; Li et al. 1997). Often, there is a lack of attention to the occupants with nonspecific complaints by the team of occupational health professionals. Moreover, the lack of an objective cause for the explanation of the facts associated with sensationalist misinformation from media can perpetuate the symptoms in susceptible personalities, even outside the workplace, creating situations such as disabling syndromes as multiple chemical sensitivities (Bardana 1997).

18.4 Individual Susceptibility and to Building-Related Disorders

The increased susceptibility to develop the allergic symptoms related to the buildings is known, but poorly understood (Brooks 1994; Ooi and Goh 1996; Bjornsson et al. 1998). Patients with asthma and young females are more likely to express symptoms. Patients with respiratory allergy may also have lowered respiratory epithelium thresholds limits to react to different pollutants exposure or temperature changes (Graudenz et al. 2006b) and perceive indoor air quality differently from controls in similar conditions. The variation of threshold limits for some indoor pollutants may vary greatly even in normal individuals (Menzies and Bourbeau 1997), making difficult to establish valid safety limits for all indoor pollutants.

Carpets are reservoirs for dust, dust mites and fungi, which can be suspended depending on the local turbulence (Skov et al. 1989). Wallace (1993) described the association of respiratory symptoms with exposure to dust and carpeted surfaces in office buildings. Menzies et al. (1998) showed an increased risk to develop work-related symptoms in employees exposed to dust mites levels greater than 1 μg of *Der p* 1 per gram of dust, or detectable levels of *Alternaria alternata* dispersed in the air. Nevertheless, these authors found no differences in skin tests for allergies to the control group.

The passive transport of substances that can trigger allergies (allergens) to public places has attracted more scientific attention as an alternative source of allergen exposure and sensitization and as a potential cause of triggering allergic respiratory symptoms has been demonstrated (Almqvist et al. 1999; Perzanowski et al. 1999; Chan-Yeung et al. 1999; Graudenz et al. 2002b), but the evidence that it is responsible for a substantial role in building related diseases and symptoms remains uncertain.

The assessment of exposure to fungal allergens is still controversial, because although they are known sensitizing agents, there are no sensitization thresholds limits widely accepted to result in allergic sensitization or allergic response to fungi exposure. Moreover, there is great variation between sampling methods (Buttner and Stetzenbach 1993; Verhoeff et al. 1994), making comparisons difficult. Some fungi are important causes of allergic respiratory symptoms, and include the genera *Cladosporium, Alternaria, Aspergillus* and *Penicillium* (Cooley et al. 1998). The outstanding growth of the fungus *Penicillium* sampled in indoor air when compared to outdoor air, as well as the presence of *Stachybotrys* mold in the internal environment may be linked to indoor air quality-related symptoms. It is a matter of current research, the role of low and repeated low dose exposure to fungi and the appearance of symptoms (Menzies et al. 1998).

Fungi and bacteria can be implicated in building-related diseases, normally a combination of non-specific symptoms with indicators of potential microbial contamination, such as high humidity, surface dust, carpets and dampness (Saijo et al. 2009). Older carpets may emanate various types of pollutants and their presence is reflected in the worsening of air quality perceived, even when these are hidden from view (Wargocki et al. 1999). In addition, there may be an improvement in the perception of QAAI associated with cleanliness (Raw et al. 1993). Unfortunately the association between exposure and health effects can be misleading. Menzies and Bourbeau (1997) demonstrated that the level of airborne fungi and bacteria is almost always low and the association with symptoms can be inconsistent. Epidemics of asthma related to occupation of office buildings are occasionally reported, however, no causative agent is routinely identified (Hoffman et al. 1993; Burge et al. 1985).

In summary, to date no single environmental factor has proved to be the sole cause of SBS. Factors associated with the perception of air quality are multiple and interactive and multidisciplinary research is needed to expand the current limitations of the knowledge related to indoor environment quality and human health.

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Chapter 19
A Continuous and Proactive Process to Enhance Well-being Indoors

Tarja Takki, Kirsi Villberg, Valtteri Hongisto, Risto Kosonen, and Anne Korpi

19.1 Introduction

The purpose of this chapter is to describe a systematic process for proactive and continuous management of indoor environmental quality. The indoor climate affects people during various human activities, such as work, learning, healing, sports, and entertainment. Indoor conditions either support or harm these activities, through a positive or negative impact on human health and comfort.

Controlling the quality of the indoor environment increases occupant satisfaction, improves productivity, supports the organisation's image, facilitates the management of risks to occupational safety and of disability pension due to deterioration in the work environment, and supports the quality management system of the relevant company.

People's well-being and environmental issues are among the major concerns of European societies today. Increased hospital admissions, extra medication, and millions of lost work days due to poor indoor environment not only are a financial issue but, above all, influence the quality of our everyday life.

People in modern societies spend most of their time (90%) in indoor spaces such as at home, work, or school and in vehicles. Improving the quality of the indoor environment enhances human well-being and productivity. Prevention of dissatisfaction and health symptoms created by poor indoor environment and incorrect operation of technical systems needs to be our aim.

Buildings are usually prototypes. They are not built as cars are by repeating the standard work phases and thus enabling a more consistent outcome. There is always a new group of designers, product suppliers, and contractors creating the new facility. In addition, it is not mandatory to inspect buildings and their performance annually, unlike with, for example, cars. Building management is not proactive, nor is it properly regulated as MOT tests are (the Ministry of Transport requires cars to be inspected regularly). Instead, it seems as if only when problems arise do the

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performance of and conditions in the building receive attention. Proactive indoor environment management is a new approach to building maintenance. The tools for it already exist, as will be shown in this chapter.

Indoor environment can create dissatisfaction and health problems for users for various reasons. Comfort-related and sometimes even health-related problems often reported by occupants include too high or low temperature, draught, stuffy or stale indoor air, lack of sound privacy in open-plan offices, and poor quality of cleaning services (Takki and Virta 2007). At the same time, average physical measurements (e.g., room air temperature) and average occupant satisfaction may show high comfort. The most common health symptoms reported in buildings include eye and respiratory tract symptoms, skin irritation, neurotoxic symptoms (e.g., headache, fatigue, and insomnia), and a sensation of unpleasant odour (Reijula and Sundman-Digert 2004; Norbäck 2009). In addition, stress symptoms and difficulties in concentration may be experienced especially in open-plan offices (Haapakangas et al. 2008).

19.2 A Systematic Method to Analyse Indoor Environment

Here, indoor environment is viewed as having seven main elements: the physical building, indoor air quality, thermal conditions, acoustics, lighting, maintenance, and building cleanliness. Various factors in these categories are described in Fig. 19.1. In a broader context, building safety and security can also be viewed as one category of indoor environment. Building safety includes assessment of injury risks, provisions for emergency situations, and personal security against theft or assault.

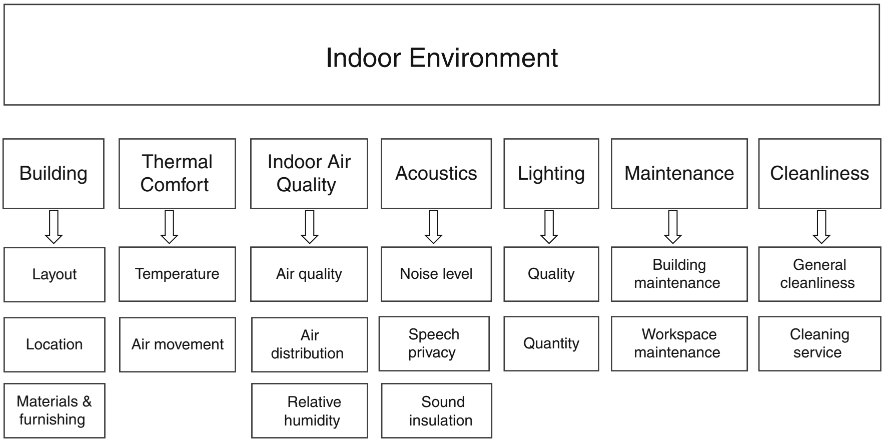

Fig. 19.1 The different factors of indoor environment

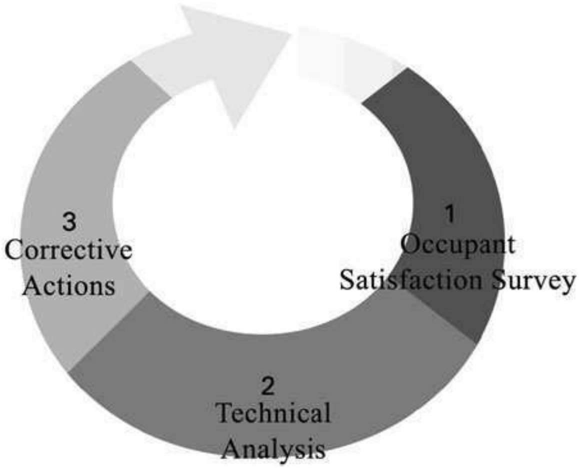

Fig. 19.2 Proactive, continuous process to enhance indoor environment quality and well-being

A systematic method for assessing and improving indoor environmental quality (IEQ) in existing and occupied buildings is presented in Fig. 19.2. The proactive and continuous indoor environment management process consists of the following three steps: an occupant satisfaction survey, technical analysis, and corrective actions.

By conducting the three phases in this sequence on a regular basis, the well-being of occupants can be enhanced and kept at a satisfactory level. This process has been successfully utilised in several projects for improving IEQ (Villberg et al. 2008). It is important to manage the indoor environment systematically, in order to prevent problems from appearing in an uncontrollable way.

19.2.1 The Occupant Satisfaction Survey

Questionnaires used for surveying occupant satisfaction and building-related symptoms (see, e.g., Andersson 1998; Engvall et al. 2004; Takki and Virta 2007; Zagreus et al. 2004) include questions on satisfaction with indoor air quality, thermal conditions and ventilation, the health status of the user (previous doctor-diagnosed asthma, current medication, and other illnesses), and symptoms. The benefits of questionnaires include that they are easy to carry out, non-expensive, repeatable, accurate, and sensitive.

On the other hand, low response rate and the list of non-specific symptoms weaken the utilisation potential of questionnaires. This is why they seldom work as a sole management method but need the inclusion of physical measurements to serve in the proactive building management process.

19.2.1.1 Comfort-Related Questionnaire

The process begins with an occupant satisfaction survey that is directed to everyone working in the building. The suggested minimum number of occupants is 20 per floor/cardinal point/department. The response rate should exceed 50–60%. Only those results for which there are more than five respondents per building area should be analysed. Respondents are asked to identify the area of the building where their workplace is located. The survey questions ask whether the workspace is in the internal or perimeter zone and whether it is near a window, and also the orientation and layout type of the office are linked with the information collected. These questions are specific to each building and tailored for the direction and shape of the building, and the wishes of the customer.

The satisfaction items encompass questions on the human perception/experience of the indoor environment. The topics are general satisfaction with the building and workspace, office layout, office furnishings, thermal comfort, indoor air quality, lighting, acoustics, building cleanliness, and maintenance. The occupants are asked to give a score indicating their personal satisfaction with each item on a scale from 'very dissatisfied' to 'very satisfied' (Zagreus et al. 2004). The numeric values are as follows (see Fig. 19.3): very dissatisfied $= -3$, dissatisfied $= -2$, slightly dissatisfied $= -1$, neutral $= 0$, somewhat satisfied $= 1$, satisfied $= 2$, very satisfied $= 3$. When the occupant chooses a negative value to describe his or her state of satisfaction, additional questions are presented to be answered.

With regard to thermal comfort, the aim is to clarify what is wrong with the temperature (too low/too high/or both/in turns), when the problem occurs (e.g., am/pm/all day/on weekends/on Monday mornings/always/unpredictably), and the apparent reasons behind thermal discomfort (draught caused by ventilation equipment or windows/stagnant air/sunshine/hot or cold surfaces/heat generated by

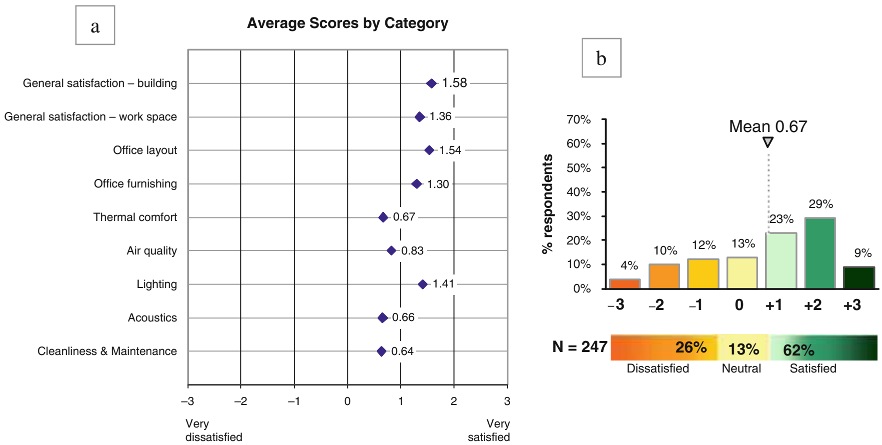

Fig. 19.3 Examples of occupant satisfaction survey results. **(a)** Average scores by category. **(b)** Satisfaction distribution for the survey responses on thermal comfort. The results show a wide distribution of results that our studies have shown to be typical of thermal comfort. Either thermal comfort overall is not managed systematically and therefore the deviation of this 'process' is high or human perception of thermal comfort varies greatly individual by individual

office machines/inaccessible thermostat/thermostat adjusted by other people/slow adjustment or insufficient capacity of heating or cooling systems).

Dissatisfaction with indoor air quality (IAQ) may be examined in more detail via questions on the presence of odours/ irritation symptoms (yes/no), when the odour/irritation problem occurs (am/pm/all day/on weekends/on Monday mornings/always/in summer/in winter/in fall/in spring/unpredictably), and the origin of the odours (tobacco smoke/office machines/food/surface materials/furniture/humans/cleaning agents/sewers/mould) or irritation (dust/humans/paper/pollen/sand/cleaning/surface materials/furniture). It is also determined whether stuffy/stale air or too high or low relative humidity causes problems.

There is always also an opportunity to give verbal feedback and answers in addition to predetermined options.

The survey can be utilised as a diagnostic tool to identify specific problems and their likely sources. When administered in Web-based form, survey can make use of streamlined, rationalised data processing. This approach has three main benefits. Firstly, it can inexpensively involve all occupants in the building. Secondly, being an interactive tool, it can reveal the areas/premises with the most dissatisfied occupants. Finally, the survey's interactive branching questions allow it to focus on items to which occupants give low ratings and thus in many cases diagnose the core of the problems. The approximate time required to complete the survey is 5–12 min.

The overall results show the average score given by respondents for each indoor environment element (see Fig. 19.3, pane a). Also the range of the responses can be seen (Fig. 19.3, b). The graph shows the overall IEQ situation in the building at a glance, and the results can be compared to a database of results for buildings of the same type. When the average satisfaction values for each of the indoor environment factors/categories are calculated, typically they fall between 0 and 2, regardless of the factor, as the figure shows. However, the range of satisfaction scores is much wider when the data set is broken down by area of the building (see Table 19.1). This means that (i) problems are local and (ii) in a building, there are both satisfied and dissatisfied occupants. Thus, even when relatively high average scores are given for satisfaction, there may exist major problems in some parts of the building. In searching for areas for technical improvement in buildings, it is more useful to present each aspect of indoor environment separately.

19.2.1.2 Indoor Environment Perception Map

The result of the comfort-related questionnaire is an indoor environmental perception map (Takki and Virta 2007). This is enabled by the respondents identifying their location in the building. The perception map locates the causes of dissatisfaction more precisely, by area, floor, compartment, cardinal point, and department as well as according to specific indoor environment factors (see Table 19.1). All who scaled their perception as slightly dissatisfied/dissatisfied/very dissatisfied are considered dissatisfied in this perception map. The perception map helps to allocate actions to specific areas where they are needed.

Table 19.1 An example of indoor environment perception map on different floors and at the various façades (dissatisfaction over 30% is highlighted)

Indoor environment category	Percentage of dissatisfied people All	2nd floor	3rd floor	4th floor	5th floor	6th floor	North	South
General satisfaction – building	3	3	0	0	13	7	3	0
General satisfaction – Workplace	5	3	6	0	29	0	0	14
Office furnishing – Comfort	10	15	12	8	0	6	7	0
Office furnishing – adjustment	10	9	15	9	0	13	10	14
Thermal comfort	26	36	12	58	0	35	19	43
Air quality	20	39	12	8	25	12	10	43
Lighting quantity	9	15	6	25	0	0	0	29
Lighting quality	12	12	12	17	13	12	16	0
Acoustic quality – sound level	16	15	21	33	13	6	10	43
Acoustic quality – acoustic privacy	32	21	36	58	25	35	16	57

Furthermore, if the exact problems have been localised, it is often possible to optimise the HVAC system such that its energy usage and the dissatisfaction of users can be reduced at the same time (e.g., when users complain of too cold room temperatures during summer). In many cases, reporting of visible moisture damage in the building may also be provided in the survey's free-comment section.

When the proportion of dissatisfied occupants exceeds a suitable threshold value (e.g., at least 30%), the next step in the protocol (i.e., the technical analysis and measurements) is to be taken.

When one is interpreting the average occupant satisfaction survey results, it is important to realise that the numeric average does not necessarily describe the *magnitude* of problems. Firstly, this is because psychologically occupants scale different elements in different ways. For example, satisfaction scores for office layout, office furnishings, lighting, and cleanliness are invariably higher than scores for thermal comfort, air quality, and acoustics, because either people normally expect more from the latter elements or less is invested in them and they are not maintained in a systematic way. This is also visible in a broader range of results for thermal comfort, indoor air quality, and acoustics. In addition, these are the elements with most of the technical problems. Secondly, people tend to emphasise a response by giving a more extreme score. Thirdly, organisational problems are reflected in overall dissatisfaction. Lastly, the time and time span of a retrospective survey may distort the scaling. Therefore, in intervention studies it is advisable to ask for current perception both before and after interventions.

In conclusion, a comfort-related questionnaire is useful in measurement of perceived indoor environment quality. As the function of buildings is to provide an indoor environment in which people conduct various activities, perceived indoor environmental quality is the main metric for building quality. The results of the survey form the basis for further actions to improve indoor conditions in existing buildings, to provide information to the design team for a new or renovated building, or to measure the success of improvement actions.

19.2.1.3 Health Symptom Questionnaire

Often the first sign of problems with indoor environment quality is the reporting of a specific health problem by a large number of occupants. The most common health symptoms reported include eye and respiratory tract irritation, and general symptoms. Eye symptoms include ocular irritation, burning of the eyes, and dry eyes. The nose symptoms consist mainly of rhinitis, stuffy nose, irritation, and also sinusitis, and throat symptoms such as hoarseness are among the typical building-related symptoms. In addition to irritation, concepts such as stinging, scratching, burning, and itching are used. Lower respiratory tract symptoms include dyspnoea and phlegm. In addition, skin irritation, neurotoxic symptoms (e.g., headache, fatigue, and insomnia), and sensation of an unpleasant odour are reported (Villberg et al. 2002; Reijula and Sundman-Digert 2004; Norbäck 2009). Dissatisfaction with acoustics can cause stress symptoms (particularly overstrain), and difficulties in concentration (Haapakangas et al. 2008).

From health symptoms alone, it is, unfortunately, difficult to draw definitive conclusions as to reasons, because various problems in indoor air/environment quality can have very similar health effects. However, it is recommended that a health symptom questionnaire, such as the Örebro MM40 questionnaire (Andersson 1998), be incorporated into the survey in order to link users' health symptoms with indoor environmental quality.

In a health questionnaire, the following symptoms may be recorded by the respondents on a weekly basis: fatigue, feeling heavy-headed, headache, difficulties in concentrating, irritation or a burning or itching sensation in the eyes, stuffy or runny nose, hoarseness or dry throat, cough, cough disturbing sleep, dry or flushed facial skin, dry or itching hands (or red skin on the hands), shortness of breath (dyspnoea), wheezing, fever or chill, joint aches or joint stiffness, and muscle pain. A symptom map is created from the responses (see Table 19.2).

The interpretation of and decisions on medical actions due to symptom data requires medical expertise. The indoor environmental specialist can conduct the health questionnaire and compile the symptom map similarly to the satisfaction survey.

In cases where dissatisfaction for certain elements and symptoms overlap, conclusions as to possible connections between causes and effects may be easier to draw. However, differences in sensitivity, and the healthy-worker effect (workers with symptoms have recently been relocated and only healthy ones remain on the premises), for example, may hamper the discovery of such connections. Therefore,

Table 19.2 An example of a symptom map, with symptom prevalence of ≥20% highlighted

Symptoms	Percentage of people having weekly symptoms							
	Building 1					Building 2		
	All (1)	South wing, 1st floor	South wing, 2nd floor	South wing, 3rd floor	North wing, 1st floor	All (2)	South wing	North wing
n	*98*	*40*	*12*	*13*	*16*	*73*	*52*	*30*
Fatigue	27	33	42	0	6	34	35	23
Feeling heavy-headed	19	25	33	15	0	27	29	17
Headache	13	20	17	8	0	21	21	13
Difficulties in concentration	10	13	17	0	0	18	21	7
Itching, burning, or irritation of the eyes	24	30	42	8	19	37	40	20
Irritated, stuffy, or runny nose	34	43	33	15	6	48	50	30
Hoarseness or dry throat	27	30	33	23	6	34	35	23
Cough	7	10	8	0	0	14	8	20
Cough disturbing sleep	3	0	17	0	0	1	0	3
Dry or flushed facial skin	15	15	25	8	6	26	21	27
Hands dry, itching, or red skin	24	28	50	8	6	30	29	23
Dyspnoea	3	3	8	0	0	3	0	7
Wheezing	3	0	17	0	0	3	0	7
Fever or chill	3	3	17	0	0	7	10	0
Joint aches or stiffness	6	3	17	0	0	10	12	3
Muscle pain	7	3	25	0	0	8	10	3
Other	1	3	0	0	0	3	2	3
Total % of symptomatic persons	65	68	92	62	31	77	73	60

a lack of clear area-based connections between indoor environment quality complaints and adverse health effects should not be considered to mean there are no such problems to be attended to.

19.2.2 Technical Analysis

A technical analysis is conducted in building areas where at least 30% of respondents are dissatisfied. Alternatively, in line with the goals set for indoor environment quality, further actions can be taken beyond a different predetermined threshold percentage.

Typically the main problem areas are thermal comfort, indoor air quality, and acoustic environment. Comprehensive analysis of indoor environment requires a multidisciplinary team representing expertise in at least IAQ, building physics, and HVAC systems. The team also needs knowledge of lighting, acoustics, and air distribution, in case these areas have been a source of significant dissatisfaction or health symptoms.

In many cases, technical problems causing local dissatisfaction can be found only if questionnaires are completed before technical analysis. The results of the physical measurements and qualitative observations are compared with reference values in the literature, standards, or results in corresponding investigations in order to define significant deviation. Corrective measures are to be determined from the results of the survey and the technical analysis.

19.2.2.1 Indoor Air Quality

Indoor air quality can be reduced by, for example, dust, man-made mineral fibres, microbial spores, propagules and metabolic products, soot, pollens, insect and pet allergens, volatile and semi-volatile organic and inorganic compounds, and asbestos. Also unsuitable relative humidity, high temperature, and high CO_2 concentration may decrease perceived IAQ and indicate problems.

Choosing the right technical measurements in situations of high prevalence of IAQ dissatisfaction requires special expertise. There is neither a systematic sampling strategy to follow nor a panacea with respect to what samples to take, since the range of things to measure is vast, as can be deduced from the list of contaminating agents. Instead, on the basis of hints obtained during the OSS as to possible causes, the technical measurements can be targeted cost-effectively. The pros and cons of the methods for measuring some of these agents are discussed in more detail in Chap. 24.

Despite the lack of clear correlation between health symptoms and underlying causes, several studies have shown that too high room temperature has a negative effect on perceived indoor air quality and increases symptom prevalence. This is because, as a result of increased temperature, also material emissions and products of human metabolism increase, and the air is perceived as dryer and stuffier. Also too high RH reduces the perceived indoor air quality. In particular, complaints of fatigue, headache, and upper respiratory tract symptoms have been reported to increase with temperature (Norbäck and Nordström 2008). This is why temperature and RH should always be routinely measured. Also the adequacy and functioning of ventilation should be a starting point especially when irritation and nose symptoms and central nervous system symptoms are recorded.

19.2.2.2 Thermal Conditions

Poor thermal comfort refers to too cold or too hot circumstances or the sensation of draught. Methods to analyse thermal conditions are dealt with in more detail in

Chap. 24. In brief, they include recordings of room air temperature, air velocity, and turbulence intensity. Also, smoke visualisation of air distribution and air flows, pressure differences, and the airtightness of certain structures is an appropriate method. Sometimes measurements of water-flow rates in heating and cooling systems – e.g., via thermal infrared imaging – should be employed. Furthermore, observations by experts play an important role in assessing the causes of the problems.

The whole-body thermal sensation may be acceptable while local perception could be dissatisfactory. Temporarily or spatially fluctuating thermal conditions are typically caused by insufficient capacity of heating or cooling systems, high thermal loads from indoor or outdoor sources, and poor control and regulating systems. Unacceptable local thermal sensations, in turn, can be caused by incorrect positioning of work areas with respect to air distribution.

Too high a room temperature is often accompanied by complaints of stuffy air due to increased material emissions and products of human metabolism. Also, complaints of fatigue, headache, and upper respiratory tract irritation have been reported to correlate with increasing temperature (Norbäck and Nordström 2008).

In the case of the need for larger corrective actions for air conditioning, mock-ups in the room or built in a laboratory might be appropriate tools, as might computational fluid dynamics (CFD) simulations. These are, however, heavy tools and require great investments in time and resources.

19.2.2.3 Acoustics

Noise is the most distracting factor in an indoor environment, especially in open-plan offices (Kaarlela-Tuomaala et al. 2009). The objective of room acoustics is to enhance desirable sounds and at the same time reduce non-desirable sounds so that they are not perceived as disturbing. Improper acoustic design can result in reduced work or learning performance and in communication difficulties or insufficient speech privacy. The negative effects of noise can be significantly mitigated by proper acoustic design. This demands special expertise that is not always available in building design. Therefore, in many cases, the acoustic problems need to be solved afterward, which is very challenging.

There are six important acoustic descriptors that need to be considered during the design process:

1. Intelligibility of speech inside the room, which is usually determined via measurement of the speech transmission index
2. The noise level of HVAC systems.
3. The reverberation time of the room.
4. The noise level of external environmental sounds.
5. Airborne sound insulation between rooms.
6. Impact sound insulation between rooms.

Acoustic design has two important elements: room acoustics and sound insulation. A room's acoustic quality depends on descriptors 1–4. Sound insulation is involved in descriptors 4–6. Determination of the acoustic descriptors is described in the standards ISO/DIS 3382 (descriptor 1) and EN ISO 10052 (descriptors 2–6).

What constitutes a good acoustic environment is determined by the purpose of use of the room. Work premises can be roughly divided into three main categories according to their room acoustic environments:

- Category 1: large spaces for several independent knowledge workers – e.g., open-plan offices, shared patient rooms, lounges, bank halls, and libraries.
- Category 2: spaces for good oral communication – e.g., auditoria, classrooms, meeting rooms, and operating theatres.
- Category 3: small rooms – e.g., private office rooms and doctor's consulting rooms.

The most common room acoustic problems for spaces in category 1 are the disturbance of surrounding speech and insufficient acoustic privacy. These cause concentration difficulties and problems in the management of confidential discussions, respectively. The problem can be solved by applying an 'ABC' principle involving simultaneous management of the following three factors (Virjonen et al. 2009):

- Absorption. Maximise the amount of absorption material in the ceiling, walls, and furniture. Textile floor coverings are recommended. However, the effect on perceived IAQ should be assessed and low-emission materials chosen.
- Blocking. Install sufficiently high space dividers such as screens and storage units between workstations and between team work areas.
- Covering. Mask speech sounds with a continuous masking sound that has the same spectrum as speech. The background sound pressure level of the room should be high enough to mask the surrounding speech. The recommended sound pressure level for masking is 42 dBA in open-plan offices and 48 dBA in other category-1 spaces.

In addition, the room should be provided with supporting spaces, such as phone call rooms and silent workrooms to permit perfect speech privacy, for temporary use.

The most common room acoustic problems for categories 2 and 3 include too high a background noise level and too long a reverberation time of (i.e., too much echo in) the room. These cause reduced speech intelligibility, which degrades both learning performance and communication quality. The noise level should be less than 35 dBA. Reverberation time can be controlled via absorption materials at the perimeter of the ceiling and in the upper part of one or two walls. The absorption area should not be more than 100% of the floor area, to keep speech sound pressure high enough throughout the room.

Sound insulation problems are similar in all three categories. In most cases, the structural sound insulation of walls and floors may be sufficient while the problems are caused by sound leaks due to negligent workmanship. These occur because of missing door seals; missing doorsills; improper sealing around the wall perimeter;

and holes made for electric, ventilation, water, or heating lines. The ventilation ducts can also transmit airborne sound between nearby rooms. Structural changes should not be made before these acoustic paths are fully eliminated. If structural changes are still needed, they should be designed by an acoustic expert, as the original structures and other edge conditions of the room need to be examined in order to find the optimal way to increase sound insulation.

If acoustic problems appear in the workplace, acoustic measurements may be necessary for uncovering the failure in acoustic design and providing information for complementary acoustic design. The measurement results are compared to national building norms or other target values presented in the building or rental contract.

19.2.2.4 Lighting

Proper lighting conditions enhance vision; reduce eyestrain and pain associated with the neck, shoulder, and head; and do not generate mental stress. In addition, proper lighting creates a comfortable work environment that has a positive impact on the employee's well-being.

The European standard CEN 12464 (2002) does not call for uniform lighting throughout a room, but the work area and areas in its close proximity have to be illuminated properly. The intensity of illumination in other parts of the room can be lower. The advantages of this guideline are flexibility in locations of light fixtures and lower energy use.

The most important factors in lighting quality are:

- sufficiency of illumination,
- suitable luminance ratios in the work area and its immediate surroundings,
- limiting of glare from both lighting fixtures and windows,
- good colour-rendering,
- comfortable and luminous colour, and
- lighting that does not fluctuate.

Our field studies indicate that lighting conditions are rarely the main cause for dissatisfaction or health symptoms. In the rare cases when dissatisfaction with lighting exceeds 30%, it is important for an expert to observe the conditions and check the illumination in the work area and luminance ratios.

19.2.2.5 Typical Technical Problems

Typical technical reasons for complaints include the following:

- non-balanced ductwork or pipework,
- unfavourable positioning of the work area with regard to supply air,
- incorrect exhaust grille positioning,
- diffusers with unsuitable throw patterns,

- furniture and light fittings directing air flows toward work areas,
- room units operating outside optimal range,
- large windowpanes causing uncontrolled air movements and asymmetric thermal radiation,
- poor operation of the building management system or room controllers,
- inappropriate materials or improperly maintained materials,
- unfavourable room acoustics,
- an insufficient number of sound absorption panels in the room,
- too little masking of background noise, and
- sound leaks through unsealed door or wall seams, electric cable holes, or duct holes.

Technical measurements that help to identify and verify the typical problems are presented in Table 19.3.

19.2.3 Corrective Actions

An action plan is created on the basis of the occupant satisfaction survey results (addressing comfort and/or health symptoms) and the technical analysis conducted for spaces or indoor environment factors representing high dissatisfaction and/or

Table 19.3 Methods that aid in identifying the typical technical problems

Technical problem	Useful measurements for identifying/verifying the problem
Non-balanced ductwork or pipes	– Air-flow rate measurement – Water-flow measurement
Diffusers with unsuitable throw patterns	– Air distribution (smoke visualisation)
Room units/terminals operating outside optimal range	– Air-flow rate measurement – Pressure level of room branch – Smoke visualisation
Large windowpanes causing uncontrolled air movements and draught	– Air-flow rate measurement – Air distribution – Temperature and RH
Poor operation of the building management system/room controller	– Check the set values and temperature sensor locations – Compare set values (temperature and flow rates) with actual values – Control the heating and cooling strategy
Inappropriate materials or materials with improper maintenance	– VVOCs, VOCs, and SVOCs – Dust and airborne particles – RH and temperature
Unfavourable room acoustics	– Sound level – Reverberation time – Speech transmission index

high symptom frequency. To ensure high quality in the work, the corrective actions must be carried out by certified maintenance and service personnel.

According to our field studies, the typical corrective actions include:

- changes in air distribution patterns,
- removal of moist building materials,
- change of interior materials,
- updating of cleaning instructions,
- air-flow rate adjustments,
- alterations to the building management system, and
- changes to room acoustics through increased use of sound absorption panels and masking of background noise.

The impact of corrective actions needs to be verified after 6–12 months. The most suitable method is to conduct a post-action survey to compare the perceived IEQ and reported health symptoms before and after the corrections. Furthermore, analysis of selected IAQ samples and technical system measurements should be part of the procedure. This method could be utilised also in refurbishment projects where the results of before-and-after evaluations show success in reaching the targeted quality levels and perceived IEQ.

Thanks to a systematic method, it is possible to rectify defects and errors in a building, not just the symptoms of these errors. As a result, user satisfaction will be improved and complaints reduced, and often also the system's energy-efficiency will be enhanced. This is especially true of modern office buildings where summertime indoor temperatures (typical set value: 21°C) are often too low to match the general clothing of occupants. Increasing the temperature set point to 24°C (and decreasing the cooling) would save energy.

19.3 IEQ Certificates

It is important to communicate to building occupants the dedication to a continuous and proactive IEQ management process. It is essential to provide them with exact and prompt information regarding indoor environment status, since IEQ is not tangible and, in the absence of proper information and knowledge, occupants may draw conclusions that are not realistic. An IEQ certificate is a tool for communication.

An IEQ certificate (see Fig. 19.4) is granted to buildings that follow the continuous and proactive IEQ management process. This certificate expresses the building management's aim to continuously maintain a good or even delightful indoor environment, and it can be displayed in the lobby of the building and on the intranet. The management's dedication to sustainable building maintenance and energy-efficiency through measurement of energy consumption and the building's carbon footprint can be added to this process. It is, however, essential to point out that buildings are for people and that the occupants' well-being should never be compromised

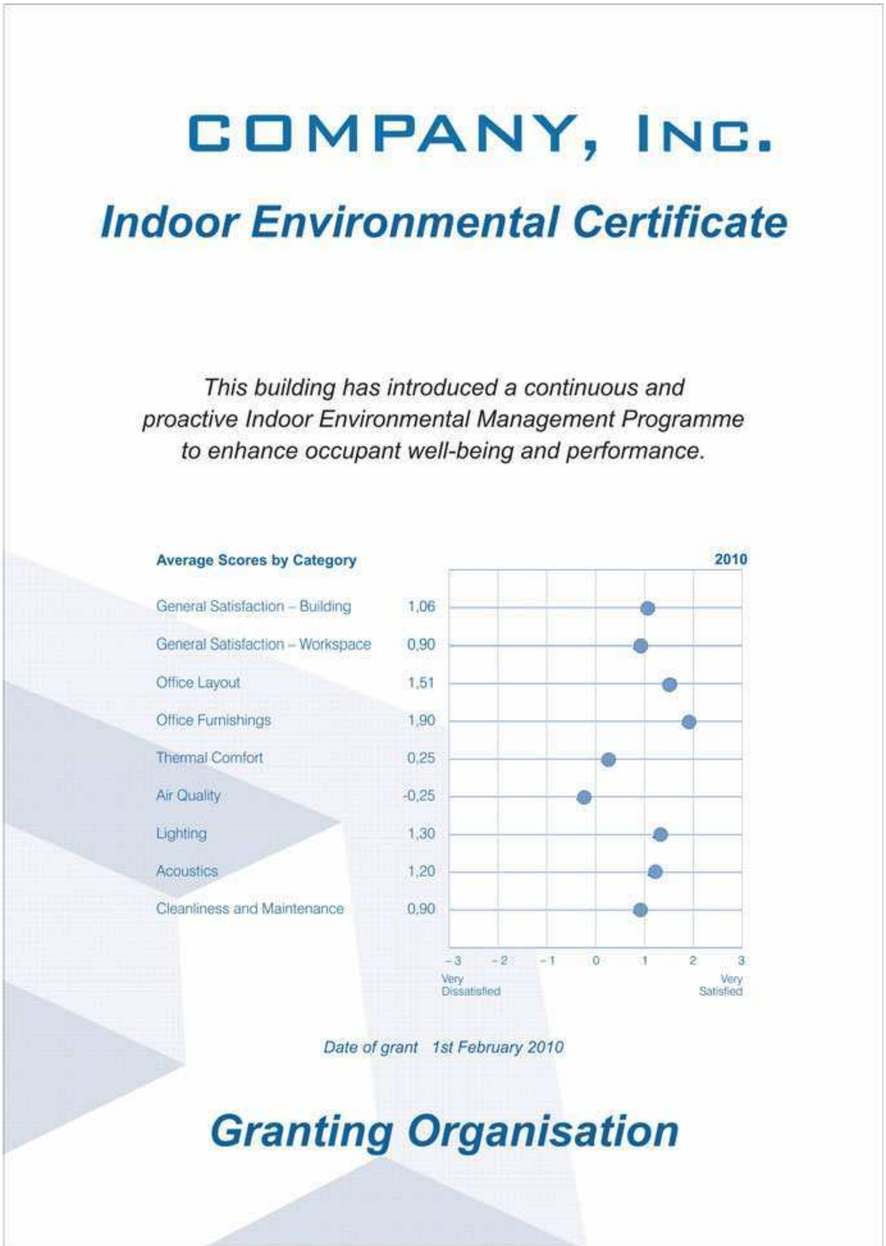

Fig. 19.4 An example of an IEQ certificate

for energy-efficiency. The granting organisation could be a local company that has been certified to utilise the indoor environmental management process and possesses the knowledge and resources to steer the process and provide the needed tools and expertise.

The IEQ management process should also include regular meetings of an indoor environment group, composed of representatives of occupants, the building management, the maintenance organisation, and occupational health care services. The aim of the meetings is to discuss the possible problems or challenges related to IEQ and to prevent serious problems from developing. The presence of indoor environmental groups has proved to enhance occupants' well-being and tenants' commitment to continuing lease agreements.

19.4 Discussion

The built environment is a critical factor in societies. The majority of our work occurs on indoor office-type premises. Thus, actions to improve productivity should be aimed at office premises instead of production premises. Good IEQ increases occupants' performance and productivity. Perceived IEQ and the health symptoms suffered play an integral role in determining the quality of a building. Even though numeric physical measurements describe IEQ accurately, only occupant satisfaction and comfort, and lack of health symptoms, indicate quality and functionality of the building. Perceived IEQ should be the measure of indoor environment. An occupant perception map (addressing comfort and health symptoms) is a useful initial tool for systematic detection of indoor environmental problems.

Sometimes the reason for an indoor environmental problem is a device fault, but very often it is just a consequence of a change in the office layout or in the usage profile of the premises. In these cases, changes have been made in furniture and wall layout while no adaptation of technical systems to the new situation has been made. The combination of air diffusion, warm or cold window surfaces and thermal plumes, and non-ideal layout of office furnishings may create unexpected air flows in the space.

Professional building-owners consider buildings to be bonds. The real value of a building is formed from the tenancy contracts. Customer satisfaction is part of long-term success in generating revenues in terms of long lease contracts. According to an American study (Boma 1999), at least 90% of office tenants consider the following six amenities and services very important: comfortable temperature, indoor air quality, quality of building maintenance work, the building management's responsiveness, the building management's ability to meet tenant needs, and acoustics/noise control. Yet, in practice, the occupant satisfaction with these features is usually the poorest. Saari and Takki (2008) have presented one market mechanism for combining customer satisfaction and lease revenues.

For IAQ or acoustics in a cellular office room, the percentage of dissatisfied persons (PPD) could be set at 15%, 20%, and 30% for an excellent, good, and basic level, respectively. For thermal conditions and lighting, the corresponding PPD values might be 6%, 10%, and 15%, respectively (Saari and Takki 2008). However, in practice, the lowest PPD values for thermal comfort are seldom realised, as a result of lack of possibilities for personal adjustments.

Currently, target values for physical parameters and proportions of dissatisfied persons by which to categorise indoor environmental circumstances exist for design purposes only. There remains no process to control how successfully the set criteria are met or to guarantee that follow-up and maintenance maintain these values. Yet it would be possible to use occupant-perceived IEQ as a basis for evaluation in such a practice.

Through requirement of certain standards for indoor environmental conditions and targets and their monitoring already in the lease contract between the lessor and the tenant, the indoor environment can be made part of the office services offered by the property-owner (Saari and Takki 2008).

New building and renovation projects rarely succeed in delivering satisfactory conditions to occupants. Buildings are prototypes, so the quality of the end result cannot be predicted. Therefore, it would be beneficial to tie some of the monetary value of the contract for the new building or correction team to the results of the post-work evaluation. This would create a value-based compensation method along with the more traditional hourly or cost-based reward. Measuring the quality of the building from the occupants' point of view would shift the construction industry at least slightly toward its main objective: providing comfortable and healthful indoor conditions for people.

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Chapter 20
Sick Building Syndrome from an Architectural Perspective

S. Müjdem Vural and Ayşe Balanlı

20.1 Introduction

People produce new and artificial environments by rearranging and manipulating the conditions provided by nature due to the fact that these conditions generally do not meet all of their needs. This activity is called building production. Construction activity has always been essential to people's efforts towards creating a compatible new environment. Environments that cannot meet the needs, structure and actions of people will adversely affect the health of their users.

Healthy life is the most basic of human rights. A healthy environment is crucial for this right. In general, people spend 80–90% of their lives inside buildings (indoor environment). Because of this, it is an important and vital right to live in a healthy building.

People in charge of design and construction stages of buildings are also responsible for the production of healthy buildings. The right of the building's users to live in a healthy environment is taken away if the design and construction stages are mismanaged and do not address the purpose of the building.

The purpose of this chapter is to contribute to the design and construction stages by determining the situations that have adverse health affects and focus on the risks during these stages.

Sick Building Syndrome (SBS) is part of the Building Related Illness (BRI). In order to establish the relation between the negative building quality and biological as well as psychological health problems, this chapter will describe the relationship between

- SBS and architecture
- SBS and quality of the building

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20.2 Sick Building Syndrome

Health problems caused by the negative quality of buildings are in the context of Building Biology (See Chap. 7) or Building Related Illness. These health problems can be biological or psychological. Biological problems include headaches, visual disorders, deafness, high blood pressure, heart throb, digestive disorders, pain, fractures, cuts, wounds, colds, allergies, itching, burning, legionnaires disease, dyspnea, lacrimation, nasal flow, metabolic diseases, throat irritation, dizziness, nausea, vomiting, memory loss, cacosmia, various types of cancers, asbestosis, pleural tumors, mesothelioma. Psychological problems include tension, irritability, anger, absentia, attention disorders, pessimism and personality disorders. Psychological problems can also lead to psychosomatic diseases. Some of these health problems appear while people are in the building and vanish some time after leaving the building. SBS is used to explain these kinds of health problems.

Symptoms of health problems may start within the first 15 min up to few hours after entering the building and vanish after leaving the building in 30 min up to few hours (Spellman 2008).

World Health Organization classifies SBS into five groups (WHO 1982; Redlich et al. 1997).

- Mucous membrane irritation: eye, nose, throat irritation
- Skin irritation: rash, pruritus, dryness, ache
- Neurotoxic effects: headache, dizziness, nausea, vomiting, physical and mental fatigue, loss of memory, lack of concentration
- Nonspecific hypersensitive reactions: asthma and other respiratory problems
- Chemosensory changes: odor and taste sensations

SBS sufferers usually show no clinical signs of illness (WHO 1982).

The age, occupation, addiction, immune system and existing health problems of building users are significant factors for SBS. Infants, children, elderly people, workers of specific manufacturing processes, smokers and drug addicts, people with immune system problems are primarily and most commonly affected by SBS.

The building must be designed and constructed with features that will not cause SBS. This is the primary concern of the field of architecture.

Architecture, in its broadest sense, is the restriction of a field in nature by covering it. In other words, architecture is the creation of an inner space that will meet its intended functions (Izgi 1999).

Architects take full charge of building construction, with its responsibilities and obligations. Architect is the person who;

- Determines the characteristics and needs of the building users
- Forms – designs the building
- Orients other designers (e.g., engineers, interior designers)
- Selects the building products
- Decides on production

- Supervises the building
- Manages relations with building inspectors
- Organizes all groups of people in the entire building (Öztürk and Balanlı 1995)

Therefore, an architect is primarily responsible for positive or negative interactions between the building and the people. The foremost cause of negative interaction is incorrect definition of user needs.

Needs arising from the nature of users are met by environmental features of the building. Building features that determine a positive quality are a result of both the design decisions of the architect as well as the successful reflection of these decisions to the actual construction.

If the architect cannot adequately define the needs of users or if the design has negative qualities, the building cannot meet the user needs, which may lead to SBS (Fig. 20.1).

It is very difficult for a healthy building to maintain this status during its entire lifetime.

Changes in time and conditions may adversely affect the sustainability of a healthy building. Time has negative effects on both the building and its users. These effects are caused by;

- Physical aging of the building
- Aging of the users

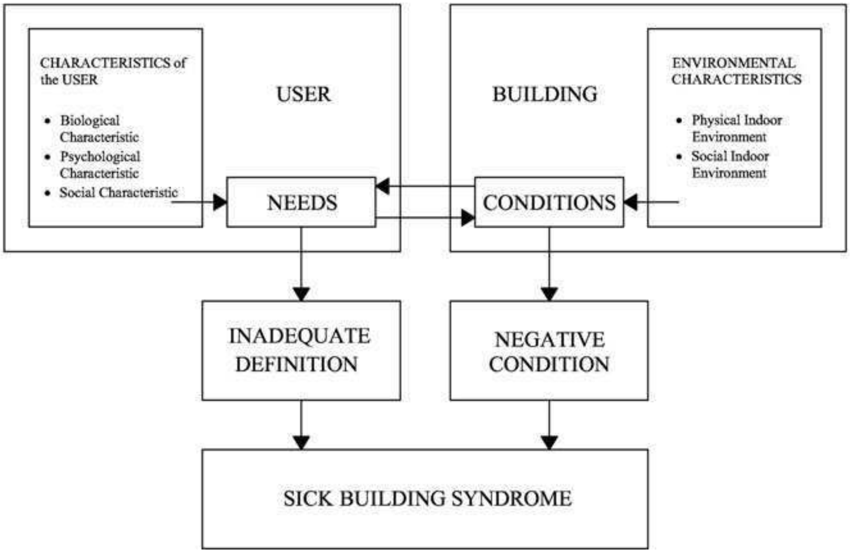

Fig. 20.1 Relationship between SBS, user and building

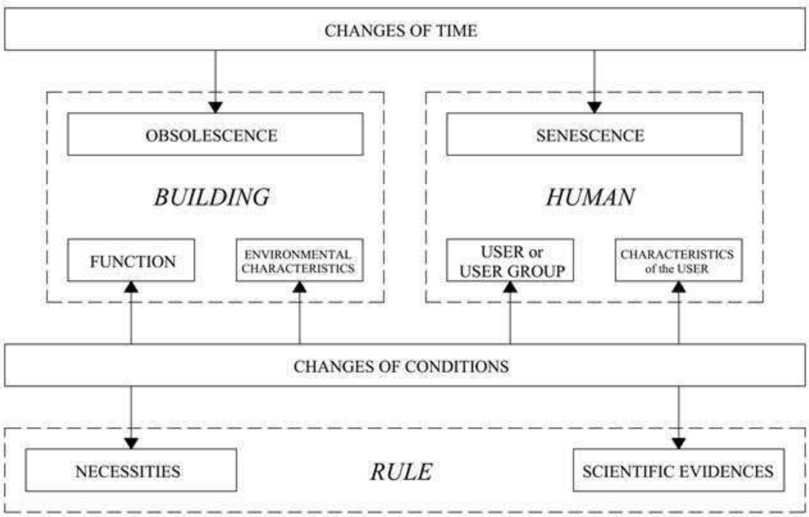

Fig. 20.2 Changes that cause a healthy building to become unhealthy building

Changes that cause a healthy building to become unhealthy occur due to;

- Building conditions (function, environmental features)
- User conditions (user, groups of users or structure of users)
- Rules (obligations and scientific findings) (Sarp 2007) (Fig. 20.2)

Determination of a healthy building's (designed, constructed and brought in use with healthy qualities) condition in the usage stage is another concern of the field of architecture. It is also the duty of the field of architecture to train experts on this topic.

Sustainability of buildings without SBS depends on periodic assessments.

20.3 Quality of Building and SBS

Physical and social characteristics related to the indoor environment of a building are affected by;

- Outdoor environment (physical and social outdoor environment)
- Building (as an object)
- Usage (See Chap. 3)

SBS can be determined with the help of the examination model given in Chap. 7. The steps of this model developed to specify the health problems caused by the building are

- The negative features within the indoor and outdoor environments of the building,
- The negative conditions due to those negative features,
- Hazardous impacts of those negative conditions on health,
- The health problems that might be caused by those hazardous impacts (See Chap. 7)

20.3.1 Physical Indoor Environment Features

The characteristics of the physical indoor environment of a building are;

- Dimensional and spatial features
- Visual features
- Auditory features
- Tactile features
- Atmospheric features

The negative physical and social indoor characteristics of a building are significant in terms of SBS.

20.3.1.1 Dimensional and Spatial Features of Indoor Environment and SBS

The needs of human beings, deriving from their biological, psychological and sociological structure are usually resolved by their actions. These actions performed within a building require, depending on the type of action, an area of a certain size, dimensions and shape.

Size of these building spaces and elements is based on the human dimensions. Dimensions of all buildings are primarily designed to comply with the dimensions of its users. This compliance must be both in terms of static and dynamic anthropometry.

Static anthropometry is the measurements of the human body taken in an erect and motionless status. Dynamic anthropometric dimensions are body measurements taken while performing specific actions (Toka 1989).

To design building spaces, one needs to determine;

- The functions of the space, actions to be taken
- Equipment required for these actions
- Shape and size of the equipment and how to place them within the space
- Required fields for the settlement and usage of the equipment

This determination is a prerequisite to the operational and effective design of the space.

The form needs to be in harmony with the function. The form must explain the mass of the structure, its expression, shape and the distinguishing features.

If the size and shape of the structure and its elements are not appropriate for the users and their actions, the design is unsuccessful and cannot respond to the requirements. This situation affects the health of the users and leads to SBS. In table 20.1 the biological and psychological SBS formation caused by negative effects resulting from dimensional and spatial indoor environmental properties will be given.

20.3.1.2 Visual Features of Indoor Environment and SBS

Visual features such as light, color related to seeing can cause different health problems.

Light from the source or objects enters through the eye. The photoreceptor neurons in the retina collect the light and send signals to neurons that then generate electrical impulses those go to the brain. The brain then processes those impulses and gives information about the sight. The visual system reacts to luminance and color differences (Drahonovska 2005; Tiller and Phil 2000).

Through out the design stage architects must work with lighting experts on illuminance, illuminance distribution, light source color, and shadow characteristics as well as natural and artificial light to create healthy buildings.

Table 20.2 shows the biological and psychological SBS formation resulting from the negative visual features of indoor environment properties.

20.3.1.3 Auditory Features of Indoor Environment and SBS

Features regarding noise and regarding acoustics (which is related to hearing) can cause different health problems.

Noise can be defined as irregular, physiologically unwanted sound. Indoor noise can result from mechanical systems within the structure, from other human activities or outdoor noise (e.g., traffic, construction) (Çevre Orman Bakanlığı 2008).

The parameters of discomfort from noise can be categorized as

- The person's psychological state at that time (angry, happy, etc.).
- The person's current action (work, sleep, rest, etc.).
- Sound quality
- Noise level
- Noise spectrum
- Personal sensitivity to noise perception
- Age (infants, children, elderly)
- Duration
- Nutrition and bad habits (e.g., cigarettes, alcohol)
- Certain drugs and toxic substances (EC 1996; Yılmaz Demirkale 2007; Berglund and Lindvall 1995; Devranoğlu 1997)

Table 20.1 Dimensional and spatial features of indoor environment and SBS

Feature	Sick building syndrome				
	Negative features of building	Negative conditions	Hazardous effects	Health problem	
				Biological	Psychological
Dimension	Space inadequate in dimensions for the needs	Difficulty of movement	Crash	Ache Injury	Stress
		Limitations of movement	Constriction	Tachyrhythmia High or low blood pressure Need of urinate Stomach and intestine movements (Öztürk 1997)	
	Space too large for the needs	Unnecessary amount of movement	Fatigue	Strength reduction	Stress Loss of concentration (Işıl 1991)
		Overwhelming effect	Depression		Stress
	Space causing frequent muscular contraction and myotonia	Low oxygen environment	Fatigue	Myalgia Shiver Difficulty in movement	Disinclination (Işıl 1991)

Table 20.1 (continued)

Feature	Sick building syndrome				
	Negative features of building	Negative conditions	Hazardous effects	Health problem	
				Biological	Psychological
	Space inharmonious with user and dimension of equipments	Too much bending	Pressure on the lungs Respiratory problems	Apnea	
		Too much reaching	Restricted blood flow to extremities	Ache, shiver (Öztürk 1997)	
	Insufficient volume	Low oxygen environment	Inadequate cell oxygen	Metabolic disorders Sleepiness Reduced brain functions	Disinclination
Form	Inadequate determination of users structure and needs in the design stage	Inappropriate form	Dissatisfied	Fatigue	Disinclination Lack of motivation Unhappiness Stress
	Aesthetic characteristics such as harmony, ratio and form neglected	Unaesthetic form			

Table 20.2 Visual features of indoor environment and SBS

Feature	Sick building syndrome				
	Negative features of building	Negative conditions	Hazardous effects	Health problem	
				Biological	Psychological
Light	Lack of light analysis (internal and external factors, user needs)	Inappropriate lighting	Stagger Fall Crash	Contusion Sprain Bleeding	Negative feelings
		Differences in either the luminance of objects or surfaces	Adaptation in the retina	Blurred and double Vision (Drahonovska 2005)	Stress Excitement Depression
		Rapid changes in contrast			Irritability
		Uniformity of artificial lighting	Stimulate fewer elements of retina and decrease visual performance	Eye fatigue (Drahonovska 2005)	Lack of perception
		Lack of daylight	Disturbance in the regular production of melatonin	Immune and hormone systems disbalance (Drahonovska 2005)	Syndrome seasonal depression
		High luminance	Discomfort glare	Increase sensitivity to glare Visual impairment	Tiredness Nervousness
		Contrast of background	Disable glare	Visual instant inability	Lack of well-being
		High glossy objects			
		Corrupted lighting fixture	Flickering light	Headache (Sarp 2007)	Negative feelings

Table 20.2 (continued)

	Sick building syndrome				
Feature	Negative features of building	Negative conditions	Hazardous effects	Health problem	
				Biological	Psychological
		Inappropriate color	Emotion changes		
Color	Lack of light analysis (internal and external factors, user needs)	Fixed patterns and colors	Time shift of retinal adaptation	After-images (Drahonovska 2005)	Stress
		Long wavelengths spectrum together with low illuminance		Transient myopia (Drahonovska 2005)	Fatigue Pessimism
Aesthetic	Aesthetic characteristics such as harmony, ratio and form neglected	Unaesthetic form	Dissatisfied		

The SBS caused by noise are

- Temporary threshold shift (TTS)
- Sleep disorders
- Stress and psychosomatic disorders

Hearing disorder is defined as an increase in hearing threshold. This rise may be temporary or permanent (Yılmaz Demirkale 2007).

When affected by severe noise, nerve cells in the cochlea of the inner ear can be permanently (permanent threshold shift) or temporarily damaged. If the hearing threshold eventually returns to its original state, this can be defined as a temporary hearing impairment. A temporary threshold shift (TTS) is a short duration reversible hearing loss of, usually returning within a few seconds, minutes, or hours after exposure (Godish 1997).

An uninterrupted sleep of sufficient duration is essential for the biological and psychological health of a human being. Sleeping disorders resulting from noise start with a noise level of 30 dBA (EC 1996). Common sleeping disorders are difficulty in falling asleep, changes in sleep patterns, deep sleep and sudden stimulation.

The definition of an unwanted sound is subjective; its effects on psychological and neurological system can vary from person to person (Sabuncu 1999). A direct correlation with increasing noise and exacerbation of existing psychological problems has been observed (Berglund et al. 1999).

Room acoustics is an important factor for audial comfort, the elements of which are the reflection, absorption, propagation, refraction, and reverberation, focus and echo of sound in enclosed spaces.

In a room volume, some of the sound waves that hit a surface are reflected, while others are absorbed or transmitted.

A person first hears the sound coming directly from the sound source within a space, then hears the reflected sound, while having difficulty hearing the sound absorbed by the soft and porous surfaces as well as other persons inside the space. Additionally, the propagation, refraction, reverberation and echo of the sound are considered as acoustic discomforts. Diversity of the forms and coating on the surfaces of the volume cause propagation of the sound, while certain obstacles (e.g., columns, beams) cause refraction of the sound.

Reverberation is the continuation of the sound energy through consecutive reflections down to inaudible levels.

The louder and longer repeat of the sound after initially being heard is called an echo (Yılmaz Demirkale 2007; Everest 2000; Cavanaugh and Wilkes 1999).

The noise within a building and its negative acoustic features can affect the health of the users may lead to SBS.

Table 20.3 shows the biological and psychological SBS formation resulting from the negative auditory features of indoor environment properties.

20.3.1.4 Tactile Features of Indoor Environment and SBS

Users tactile interaction with the surface of building elements can also create problems. In general people interact with walls, floor coverings and service elements.

Table 20.3 Auditory features of indoor environment and SBS

Feature	Sick building syndrome				
	Negative features of building	Negative conditions	Hazardous effects	Health problem	
				Biological	Psychological
Noise	Lack of noise analysis (internal and external factors, user needs)	Inadequate sound isolation	Short term hearing problems	Temporary threshold shift Tachycardia	Stress
			Sleeping disorders	Fatigue Immunodeficiciency disorders Tachycardia (Berglund and Lindvall 1995)	Mental disorders Distraction
			Stress	High blood pressure Nausea Dizziness Migraine Throat irritation Asthma exacerbation Itching Sweating (Berglund and Lindvall 1995)	Lack of concentration Anxiety Distressing Abstraction Nervousness Disquietude (Köknel 1997)
Acoustics	Insufficient room acoustic analysis	Reflection, absorption, propagation, refraction, reverberation, focusing and echo	Lack of acoustic comfort Lack of hearing Inability to understand Inability to discern (Öztürk and Balanlı 1995)	Headache Migraine	Stress Acrimony Anger Nervousness

Elements and components may have slippery, rough, prominent, sharp, hot or cold features.

Design decisions, building product decisions, bad application or usage are the main reason for these elements causing negative conditions.

Slipperiness in particular is an issue of floor coverings. The reasons for slipperiness are,

- Surface of floor finishing being slippery
- Slope of walking surface being unsuitable for use
- Loss of adhesion properties of surface due to water, oil, mud or similar substances (Reese 2008)

Roughness, similar to slipperiness, (R-Value, Class A) is a surface property that can be classified (Rz surface roughness) (HSE 2007) and is relevant for all surfaces that can be touched. Roughness is a positive factor against slipperiness but it is a negative factor for accumulation of dust and bacteria.

Difference of levels on surfaces, especially in flooring, is the result of faulty design and wrong application. When unnoticed, small differences of levels may cause tripping and falling.

Sharp-edged surfaces and building products are dangerous, especially in locations used by children, disabled, sick, elderly people.

Hotness or coldness of a surface is detected by skin contact. There is heat loss if a cold surface is touched and there is heat gain if a hot surface is touched. Heat loss and gain are crucial for thermal comfort. The biological and psychological SBS formations caused by negative effects of the tactile indoor environmental properties are given in Table 20.4.

20.3.1.5 Atmospheric Features of Indoor Environment and SBS

The condition of the indoor air can cause different health problems. In term of users' health atmospheric features can be classify as;

- Air quality
- Temperature
- Humidity
- Air flow
- Electromagnetic fields

Design decisions, building product decisions, bad application or usage are the main reason for these elements causing negative conditions.

Atmosphere contains nitrogen, oxygen, argon, carbon dioxide and trace amount of other gases. When the ratio of these components changes the air quality changes called as air pollution. Indoor air quality is also changes as the ratio of indoor atmosphere components changes. This pollution has negative effects on users' health.

Table 20.4 Tactile features of indoor environment and SBS

Feature	Building syndrome				
	Negative features of building	Negative conditions	Hazardous effects	Health problem	
				Biological	Psychological
Slipperiness	Slippery materials selection	Slipperiness	Stagger		
	Loss of surface adhesion		Fall	Contusion	
	Inappropriate slope		Difficulty in walking	Sprain	
Roughness	Rough materials selection	Rough surfaces Dust and bacteria accumulation	Crash Touch Friction	Pain Bleeding Allergy Microbial disease	Stress Excitement
Protrusiveness	Design or construction problems	Level differences	Trip Fall Friction	Contusion Sprain Bleeding Pain	
Sharpness	Touched surfaces and edges too sharp	Sharp edges	Crash Touch	Bleeding Pain	
Temperature	Touched surfaces too cold or too hot	Uncomfortable surface temperatures	Chill Burned	Cold Ambustion	Stress Dissatisfaction

The detailed study about the health effects of indoor air pollution is given in Chap. 3. Some indoor air pollutants can cause SBS. Temperature of the human body is between 36.5 and 37.5°C. This temperature is affected by the condition of indoor environment because of continuous heat exchange between the body and air around it. Thermal comfort zone differs for each user according to

- Temperature
- Activity level
- Insulation value of clothing
- Age
- Gender
- Medical background (Balanlı and Öztürk 2006).

Humidity is the amount of water vapor in the air. Mainly sweating controls body temperature. At high humidity, sweating is less effective. One of the factors that affect comfort zone of users is relative humidity (Balanlı and Öztürk 2006).

Airflow is created by differences of air pressure levels, which basically depends on the air temperature. Hot air dilates and rises with the decrease in its pressure replacing by cold air. Various environmental factors can affect the air movement and cause changes on the aspects of airflow. The speed of the flow, contents and temperature of the air and air change rates of indoor spaces should be sufficient and accurate. Inadequate airflow may cause SBS (Darçın and Balanlı 2010).

Electro magnetic fields determine the electrical characteristics of air. Pollution of electro magnetic fields affects biological and psychological structure of users. Lack of negative ions is one of the important factors of SBS (Topar 1996). The biological and psychological SBS formations caused by negative effects of the atmospheric indoor environmental properties are given in Table 20.5.

20.3.2 Social Indoor Environment Features and SBS

Needs arising from social natures of users:

- Living in groups
- Obeying norms
- Socialization processes (See Chap. 7)

If social needs are not fulfilled, health effects on user will have long-term results. Some negative building conditions related with social environments can cause SBS even in short usage duration. The relation between social indoor environmental features and SBS is given in Table 20.6.

Table 20.5 Atmospheric features of indoor environment and SBS (See Chap. 3)

Feature	Sick building syndrome				
	Negative features of building	Negative conditions	Hazardous effects	Health problem	
				Biological	Psychological
Air Quality	Lack of pollutant analysis (internal and external factors, user needs) False building product selection Inadequate details	Poor indoor air quality	Carbon monoxide	Headache Fatigue Breathlessness Weakness Dizziness Dimness of vision Vomiting	Lack of coordination and performance Confusion
			Carbon dioxide	Drowsiness Dizziness Headache Nausea Breathlessness	
			Nitrogen oxides	Burning and stinging of eyes, nose and throat	
			Sulfur oxides	Coughing	
			Toluene	Fatigue Disturbed sleep Eye irritation	Lack of coordination

Table 20.5 (continued)

Feature	Sick building syndrome				
	Negative features of building	Negative conditions	Hazardous effects	Health problem	
				Biological	Psychological
			Formaldehyde	Burning of eyes and lacrimation Sneeze Headache Nausea Vomit Diarrhea Allergen trigger Coughing Fatigue Disturbed sleep	Uncomfortable of odor Inquietude
			Ozone	Dimness of vision Chest pain Coughing Headache	Lack of concentration
			Pollen		
			House dust mite	Allergen trigger	
			Dust		

Table 20.5 (continued)

Feature	Sick building syndrome				
	Negative features of building	Negative conditions	Hazardous effects	Health problem	
				Biological	Psychological
Temperature	Lack of analysis (internal and external factors, user needs)	Inadequate heat isolation	Expose to temperature not with in the thermal comfort zone	Erythema Cold or sweating Eye irritation (Sarp 2007)	Lack of concentration
			Sleeping disorder	Fatigue	
Humidity		Inadequate ventilation	Low or high humidity	Erythema Headache Lassitude (Spengler et al. 2000)	
Airflow			Dry air	Eye irritation	
			Changes in the speed of air flow	Cold or sweating (Darçın and Balanlı 2010)	Disquietude Dissatisfaction
Electro magnetic field		Space	Electro magnetic field	Myalgia Eye and skin irritation Fatigue Headache Dizziness (Topar 1996)	Stress Distraction Nervousness Aggression Anger Unhappiness
		Decrease in negative ions	Increase in serotonin Decrease in melatonin		

Table 20.6 Social indoor environment features and SBS

Feature	Sick building syndrome				
	Negative features of building	Negative conditions	Hazardous effects	Health problem	
				Biological	Psychological
Group	Errors in group characteristics assessment	Inadequate space for group characteristics	Lack of communication Social clashes Noise Privacy Suffocation	Headache Physical and mental fatigue Throb	Stress
Norm	Errors in user norms assessment	Inappropriate space for norms (e.g., religious, ethical, traditional)	Clash Privacy Violation of norms		
Socialization	User socialization processes neglected	Spaces that hinder socialization	Displeasure Suppressed personality		

20.4 Conclusion

Users of building can have health problems caused by the building. Not all of these health problems can cause SBS. SBS is used to explain the health problems that appear while people are in the building and vanish some time after leaving the building.

Architects design and construct buildings that will meet the users' needs of physical and social indoor environment by following some features. The characteristics of the physical indoor environment of a building are;

- Dimensional and spatial features
- Visual features
- Auditory features
- Tactile features
- Atmospheric features

The negative physical and social indoor characteristics of a building are significant in terms of SBS.

To prevent SBS

- User must leave the building
- Reduce the effects of SBS factors
- Dispose of SBS factors (e.g., ventilation)

Architects can use the given model in this chapter to design health buildings and prevent SBS or define the causes of users' health problems.

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Chapter 21
The Role of Demographic and Psychosocial Factors in Predicting SBS Symptoms in Workplaces

Gail Kinman and Andrew Clements

21.1 Introduction

The World Health Organisation (WHO 1983) introduced the term 'Sick Building Syndrome' (SBS) to refer to a range of physiological, cognitive, psychological and neurological disturbances experienced by employees whilst in their working environment. As there is no generally accepted definition for SBS (or indeed an agreed upon set of symptoms) estimates of prevalence vary widely. A review of the literature by Glas (2010) highlighted prevalence figures ranging from 4% to 88%. SBS symptoms are more frequently reported in offices, hospitals and nursing homes, and schools and day-care centres (Norbäck 2009). A greater prevalence of SBS symptoms has also been found amongst regular computer users (Skyberg et al. 2003; Bakó-Biró et al. 2004) and in densely populated buildings (Chao et al. 2003).

A wide range of symptoms has been associated with SBS. These include skin irritations, eye, nose and throat complaints, musculoskeletal problems, nausea, dizziness, headache and lethargy (Hedge 1996), but mental fatigue, confusion and irritability have also been reported (Bachman and Myers 1995; Hedge et al. 1992; Ooi and Goh 1997; Wargocki et al. 1999). Extensive costs to industry have been highlighted through sickness absence, impaired productivity and employee litigation (Wargocki et al. 2000; Mendell et al. 2002; Burge 2004; Niemelä et al. 2006; Rostron 2008). The negative impact of building related factors on objectively and subjectively-rated job performance has been demonstrated. An experimental study conducted in an office environment by Wargocki et al. (1999) found that exposure to a source of indoor pollution resulted in lower levels of self-reported effort during a text typing and calculation task, as well as participants working more slowly than when the pollution was absent.

Many studies have found relationships between self-reported symptoms and both independent assessment of the built environment and objective clinical assessment

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of employees (e.g. Pejitersen et al. 2001; Stenberg and Wall 1995). Nonetheless, a specific environmental cause for symptom reporting frequently cannot be found (Bachman and Myers 1995; Rothman and Weintraub 1995; Marmot et al. 2006). For example, an epidemiological study of 2,160 office workers in 67 locations in Singapore conducted by Ooi and Goh (1997) found that factors related to the physical environment failed to account for the variance in self-reported SBS symptoms. Moreover, a prospective study of Danish employees conducted by Brauer et al. (2006) found significant relationships between perceptions of the indoor environment and a number of "symptoms" that had not previously been causally related to environmental factors, as well as associations with symptoms traditionally connected with SBS.

In order to explain such findings, it has been suggested that a range of demographic and psychosocial factors might be at least as important as features of the working environment in self-reported SBS symptoms in employees. This chapter reviews the literature that has examined sex and age as predictors of SBS, as well as several psychosocial and work-related factors such as stress, mood, job satisfaction, perceived control and social support.

21.2 Demographic Factors

21.2.1 Sex Differences in Symptom Reporting

The majority of studies conclude that SBS symptoms are more frequently reported by women (e.g. Brasche et al. 2001; Marmot et al. 2006; Runeson et al. 2006; Hansen et al. 2008). A study of Swedish office-based staff conducted by Stenberg and Wall (1995) found the overall prevalence of SBS for females to be approximately three times that for males. Moreover, men were more likely to be classified as "false positives" and women "false negatives".

Several reasons have been proposed for the higher prevalence of SBS symptom reporting in women. It has been argued that males and females differ in terms of inherited biological risks, acquired risks relating to work, leisure and lifestyle, perception of symptoms and help-seeking, and general health reporting behaviour (Stenberg and Wall 1995). An increased prevalence rate of SBS symptoms amongst women may reflect a general tendency for women to report higher rates of general psychosomatic complaints (Popay et al. 1993). Women may also be more sensitive to the various factors related to the physical and psychosocial working environment (Brasche et al. 2001). It has also been proposed that women employees experience more symptoms associated with SBS than their male counterparts as they typically work under physical and psychosocial conditions that are less favourable. A study of office workers conducted by Brasche et al. (2001) tested this proposition. Findings revealed that men evaluated the physical working environment more positively than women, and women had higher SBS prevalence rates irrespective of environmental, personal or work-related factors. Interestingly, women working alone in offices had particularly high prevalence rates, whereas women working in offices with two or three other people had the lowest. Future research should examine the role played by social isolation and social support as moderators of the impact of sex on symptom reporting.

A study conducted by Kinman and Griffin (2008) found some evidence that sex differences in symptom reporting may be at least partially attributable to inequity in working conditions. Their sample comprised 346 informational technology workers where males and females were of similar occupational status and performed virtually identical work. No sex differences emerged in the extent of symptom reporting, with the exception of women reporting experiencing more headaches at work than their male counterparts. Nonetheless, male and female employees differed in the psychosocial factors that predicted SBS symptoms and the proportion of variance in symptoms that was explained by these factors.

21.2.2 Age Differences

The findings of research conducted in several countries suggest that SBS symptoms are more commonly reported by younger and middle aged employees than those who are older (Marmot et al. 2006). An epidemiological study conducted in Sweden found that SBS symptoms are twice as common in younger employees (i.e. age group 30–39) (Eriksson and Stenberg 2006). Research conducted in Singapore by Ooi et al. (1998), who sampled 2,826 office workers from 126 offices in 56 randomly selected buildings, also found an increased prevalence of self-reported SBS symptoms amongst younger age groups. Research findings are not, however, unequivocal. A study of German office buildings conducted by Brasche et al. (2001) found age to be a significant risk factor for men only, whereby SBS prevalence was higher in male employees who were younger than 31 years (OR=2.1) or older than 50 years (OR=2.4).

It has been suggested that the increased prevalence of SBS symptom reporting in younger employees might be due to the ‘healthy worker effect’ (Ooi et al. 1998), whereby older employees who were unable to cope with chronic and debilitating health symptoms left employment. As with sex differences in SBS symptomatology discussed above, however, it is also likely that younger employees will be working under less favourable physical and psychosocial conditions than those who are older and more experienced. This inequity may account for the increased prevalence in younger people that is commonly found.

As women and younger workers tend to report higher levels of SBS symptoms, it has been suggested that future studies should control for demographic differences. Whilst this might be valid under some conditions, it is also important to establish the mechanisms that underlie such differences. Clearly, further research is required in a variety of workplace settings with employees of differing demographic profiles in order to further investigate the reasons for sex and age differences in SBS symptom reporting.

21.3 Psychosocial Factors

A wide range of work-related factors such as stress, high workload, lack of social support, conflict at work, poor communication patterns, poor management, and organisational change has been related to the reporting of symptoms typical of SBS. Other studies have also examined the contribution made by job control, job satisfaction and affective variables such as mood (Skov et al. 1989; Norbäck and Edling 1991; Ryan and Morrow 1992; Bachmann and Myers 1995; Crawford and Bolas 1996; Arnetz and Wilholm 1997; Ooi and Goh 1997; Spurgeon et al. 1997; Mendelson et al. 2000; Thorn 2000; Lahtinen et al. 2004). These studies will now be reviewed.

21.3.1 Job Stress

Several studies have found work-related stress in general to be a significant predictor of SBS complaints (e.g. Ooi and Goh 1997). The majority of studies has been cross-sectional and correlational in nature, and utilised self report measures of stress. Hansen et al. (2008) examined the role played by several physiological and self-reported stress indicators as predictors of SBS symptom reporting in teachers working in three Danish schools. Although a significant association was found between self-reported stress and symptoms, with the exception of a higher level of serum testosterone no relationships emerged between physiological indicators of stress and symptom reporting. Interestingly, significant relationships were found between subjective and objective stress markers for women only. The extent to which this sex difference confounded the findings of the study is, however, not possible to identify.

Although relationships have been found between stress in general and SBS symptoms, associations with more specific job stressors have also been examined. Organisational change appears to be of particular importance. Based on a review of several studies, Arnetz and Wilholm (1997) argued that organisational re-engineering and rapid introduction of modern information technologies are major precipitating factors in outbreaks of SBS. Studies conducted in a range of different occupational settings have also highlighted high workload and high job demand as risk factors for SBS symptoms (Bachmann and Myers 1995; Marmot et al., 2006). Role stressors (such as role overload, conflict and ambiguity) have also been associated with specific symptoms (Ooi et al. 1998; Mendelson et al. 2000; Marmot et al. 2006). As well as work-related stress having a more direct relationship with SBS symptom reporting, it is also possible that working under conditions of chronic stress is likely to lead to impaired immune functioning making an employee more vulnerable to infection. This process has been demonstrated in many studies in the field of psychneuroimmunology, whereby acute stress enhances immune response in the short term, but impairs it over the longer term (Cacioppo et al. 2007). Such a process might account for some symptom reporting.

21.3.2 Job Control

Low levels of perceived control (or poor job autonomy) have commonly been linked with negative health status in general (e.g. Spector 1986). In 1983, the WHO suggested that lack of control at work is likely to be related to SBS symptom reporting. It has also been argued that, over the long term, low control at work leads to a state of learned helplessness that might manifest itself as SBS symptoms (Rostron 2008). This is supported by findings that SBS symptom reporting is higher in people with a more external locus of control (Brasche et al. 2001). Such an explanation draws on general observations in the field of social psychology whereby people are more likely to blame negative outcomes on external rather than internal causes.

Although higher prevalence rates have been observed amongst employees at lower levels in organisational hierarchies (Zweers et al. 1992), until recently the relationship between job control and SBS symptom reporting has been little examined. A study of IT workers conducted by Kinman and Griffin (2008) found positive relationships between job control and symptoms associated with SBS. This study utilised a measure that encompasses perceptions of control over a variety of work domains, including task variety and order and scheduling of breaks, suggesting that increasing levels of autonomy over these factors might reduce symptom reporting. It could also be argued that opportunities for employees to influence their *physical* working conditions might be a particularly strong predictor of SBS symptoms (Vischer 2007). Indeed, a study of 4,052 office-based civil servants working in 44 buildings in the UK found significant relationships between control over aspects of the physical environment such as heating and lighting and symptoms (Marmot et al. 2006). Clearly more research is required to examine the aspects of job control that are more closely associated with SBS symptom reporting, and whether or not enhanced control over these domains lead to changes in symptom reporting.

21.3.3 Mood

Although a considerable body of research has examined relationships between employee affective state and psychosomatic symptoms, very few have focused specifically on SBS symptoms. Based on a sample of 624 office workers in South Africa, Bachmann and Myers (1995) found psychological distress (measured by Profile of Mood States) accounted for between 15 and 19% of the variance in symptoms of SBS. Anxiety, in particular, has been positively related to symptom reporting (Runeson and Norbäck 2005). Bauer et al. (1992) compared a range of affective states between employees working in a building with known SBS problems and a control building with no known problems. Findings revealed higher levels of anxiety in the SBS building, as well as more defensiveness and resentment.

More recently, it has been argued that symptoms experienced when employees are in their working environment might exert a greater influence on mood that is work-related. Kinman and Griffin (2008) investigated associations between work-related anxiety and depression and self-reported SBS symptoms. Findings revealed that respondents who were more depressed and anxious in relation to their work tended to report more symptoms. Marked sex differences were, however, observed in the strength of the contributions made by the two mood dimensions. For males, job-related depression was a more robust predictor of symptoms than anxiety, whereas job-related anxiety made the strongest contribution to variance for women.

Individuals with higher levels of trait negative affectivity (NA) have a tendency to experience a wide range of negative emotions (including anger, guilt, tension and worry). They have also been found to demonstrate a greater reactivity to stressors and hyper-vigilance to subtle bodily sensations and, accordingly, report more symptoms of ill-health (Watson et al. 1987). NA is therefore believed to underpin many observed relationships between stress and health. Perhaps unsurprisingly, it has been suggested that NA might be an important predictor of self-reported symptoms typical of SBS (Hedge 1996). As yet research findings are inconclusive, but little research has been conducted in organisational contexts. A large-scale study of UK civil servants found that NA moderated the relationship between aspects of the physical and psychosocial working environment and SBS symptoms (Marmot et al. 2006). In a study of informational technology workers, Kinman and Griffin (2008) found strong relationships between NA and an index of symptoms associated with SBS. Multiple regression analysis revealed that NA was also a significant predictor of variance in symptoms when other factors (such as job control, job satisfaction and job-related mood) were held constant.

The personality dimension of neuroticism is frequently used as a proxy for NA. Neuroticism reflects the tendency to experience emotional distress and an inability to cope effectively with stress. A study of 221 Croatian employees conducted by Bobic et al. (2009) found that people who were more emotionally stable (in terms of lower levels of neuroticism) reported fewer SBS symptoms.

There is some evidence that a tendency to respond negatively (or positively) to measures of physical and psychosocial working conditions and health status might underlie some of the associations found in SBS research. Nonetheless, there is also evidence that significant relationships between these factors remain even after controlling for NA (Marmot et al. 2006). The role played by NA in the reporting of such symptoms in working environments is as yet relatively unexplored and more research is required.

Whilst affective state appears to be related to SBS symptoms, as the majority of studies are cross-sectional and correlational the direction of causality cannot be established. It is not unreasonable to suggest that a negative affective state (whether state or trait) might lead an employee to be more sensitive to physical features of the working environment. The issue of causality and the need for longitudinal research in order to establish this is discussed later in this chapter.

21.3.4 Job Satisfaction

Research that has examined relationships between job satisfaction and SBS symptoms tends to conclude that employees who are less satisfied with their work report more symptoms (Norbäck et al. 1990; Hedge 1996). Many studies, however, utilise single item and/or dichotomous measures of job satisfaction (e.g. Brasche et al. 2001). Kinman and Griffin (2008) provided greater insight into the relationship between job satisfaction and SBS symptom reporting by differentiating between intrinsic and extrinsic job satisfaction in a study of IT workers. Intrinsic satisfaction encompasses features integral to the job (such as recognition for good work, responsibility, and skill utilisation), whereas extrinsic satisfaction covers features external to the job (such as physical surroundings and opportunities for promotion). Significant relationships were found between symptom reporting and both intrinsic and extrinsic satisfaction. Nonetheless, only satisfaction with extrinsic features of the job was a significant predictor of symptomatology. A potential pathway through which extrinsic job satisfaction may lead to self-reported building-related symptoms was highlighted by Ooi and Goh (1997) who argue that job dissatisfaction might make employees more aware of, or more critical of, their physical working environment. This proposition should be further examined using multi-dimensional measures of job satisfaction.

21.3.5 Social Support and Management Factors

Several studies have found social support at work to be inversely related to self-reported SBS symptoms. The extent to which employees feel integrated into the organisation and the general quality of interpersonal relationships have been found to be related to symptom reporting (Skov et al. 1989; Thorn 2000). Research conducted by Ooi and Goh (1997) found an increasing prevalence of SBS symptoms in employees who perceived a poor climate of co-operation at work. Similarly, Rostron (2008) has argued that management attitudes are also important factors in predicting SBS symptoms. He highlights two pathways by which poor quality management might be associated with symptom reporting: (a) *a direct route*, whereby poor management can lead to adverse environmental conditions that can cause SBS symptoms; (b) *an indirect route*, where poor quality management might enhance the sensitivity of employees to environmental conditions that were previously considered satisfactory.

Several different types of social support can be determined, such as emotional, instrumental, informational and network support (Cohen and Wills 1985). Multi-dimensional measures of social support should be utilised in order to examine the types of support that are more likely to protect employees from SBS symptoms. The relative impact of different sources of support, such as that from management and colleagues, should also be investigated. The extent to which sensitive and responsive management is a protective factor should also be examined.

21.3.6 Other Psychosocial Factors

There is some evidence that personality variables may be valid predictors of self-reported SBS symptoms. Sense of coherence (SOC) is viewed as a dispositional orientation or a 'generalised resistance resource' (Antonovsky 1987) that can be utilised in dealing with a wide range of situations and stressors. The SOC construct comprises three dimensions: comprehensibility, manageability and meaningfulness. A body of evidence indicates that the stronger the SOC the better the health status, regardless of demographic factors such as age (Eriksson and Linstrom 2006). Runeson and Norbäck (2005) examined the role played by SOC in SBS symptom reporting in a cohort of 194 employees working in buildings with indoor air problems. Findings revealed that a low SOC measured at baseline was associated with greater prevalence of tiredness, headaches and ocular, nasal and throat symptoms up to 10 years later. Moreover, employees with a lower SOC tended to develop more symptoms during the 10-year study period. Although only one study on the role played by SOC in SBS symptom reporting has yet been conducted, these findings are promising. Further research might consider the role played by other dispositional variables such as coping styles and hardiness. Interventions that acknowledge the role played by such dispositional variables might be more successful than those that assume there is little variation in response to objective building-related factors.

21.4 Discussion

This chapter has presented evidence that demographic variables, features of the psychosocial working environment and other individual difference factors make a strong contribution to self-reported symptoms compatible with SBS. It should be emphasised, however, that this does not mean that SBS is not a genuine illness. Nonetheless, it has been argued that the continued use of the term "sick building syndrome" may be misleading, as symptom reporting appears to be ". . . due less to poor physical conditions than to a working environment characterised by poor psychosocial conditions" (Marmot et al. 2006). Investigations that consider the contributions made by some of the variables reviewed in this chapter (such as employee attitudes, personality, behaviour patterns and mood) as well as resources such as job control and support, are likely to provide a more valid explanation for SBS symptom reporting than those that solely consider the features of the objective physical environment. It should be noted, however, that the interactions between the indoor environment, stressful working conditions and individual differences are likely to be complex.

In order to gain further insight into the SBS phenomenon, it seems necessary for future research to utilise more valid measures of SBS and psychosocial variables. The risk of using "biased, ambiguous, badly scaled, and poorly designed" questionnaires has been recognised (Hedge 1996). Particular problems have been identified in the use of leading questions when examining the prevalence and predictors of SBS (Marmot et al. 2006). Questions that ask participants to indicate the extent to which they believe that their symptoms are *caused* by the building in which they work are also commonplace. Such questions should be avoided as they might promote the reporting of building-related symptoms. Raw et al. (1996) tested 25 versions of a questionnaire to measure SBS symptoms in a large sample of office workers in the UK. Different versions of the questionnaire yielded differing results; more specifically, symptom reports were strongly influenced by the way the symptoms were described, and both symptom reports and ratings of environmental discomfort were affected by the scale that was utilised to assess frequency. The authors concluded that, in order to enhance comparability between different SBS studies, a standardised questionnaire is required.

Studies that examine the impact of psychosocial and work-related variables on SBS symptom reporting frequently utilise single-item measures rather than validated scales. Moreover, some studies have aggregated diverse factors, such as work content, workload and job control, into an index. Although the need for brevity is recognised, such practices can tell us little about the specific psychosocial variables that are the strongest predictors of symptoms and/or interact with factors relating to the objective working environment.

21.5 Priorities for Future Research

It has been recognised for some time that multidisciplinary teams are needed to engage collaboratively in research projects (Hodgson and Storey 1994). Such teams should identify ways in which organisations might manage the physical and psychosocial working environment in order to protect employees from SBS symptoms. An examination of relationships between symptom reporting and aspects of job control in Call Centres might be particularly fruitful. Many of the job characteristics that have been associated with SBS symptoms, most notably low autonomy, tend to be found in such working environments (Sprigg et al. 2003). Common features of Call Centre work (such as dense population, habitual computer use with limited opportunities for breaks, and inadequate responses to variations in temperature and lighting) might also place employees at greater risk (Brasche et al. 2001).

Most studies that have examined the psychosocial features of the working environment that predict SBS symptoms have been cross sectional. The direction of causality cannot, therefore, be established. It has been recognised that stress may be a reaction to working in an environment that is affected by SBS rather than an actual cause of symptoms (Bauer et al. 1992; Crawford and Bolas 1996). The findings of studies might suggest that, for example, employees report more SBS complaints under conditions of low job control and poor social support, where job-related mood is negative and job satisfaction is low, and negative affectivity is high. Nonetheless reverse causality is an equally plausible interpretation, as regularly experiencing health symptoms at work might erode perceptions of job control, impair job satisfaction and lead to more negative job-related mood. Although longitudinal research could provide more valid indicators of the direction of causality in symptom reporting, very few studies have yet been conducted that have examined the role played by psychosocial factors. Daily diaries would be a particularly appropriate way of measuring risk factors and symptoms of SBS over time, as well as examining the impact of controlled interventions on symptom reporting. The relative contributions of building-related and psychosocial factors to SBS symptom reporting, as well as the nature of their interaction, might be facilitated by the use of daily diaries. Multi-level modelling techniques might be a particularly appropriate medium through which to examine day-to-day within-person effects of building-related and psychosocial factors on symptom reporting, and the impact of between-person factors that might be potential moderating variables.

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Chapter 22
Epidemiologic Investigation Methods for Sick Building Syndrome

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22.1 Introduction

The Sick Building Syndrome (SBS) has been a public health concern since the 1970s when anxiety arose regarding the effect of indoor air quality on health outcomes. SBS has been defined by the World Health Organization (WHO) as: "*an excess of work-related irritations of the skin and mucous membranes and other symptoms, including headache, fatigue, and difficulty concentrating, reported by workers in modern office buildings*" (World Health Organization 1983). This definition refers to any situation where a proportion of building occupants (office or residential) experience discomfort and poor health outcomes associated with a temporal exposure to indoor pollutants within the building. Although SBS started as an urban oriented indoor air hazard, starting from late 1980s investigators reported health problems, caused by indoor air in rural communities (Clark et al. 2010; Colbeck et al. 2010; Pandey et al. 1989). This observation, not only highlighted the scope of the problem, but also pointed an urgent need for further field investigations.

In the investigation of SBS and indoor air related health problems, there is a need to determine the relationship between building related exposures and health outcomes. SBS in public buildings presents a complexity of multiple exposure factors and variables, which creates a challenge for field investigators. Clinical diagnosis may be a "gold standard" for the identification and evaluation of health problems related to SBS; however, clinical investigations are usually costly and impractical in terms of coverage for the whole community or all the occupants of a sick building. The most reliable way of demonstrating this relationship is through epidemiologic field investigation. A good methodological design of the investigation is crucial to evaluate the outcomes and risk factors; with standard and validated data collection methodology and detailed data management procedures playing an important role in the final outcome and success of the investigation.

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In this chapter, the epidemiologic methodology of field studies and their practical applications; and exposure assessment from an occupational and environmental epidemiology perspective in SBS is discussed. This chapter also intends to summarize practical aspects of the epidemiological investigation, without going into theoretical concepts and technical details, therefore helping researchers to successfully utilize this useful toolbox called epidemiology.

22.2 Sick Building Syndrome: Epidemiological Perspective

Sick building syndrome came to attention after publication of case studies reporting adverse health impacts on building occupants exposed to unvented combustion products, as well as to organic chemicals produced from consumer products (World Health Organization 1983). This led to investigation of the factors that affect indoor air quality. Implicated factors include the presence of wall-to-wall carpeting; room temperature and the type of ventilation present; and air humidity. In addition it was observed that females and persons with a history of allergies were found to be more at risk.

Symptoms of SBS generally increase with the duration of time spent in the building and in some cases conditions improve or even disappear when away from the building. There is no specificity in the symptoms of SBS, which are often associated with allergies and common illnesses; however the most familiar features include:

- Irritation of the mucus membranes: blocked or runny nose; dry or watering eyes; dry or sore throat,
- Respiratory symptoms: asthma-like symptoms, wheezing, shortness of breath, and chest tightness,
- Dry skin and skin irritation, itching and rashes,
- Central nervous system problems: lethargy, headache, fatigue and difficulty concentrating,
- Chemosensory symptoms: enhanced odor perception (Hodgson 2005; Redlich et al. 1997).

The field of epidemiology has been used in the investigation of SBS however its application has been limited and some shortfalls exist in using epidemiological instruments. It has been reported that there were gaps in the investigation of sick building syndrome relating to design, collection and interpretation; the need for developing a theoretical framework; and standardization of the data collection tool used (Dingle 1997; Raw et al. 1996). Additionally, poor sample selection has also presented limitations in terms of generalizability of the results since some studies select the building as the unit while other select occupants within the building (Apter et al. 1994). Cross-sectional epidemiological studies have been widely used to investigate SBS; however, these are limited in that there has been inadequate characterization of exposure (Apter et al. 1994); investigators having problems with case definitions and exposure assessment (Laumbach and Kipen 2005). Therefore, proper planning plays a critically important role in the success of field investigations.

Epidemiological studies on SBS generally attempt to determine the prevalence of symptoms rather than the prevalence of the condition; however some investigations have attempted to determine population prevalence. Apter et al. (1994) reviewed several studies including one, which showed a high prevalence of complaints in the sampled population. In another population study, prevalence was high and it noted also that there was a 20% decrease in productivity as a consequence of SBS.

22.3 Principles of Epidemiological Field Investigation for Sick Building Syndrome

The Dictionary of Epidemiology defines epidemiology as "*The study of occurrence and distribution of health-related states or events in specified populations, including the study of the determinants influencing such states, and the application of this knowledge to control the health problems*" (Porta 2008). This concise, yet detailed definition brings all components of good epidemiological practice together. By using epidemiology investigators can:

- Study occurrence and distribution of the problem.
- Investigate the determinants.
- Control the health problems by using this knowledge.

When an unexpected health problem occurs in the community, not only the members of the community but also the health professionals might be caught off guard. Any part of the community might be affected: children, adults, or the elderly, houses, office buildings, public areas, schools, hospitals, work places, or vehicles. In other words any person or location can be affected by the problem. It is likely that either the problem starts as an acute case, or a chronic problem that attracts attention with an unexpected acute exacerbation. In both scenarios, and regardless of the topic, health investigators face two major challenges:

1. Neither community, nor investigators might be fully prepared to deal with the problem. From the epidemiological aspect, there will be no study plan, hypothesis, immediate goal nor objectives available. Investigators therefore, might be responsible for understanding, describing, hypothesizing, analyzing, and developing a solution for the problem.
2. Time is a critical factor and may be the least available resource. The daily routine of persons in the community who are suffering from the problem might be disturbed, and more importantly they would want an immediate solution. In situations involving health investigations, the public reflex expects a solution for the problem as soon as possible if not immediately. Therefore, the investigation must

start right away, and without compromising scientific integrity it has to move as fast as possible towards a solution.

Under these conditions, the most common dilemma when a health investigator faces such problem is to decide where to start, how to start, and what to do. Not knowing the answer to this dilemma is usually the most common cause of delays and errors.

22.4 Basic Steps of Epidemiological Field Investigations

Epidemiological field investigations follow a defined procedure even when steps or stages are combined. These steps can be grouped into categories, namely identifying and describing the problem; systematic evaluation of the problem; and data analysis and interpretation. Based on a modification of the ten steps of field investigations published by Gregg (2008), these are:

I. Identifying and describing the problem:

   a. Determining the existence of a health problem,
   b. Confirming the diagnosis,
   c. Developing a case definition and counting cases,
   d. Describing the problem,
   e. Determining the population-at-risk of becoming ill,

II. Systematic evaluation of the problem:

   a. Hypothesizing the possible causal relationship between exposure factors and outcome,
   b. Planning a more systematic study,

III. Data analysis and interpretation:

   a. Analyzing available data to test the hypothesis,
   b. Preparing a written report of the results and evidence,
   c. Developing control plans and preventive measures to be implemented.

22.4.1 Identifying and Describing the Problem

The first four steps of the investigation can be defined as “descriptive steps”. The investigation may start as a result of contact (a call or letter) from community members, workers, or even from the local or regional authority itself. The investigators then try to understand what the problem is and what the clinical or technical diagnoses are. They try to define and describe the problem by first consulting with the health authorities.

22.4.1.1 Determining the Existence of a Health Problem

In SBS, this would involve a visit to the building site to get an overview of the layout and to consult with those involved. Medical records of those affected may be obtained and reviewed in consultation with doctors to ascertain that there is a medical problem. Medical symptoms may also be verified at this time.

The health authority is responsible for starting an investigation and the first step involves verification. Each complaint received must be taken into serious consideration and evaluated thoroughly until the investigation team concludes whether the claimed health problem really exists or the community faces a serious risk. In addition to the first complaints, investigators need to collect further information and available data to determine the existence of the problem. Local health authorities, local government, municipalities, health care providers, law enforcement officers, local community leaders, workers, and the community members are therefore critical partners in the investigation. Hence investigators must immediately partner with local communities and authorities to access information and available data. The most critical key word for the success of this effort is “communication”. Once the communication is established and the data and information become available, investigators should search for any unexpected increase or change in the occurrence of symptoms, diagnoses, or any noticeable disease clusters in the community.

Investigators also face various other challenges. The local culture might be unfamiliar; there might be language barriers; the geographical region might be new to investigators; or the industry and occupation might be unknown to the investigation team. The key to success therefore is to learn from the local community since no one would know the region, culture, customs, or language better than residents of the community. No one is a better expert of the work, than workers themselves.

22.4.1.2 Confirming the Diagnosis

During this descriptive step of the investigation, local health records and laboratory results can be used to verify the diagnosis. It is recommended that additional independent laboratories and validated diagnostic techniques be used to double-check the diagnosis; although highly recommended, this is not one of the most critical steps at the beginning of the investigation. What investigators need to plan for this purpose is to arrange laboratory connections before going to the field and prepare sampling protocols for all samples including dust, mold, and any others required for chemical and biological analysis. We discuss exposure assessment aspects of the investigation in more detail later in the chapter.

22.4.1.3 Developing a Case Definition

In order to identify cases and describe the problem existing in the community, investigators need to have a valid case definition addressing the needs of the investigation and the nature of the problem. There are numerous case definitions developed for communicable and non-communicable diseases. Investigators can adopt one of those case definitions, modify it according to the needs of the investigation, or develop a new one.

Asthma is one of the most prevalent health problems related to sick building syndrome. A study investigating asthma might aim to identify the prevalence of self-reported physician diagnosed asthma cases in the population. In this situation the following case definition for asthma would be appropriate:

1. A positive response to the survey question, "Did a doctor ever tell you that you had asthma?"
   AND
2. A positive response to any of the following survey questions:
   (a) "Do you still have asthma?"
   (b) "Have you taken prescription medications for asthma during the past year?"
   (c) "Have you had a wheeze episode in the past year?" (National Heart Lung and Blood Institute 1995; National Asthma Education and Prevention Program 1997;).

However, if the study aims to include incident cases and requires investigators to determine the clinical diagnosis, then the case definition should be:

A confirmed asthma is one that meets any of the following clinical symptoms at least three times during the past year AND at least one of the laboratory criteria:

Clinical criteria:

1. Presence of wheezing lasting two or more consecutive days,
2. Persistent chronic cough, which responds to bronchodilator, continuing 3–6 weeks in the absence of allergic rhinitis or sinusitis,
3. Nocturnal awakening with dyspnea, cough and/or wheezing in the absence of other medical conditions known to cause these symptoms.

Laboratory criteria:

1. Pulmonary function testing (FEV1, FVC) demonstrating a 12% increment after the inhalation of a short-acting bronchodilator;
2. A 20% decrement in FEV1 after a challenge by histamine, methacholine, exercise or cold air
3. A 20% diurnal variation in peak expiratory flow over 1–2 weeks

It is important to note that developing a loosely defined case definition would identify a large number of people falsely as "disease (+)". Too tightly defined a case definition on the other hand, would falsely identify a lot of people as "disease (–)". While this is not necessarily a negative concept, it actually depends on how aggressive the investigation focuses on the problem and how critical it is to find all cases.

22.4.1.4 Describing the Problem

The classic trilogy of "PERSON, PLACE, AND TIME" is the first epidemiological tool that the investigator uses to describe the problem. Even under the most challenging conditions, approaching the problem with these three indicators, which epidemiologists call "descriptive variables", would be the first step in conducting a successful investigation.

The determinant factors for the actual list of descriptive variables are the nature of the problem and the target of the investigation. For instance, an investigator focusing on respiratory health effects related to the quality of indoor air in an office building needs to know about smoking habits, current and past respiratory symptoms, allergic history, and physician diagnosed diseases of the occupants of the building. Time onset of the symptoms and the spatial distribution of the problem are also critical information to describe the problem. Let's look at an example on person, place, and time variables:

> "The National Institute for Occupational Safety and Health (NIOSH) received a request for a health hazard evaluation of an office building in the northeastern USA. Workers reported respiratory and dermatological conditions that they perceived to be building related. Post-occupancy onset of asthma, HP, and sarcoidosis had been documented in building occupants. Approximately 1,300 people worked in this smoke free building. The facility was a 20-floor building with parking garages on the bottom four floors and a lobby/cafeteria/mezzanine area on the fifth floor. It had a history of water damage, particularly on the upper floors of the building. Since the mid-1990s, the building had incurred water intrusion through the roof, around windows, and through sliding doors of terraces. The upper floors had suffered the most water damage and mold contamination" (Cox-Ganser et al. 2005).

The best way of describing the problem is to collect information by asking various questions which can be organized using the descriptive variables. In practical application of epidemiology, there are widely accepted default variables or questions regarding to these three basic indicators.

PERSON: (Who?) To collect information about person(s) affected from the problem, an investigator needs to know certain characteristics of affected individuals and the population. Age, gender, ethnicity, education level, marital status, socioeconomic status, etc. are some of the examples of descriptive variables of "PERSON". In the case example, we know that approximately 1,300 people worked in the building. Additionally Cox-Ganser et al. (2005) reports:

> "We had demographic and participation information on the 689 employees working for one of the two building tenant organizations. These employees had a mean age of 45 years, and 74% were white, 19% were black, and 53% were female."

Workers reported respiratory and dermatological problems and they perceived that these problems might be related to the indoor air problems in the office building they work.

- PLACE: (Where?) The geographical location and distribution of the problem is another important aspect that investigator needs to know to describe the case.

Therefore the questions pertaining to address, geographical location, and the spatial nature of the problem as well as affected people, need to be answered. From the case above, place information reveals that the building is a smoke free 20-floor building. There are parking garages on the lower four floors and social gathering areas such as a lobby, cafeteria, and mezzanine are located on the fifth floor. We also learn that the upper floors of the building had a history of water damage.

- TIME: (When?) Seasonal changes, cyclic fluctuations, secular time trends, and temporal relationships are important pieces of information to describe the problem. In the example, there has been at least a decade long history of water damage and mold contamination, especially in the upper floors of the building.

In addition to these three basic variables to describe the problem, one may add another indicator:

- COUNT: (How many? or How much?) Starting to collect information on the quantity of the various aspects of the problem, as early as possible, helps investigators to understand the magnitude of the problem. It also helps to track and record the changes. One may need to know how many of those 1,300 office workers are affected and developed respiratory and dermatological problems in the water damaged building. The sample case states:

> "The prevalence of adult-onset asthma was 12% (103/865).... Two-thirds (66/103) of the adult-onset asthma occurred after occupancy of the building" (Cox-Ganser et al. 2005).

22.4.1.5 Determining the Population-At-Risk of Becoming Ill

Population-at-risk is one of the most useful tools to quantify the problem in the population. It refers to members of the community who have not developed the health problem yet, but carries a risk of becoming ill. Therefore population-at-risk excludes those who already developed a disease. In determining the population at risk, an estimation of the population size is required. When considering SBS there may potentially be a large population at risk; this information is critical to the investigator especially when considering any large workplace. Determining the population at risk may not be possible depending on the size of the building and the services offered, since customers may also be affected. However the population at risk among the regular occupants of the building can be determined and their location within the building established. Additionally, numbers of high risk populations (women, persons with allergies and other risk factors) must be obtained.

22.4.2 Systematic Evaluation of the Problem

From the description of the problem, a hypothesis can be generated which is then tested in a systematic evaluation. This is achieved by conducting an epidemiological study; environmental monitoring of the location; and medical testing of affected persons. In the epidemiological study, a survey questionnaire may be used to elicit information regarding personal characteristics and social behavior that may have an impact on health; as well as perceptions of the environment. In the above example, a logical working hypothesis would be that the health of the office workers is affected by the by the presence of mold contamination in the building, a consequence of past water damage. Investigators can even further hypothesize that the risk might be differentiated according to the floor and the intensity of the damage. For instance investigators might ask study question such as “Are the workers who occupy the upper floors at the highest risk of experiencing illness?”. Such questions lead investigators to identify and formulate goals for the study.

In the epidemiological investigation, the environmental exposures and threats are identified and from the findings goals are defined to resolve the problems experienced by the building occupants. Goals should be clear and measureable and can be categorized as being either substantive or procedural.

A substantive goal is one that refers to the characteristics that are desired in the context of the situation. An example of such a goal would be to reduce the exposure to pollutants within the building environment by guaranteeing the structural integrity and the use of safe building materials in the renovation of the building to meet health-related goals.

A procedural goal supports the substantive goal and addresses its implementation. Such a goal would therefore give specific instructions for the performance of the objective. An example of a procedural goal would be to establish clear and specific decision-making processes that would promote involvement of all stakeholders (employers, workers, building designers and health officials) in the development of policies and interventions that lead to improved health outcomes within the building.

22.4.2.1 Planning a Systematic Study

Several questions should be considered at the start of the systematic planning of an epidemiological field investigation. These questions (Table 22.1) guide the researcher in creating a conceptual framework based on the research hypothesis and question(s). The conceptual framework provides a map of organized ideas or concepts that explains the practical application steps and methods that would be used to have a successful study.

With the help of these guideline questions, the variables representing outcomes to be investigated can be established. The framework would then show the relationship(s), if any, that exist between the variables. Decisions can therefore be made on how the variables can be measured – quantitative or qualitative. This actually brings another useful tool to discuss: variable lists.

At this stage, investigators already know what the problem is; they may not know yet what caused this problem and how to solve it; however they are developing hypotheses to investigate the problem further and hopefully find the cause to fix it. A “variable list” is a useful tool employed to organize various contributing factors and their hypothesized relationships, enabling investigators to easily follow every

Table 22.1 Practical guideline questions for the SBS researcher

1. Determine: "What are you going to do?" This should be clear, concise, and self contained. A reader should understand the aim, the target population, and the dependent variable(s) of the investigation.
2. Establish: "What is the problem and why is it important?" This section gives a brief description of the problem from a public health perspective. The study can be justified since there would be an immediate need to investigate the problem occurring in the SBS location.
3. Develop the hypothesis, objectives and goals: "What are you planning to investigate and accomplish? Goals and objectives should be established at this point. The researcher needs to identify the measurable, accessible, and realistic objective(s).
4. Review the literature: "What has been reported on this problem?" Knowledge of the state of the science surrounding SBS is important to the epidemiological process since this would assist in framing the hypothesis, refining goals and designing the investigation.
5. Develop methods: "How are you going to implement this study?" Study protocols manuals containing details on the study design are produced.
   a. Target population: "In which population are you going to do this study?" The target population should be defined in clear terms addressing time, geographic location, and demographic indicators (please remember PERSON-PLACE-TIME).
   b. Study population: It is recommended that, if needed, a representative sample may be selected from the target population hence there is a need to explain:
      i. What inclusion and exclusion criteria will be used to select the study population?
      ii. How the sample size will be calculated?
      iii. What sampling method will be used?
      iv. Details on the control group, if used.
   c. Variables: "What are the dependent and independent variables?" To reach proposed study's goals and objectives, dependent and independent variable list for the study should be developed. Each variable must be clearly defined in terms of conceptually and operationally.
   d. Data collection: "How are you going to collect data?" Data collection methodology is discussed – questionnaire or tool used produced.
   e. Data analysis: "How are you going to analyze the data?" A data analysis plan is created and should include the analytical techniques to be used.
   f. Limitations and strengths: "What are the strengths and weaknesses of the study?" T limitations and strengths of the study should be considered and how limitations may affect the study results needs to be explained.
6. List outcomes: "What are the anticipated outcomes of the project?" Details of the end products of the study are given. How would the extent of the problem be assessed and the benefits to the target population and the community explained.
7. List outputs: "What are the planned outputs of the project?" The channels of disseminating and sharing the results of the project with the community, peers, and the scientific audience are considered.

step of their investigation (Table 22.1). Without going into technical details, one can categorize variables into two main groups:

1. Dependent variables: The main problem on which the investigation is focused determines the dependent variable. In other words, investigators should ask this simple question to determine the dependent variable for the investigation: "What is the main problem are we investigating?".

In the office building case for instance, the investigation is focused on respiratory and dermatological health problems. Suppose the investigators decided to investigate asthma as the respiratory heath problem, then the dependent variable for his investigation would be the occurrence or diagnosis of asthma. So then it can be hypothesized that mold exposure caused asthma among the office workers. However, if the investigation focuses on mold infestation alone, than the dependent variable would be identification the mold infestation in the building. In this case, the hypothesis would be that chronic water damage caused mold infestation in the building.

2. Independent variables: All other variables that the investigators suspects or literature reports as related, contribute, predispose, enable, precipitate, or reinforce the development of dependent variable. Some of these independent variables can be listed as "risk factors" as well. Age and previous respiratory health problem might be predisposing factors for asthma. Mold exposure on the other hand is a precipitating factor for asthma development. Additionally, it is a common practice to list demographic, socioeconomic, occupational, and environmental variables as default components of the variable list in field investigations.

Once the variable list is prepared, investigators must identify the operational definition and the measurement scale for each variable. This actually brings us back to case definition, since the case definition is a good example for this.

22.4.2.2 Data Collection

The next step would be to interview and administer the data collection instrument to all workers. Data collection involves the systematic recording of information and one of the most practical instruments used in these investigations is the questionnaire. Questionnaire design is a key part of the epidemiological process and importance can be best illustrated by the statement: "*The quality of your data will be no better than the most error-prone feature of the survey design*" (Fowler 1993).

In any epidemiologic investigation, knowing the right question to ask is at times difficult. Framing and refining of the hypothesis about the problem is the first step in creating the data collection instrument. This step can assist with decisions on what information is required to test the hypothesis and examine confounding factors. Knowing this, questions can be developed to obtain the data however wording, organization and question type (open or closed-ended) should be carefully considered. Typically information collected can be grouped into: demographics, environmental and occupational data, exposures or risk factors, and clinical data.

In the case example, possible questions would address current and previous history of respiratory illness; current and past smoking habits; length of time working in the building; work and social activities when in the building – use of the lobby, cafeteria and mezzanine; and other questions relevant to the situation. The answers obtained through questionnaires are important since they are in some way related to the outcome under consideration. For example, we know that respiratory health may be affected by exposure to cigarette smoke hence in an assessment of indoor air quality on health, information relating to past or current smoking habits need to be obtained. A well-developed question should therefore collect data that would enable formation of a hypothesis or measurement of the relationship between exposure and outcome.

22.4.3 Data Analysis and Interpretation

22.4.3.1 Data Analysis

All data collected – questionnaire, clinical, and laboratory, – have to be reviewed, analyzed and interpreted. Technical details on data analysis are beyond the scope of this chapter and will not be discussed here.

Data analysis helps to identify significant associations between exposure and health, as well as the contribution of multiple risk factors to health outcomes; in other words relationship between dependent and independent variables is revealed by data analysis. This stage is often exciting for field epidemiologists since like any mystery the answers will be discovered during the analysis. After all the hard work, the investigators get a chance to bring all the pieces of the puzzle together in a picture that can be shown to and easily understood by all. The findings are then complied in a report that documents the process used, and the recommendations for control and prevention. Caution, record keeping, and teamwork are key facets of this process.

Data analysis should only be conducted after the data entry has been finalized: data is cleaned and checked for accuracy. However, the data analysis plan should be constructed during the hypothesis formulation and study design steps. The plan should be based on the research question(s) arising from the hypothesis, study design, and sampling method. It should detail the purpose of the evaluation; questions to be answered and what needs to be learnt; the technique for analysis; and method of data presentation. The plan can therefore be used to assist with selecting the type of question and response options on the questionnaire, hence enabling efficiency in data collection.

While having a data analysis plan ensures that the survey instrument will obtain the required information, it also makes the investigator think about how to “report” the data during the designing of the survey instruments. There have been cases where investigators collected categorical data and realize that the data should have been collected as a continuous variable; or respiratory data collected on a weekly basis when daily data was necessary to identify unique events distinguished by considering intervals or less than 7 days between events. Hence investigators must be careful in identifying an operational definition and measurement scale for each variable in the planning phase.

The main objectives of data analysis are to:

- Describe the study population,
- Assess for potential bias,

- Estimate the measures of frequency and strength of association,
- Assess the degree of uncertainty,
- Examine the effects of other factors and control for these,
- Clarify relationships observed and evaluate the impact and importance.

The common approach to data analysis is to first explore the data. Descriptive analysis helps in understanding the data – outliers, missing data etc. It provides information relating to frequency (incidence, prevalence), association (differences) and impact (attributable fractions) for subgroups considered in the study. Investigators therefore get a "feel" for the data before beginning more complex data analysis.

The next step would be to consider the research questions that arise from the hypothesis or study objectives, as well as any that may arise from patterns observed during the descriptive analysis. Data are interpreted based on background knowledge and experience.

Adjustments are made during this phase to account for age differences and other risk factors. In the example length of time employed would be a factor that should be considered in the analysis, since the longer the duration of exposure the greater the likelihood of a negative health impact. The study hypothesis is evaluated with respect to these factors and other forms of bias identified. The role of chance has to be evaluated also. The most common procedure currently used is the test of significance; however interpretation of p-values is difficult even for the most knowledgeable epidemiologist. Confidence limits, which define the interval in which the estimated population parameter exists, are also reported to quantify the degree of uncertainty in an estimate.

22.4.3.2 Preparing a Reporting

Data analyses and results are then presented in a format that is understandable and useful to the key stakeholders. Since there are several target audiences, the way in which results are presented is important. Experienced epidemiologists know that findings should be presented in a simplified form that is appropriate to audience. A report can and should be produced in such a way that it contains technical language, yet is informative and easy to understand by nontechnical persons.

Communication of research findings is essential in any study since the affected population, health policy planners, and other stakeholders use the feedback to plan the next step. Reports should be clear, concise and logically structured. It should highlight the most important findings and emphasize those points that warrant immediate attention. Recommendations and intervention plans are also discussed within the report.

22.4.3.3 Development of Control Plans and Preventive Measures

Planning interventions to address SBS will require adoption of policies that will reduce the health risk to the building occupants. For any intervention, goals are defined and a timetable established to achieve them. Progress in the implementation of the goals and the effectiveness of the implementation are then evaluated. Assessment will enable adjustments to be made in the intervention plans, policies and methods of implementation. In addition, allocation of resources can be re-considered to address those gaps identified in the assessment.

22.5 Principles of Exposure Assessment for Epidemiological Investigations

Exposure assessment can be defined as the appraisal and quantification of the possible exposures in the environment that affect human health. In the risk assessment, levels of exposure are determined. Exposure or risk factor data are then used to test the hypotheses and will be the major focus of the investigation. Information collected includes: the exposure specific to the issue; amount of exposure; duration of exposure; and other relevant details.

22.5.1 The Concept of Exposure

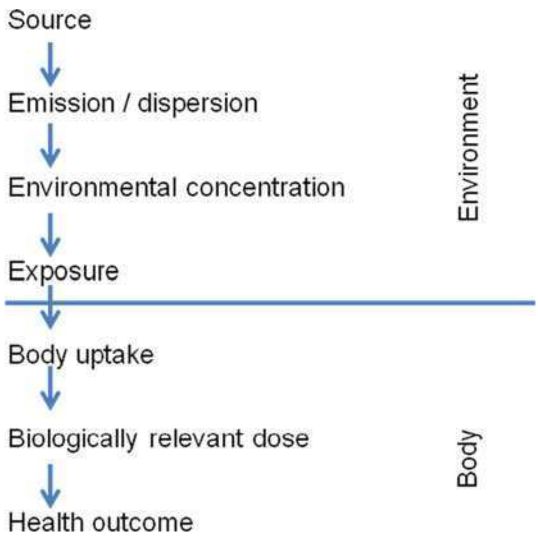
Any contact between a physical, chemical, or biological agent in the environment and the human body through inhalation, ingestion, or dermal or mucosal contact is defined as exposure (Nieuwenhuijsen 2003). A person therefore becomes exposed when he/she is in contact or close proximity to the risk factor. Exposure may be short term (acute), of intermediate duration, or long term (chronic). Acute exposure may defined in terms of number – a single exposure to a toxic substance that results in a severe medical condition or death; or duration – exposure for up to 14 days. Intermediate duration exposure refers to contact for more that 14 days and less than 1 year; while chronic exposure refers to contact for a prolonged period of time, usually more than 1 year. Duration of exposure therefore affects the level to which a person is exposed. Exposure levels also depend on the initial concentration of the agent (Checkoway et al. 2004; Rappaport et al. 1991). Investigators therefore need to understand steps between exposure source and the health outcome as demonstrated in Fig. 22.1 (Nieuwenhuijsen 2003).

22.5.2 Framework for Assessing Exposure

Frameworks assist in understanding the dynamics of the multiple exposure factors that impact on health outcomes. In assessing risk, the factors are determined based on experience and knowledge of the problem, which is then investigated using environmental and/or exposure assessment techniques (Fig. 22.2).

Exposure assessment can be defined as the appraisal and quantification of the distribution and determinants of exposures in the environment that affect human

Fig. 22.1 Source-receptor model for air pollutants (Nieuwenhuijsen 2003)



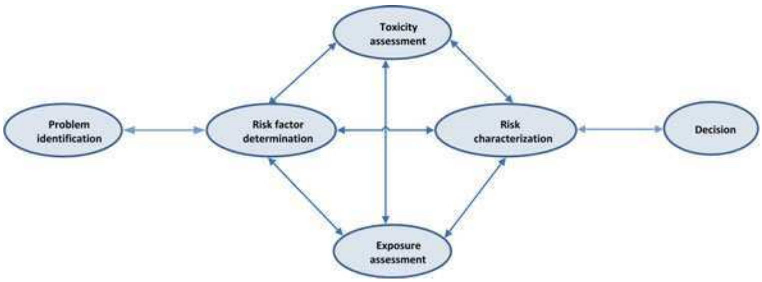


Fig. 22.2 Risk assessment framework

health. From an epidemiological perspective, the success of exposure assessment is dependent on good study planning, data collection, analysis and interpretation. Therefore, not only the epidemiological investigation, but exposure assessment also needs to be thoroughly planned; and resources, knowledge, and teamwork must be established.

The aim of this effort is to identify the risk factors in order to decrease health effects and control the hazard. As mentioned earlier in this chapter, all relevant information and data are used to describe the problem; identify the possible variables; and develop hypotheses on the exposure health outcome relationship. Information collected includes: concentration, duration, frequency, and intensity of exposure (Akpinar-Elci and Elci 2002). It is also necessary to identify the chemical, physical, or biological composition of the exposure; and the metabolic and pathophysiological pathways. However, it is almost impossible to measure all aspects of exposure for all times. It is usually highly expensive, time consuming, and ineffective to attempt to collect such data. Instead various exposure measurements, classifications and modeling are used to assess exposure and its relationship with health outcomes (Checkoway et al. 2004).

Biological and personal exposure monitoring are the most commonly utilized direct exposure assessment methods. Indirect assessment methods such as environmental monitoring, exposure modeling, surveys, self-assessment questionnaires, and expert assessments are also commonly used in exposure assessment. Even though many of these methods utilize time weighted average exposure to assess exposure levels, in some cases short term high intensity exposure might be a relevant way to understand exposure pattern (Elci et al. 2003). Further details of exposure assessment methods are beyond the scope of this chapter.

Six questions are generally used to guide the assessment process (US Environmental Protection Agency 1998):

1. How does exposure occur?
2. What is exposed?
3. How much exposure occurs? When and where does it occur?
4. How does exposure vary?
5. How uncertain are exposure estimates?
6. What is the likelihood that exposure will occur?

Based on the answers to these questions, an exposure assessment framework can be created (Fig. 22.3). The framework can be used to:

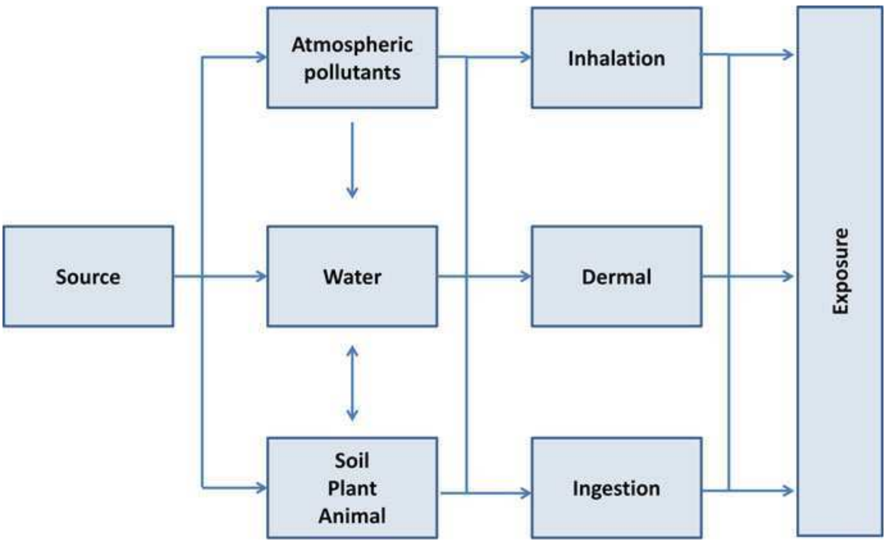


Fig. 22.3 Exposure assessment framework

1. Characterize the source – chemical, biological or physical properties
2. Determine the method of spread of the source – airborne, waterborne or via soil
3. Assess the pathways for human exposure and the uptake relative to that pathway.
4. Establish the interrelationships of the transport pathways prior to conducting a systematic evaluation,
5. Assess the dose-response relationship that results in adverse health outcomes.

22.6 Conclusion

This chapter presented practical steps of epidemiological investigation for the researcher investigating SBS. Once a problem has been identified, hypotheses and objectives are established; potential data required and risk factors that predispose a person to become adversely affected are determined. The next stage would then involve exposure assessment, which tries to understand "how the person is affected by the agent". Exposure assessment and related data are used to test these hypotheses and further understand the relationship between exposure factors and their impact to human health. Therefore successful exposure assessment is a critical component of the investigation that produces valid and desired solutions. It is hoped that using the guidelines, non-epidemiologists can produce a conceptual framework from with the data collection tool, data management and analysis plans can be formulated.

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Chapter 23
Noninvasive Health Assessment Methods in Sick Building Syndrome

Muge Akpinar-Elci and Omur Cinar Elci

23.1 Introduction

Throughout history, successful survival of the human depended on finding protective shelters to inhabit. With the second half of the twentieth Century, people began to live in modern houses and work in modern office buildings. Public buildings and facilities provided services for people beyond the basic needs of sheltering (Zhang and Smith 2003). Since energy conservation became an important topic in the late 1970's, developed countries began to build energy conservative buildings with the goal of producing a decrease in energy loss. With this trend the ventilation between indoors and outdoors decreased. In addition, different chemical agents and synthetic materials have been extensively used in air tight energy efficient buildings. In the early 1980's, the first adverse health outcomes of this transformation in building construction were reported. Especially in public and office buildings, the combination of poor ventilation and intense use of various indoor hazardous agents has been associated with building-related health symptoms of occupants or employees (Abbritti and Muzi 2006).

In their review paper, Laumbach and Kipen (2005) stated that "Sick building syndrome is a poorly understood condition that can be vexing to clinicians and public health investigators alike. Concerns about possible causes have recently shifted to bioaerosols, especially indoor mold contamination. Recently, controversy over the health effects of indoor bioaerosols has intensified in the media and in medical forums. Allergists and other clinicians are increasingly being asked to evaluate cases of sick building syndrome attributed to bioaerosol exposure. Although allergy may play a role, it is unlikely to fully explain the nonspecific symptoms of the condition".

Today we know that many cases of allergic and respiratory diseases such as asthma and sick building syndrome are related with poor indoor air quality in developing and developed countries (Smith 2002; Spengler et al. 2001). Sick building

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related exposures commonly cause airways inflammation. Therefore, one of the major goals in studying building related airways inflammation is to demonstrate relationships between building related exposures and health outcomes, which is not an easy task. Although there are methodological limitations, epidemiological and toxicological studies provide evidence. In cross-sectional studies an association between bioaersol exposures and health problems has been demonstrated (Laumbach and Kipen 2005). Epidemiologic studies investigating indoor air related problems often document adverse respiratory health effects by using questionnaires to describe symptoms and pulmonary function tests for objective assessment of functional impairment. Pulmonary function tests such as spirometry or peak flow monitoring only investigate the functional changes in lower airways which may be in an irreversible stage of disease and may not reflect the inflammatory status of the airways. Assessment of pulmonary function alone may underestimate building related airways disease because airways inflammation and pulmonary function changes may occur at different times in the pathophysiological process of disease development (Akpinar-Elci et al. 2005; Lemière 2002). Direct monitoring of airways inflammation in response to building related exposures, are receiving increased attention since they may discover inflammatory changes before the injury becomes irreversible. It could also be useful for the follow-up of persons with inflammatory disease, and for guiding drug treatment. Invasive approaches such as bronchoalveolar lavage and bronchial biopsies have been used to assess airways inflammation. These methods however, are not practical for use in field investigations (Akpinar-Elci et al. 2007b).

Due to the nature of these diseases, accurate, practical, and objective diagnostic measurement techniques are needed in field investigations. Thus, much work has been focused on the development of noninvasive methods for monitoring inflammation in building related health problems (Quirce et al. 2010). The recent most commonly used noninvasive techniques in field investigations are exhaled nitric oxide, nasal nitric oxide, induced sputum, exhaled breath condensate, and nasal lavage. This chapter will discuss the practical application of these methods in sick building syndrome as well as technical details and the validity.

23.2 Noninvasive Inflammatory Marker Assessments in Sick Building

Wilcosky (1993) stated that noninvasive markers are more beneficial and valuable for field studies than invasive markers. In the same article he also stated "Unfortunately, the lack of basic information about marker properties (e.g., sensitivity, variability, statistical link with disease) currently precludes the effective use of most markers in studies of complex mixtures".

Today almost two decades later, medical science has been able to expand upon what is known about noninvasive markers and extrapolate a new technology. This progress increases our chance to diagnose a problem at an early stage before any structural damage occurs. Noninvasive inflammatory markers provide tremendous information about the health outcomes of building related exposure.

23.2.1 Importance of Inflammatory Markers in Building Related Symptoms

The mechanism of inhalation hazards to the lungs starts with an inflammatory response. Inflammation is designed to protect the body from external harmful agents, but when prolonged, it does more permanent damage to the lungs than protection. Inflammation is a very complex process, which depends on largely unknown factors, different cells, mediators, and pathways. The types of lung inflammation that have been studied most intensively include asthma, emphysema, and interstitial fibrosis. Inflammation assists to identify these diseases in the early stages. Diagnosing sick building related diseases in the early stage is important for control of disease and prevention of disease in other building occupants.

Inflammation of the lung might cause many types of respiratory symptoms such as cough, wheeze, phlegm, breathlessness, as well as systemic symptoms (fever, malaise, tiredness, fatigue). There may be indications of inflammation in the blood, such as increased numbers of cells (neutrophils, eosinophils, or lymphocytes), or inflammatory mediators (C-reactive protein, interleukins, etc.), or an increase in erythrocyte sedimentation rate. However, these indicators in the blood are nonspecific and could be a result of inflammation of any organ system (Pizzichini et al. 1997). The gold standard to diagnose inflammation of the lung is biopsy or bronchoalveolar lavage (BAL), but as we stated earlier, these invasive procedures are expensive, impractical, and not suitable for screening or repeated follow-up programs (Fireman et al. 1999). During the last decade, considerable advances have been made in non-invasive measurements of airways inflammation by examinations of sputum or nasal lavage fluid, exhaled gases such as exhaled NO, and exhaled vapors through exhaled breath condensate. These techniques are widely used in field studies and building related health problems. A recent European Academy of Allergy and Clinical Immunology (EAACI) task force consensus report states “There is a need to increase the use and availability of these tests in the investigation of occupational asthma, nonasthmatic eosinophilic bronchitis, and occupational rhinitis. It should be considered, however, that subjective symptom scores and objective physiological measurements are not necessarily correlated with the severity of airway inflammation. This is probably because of the fact that neural regulation, hyperreactivity, and perception of severity of symptoms play an important role in overall severity of the disease” (Quirce et al. 2010).

The cytokines are useful diagnostic markers of airways inflammation, especially in the early stages. “Cytokines are polypeptide mediators produced by a variety of cell types that play crucial roles in inflammatory responses (Barnes et al. 1998). They are often categorized as being involved in Th1 responses (examples: interleukin (IL)-1, IL-6, IL-12, Tumor necrosis factor (TNF)-α, IFN-γ) or

Th2 responses (examples: IL-4, IL-5, IL-10 and IL-13). The activities of pro-inflammatory cytokines such as IL-1, IL-6, IL-12, IL-18, and TNF-α are tightly regulated, in part by negative feedback mechanisms mediated by anti-inflammatory agents such as IL-1 receptor antagonist (IL-1RA), transforming growth factor (TGF) β1 and IL-10. Complex interactions of cytokines are referred to as cytokine networking and have been implicated in the pathogenesis of many complex inflammatory lung diseases. Genes that code for cytokines are highly polymorphic and some of the polymorphisms directly or indirectly influence cytokine expression. Most respiratory diseases involve both with genetic and environmental factors" (Akpinar-Elci et al. 2007). Epidemiological studies have identified associations between specific genetic variants and susceptibility and severity of environmental related inflammation such as asthma, chronic obstructive pulmonary disease (COPD), and hypersensitivity pneumonitis (Asada et al. 2005; Howard et al. 2001).

Cytokines can be measured in bronchoalveolar lavage fluid or bronchial biopsy tissue to assess airways inflammation (Barnes et al. 2006). Since the 1990s, noninvasive methods such as nasal lavage, induced sputum, and exhaled breath condensate provide the opportunity to use cytokines as objective biomarkers of airways inflammation.

Another useful diagnostic marker of airways inflammation is nitric oxide (NO). In the early stage of airways inflammation, one of the major acute inflammation mediators is histamine, which induces bronchospasm. Late airways inflammation however, creates a more chronic and complex local inflammation. An endogenous mediator NO as a part of this late airways inflammation causes bronchodilation and anti-inflammation. NO is the most well characterized endothelium-derived relaxing factor (EDRF) which is produced and released by the endothelium that results in smooth muscle relaxation. As part of the immune response, NO is also produced by phagocytes, which are armed with inducible nitric oxide synthase (iNOS). iNOS is activated by interferon game (IFN-γ) and TNF, and inhibited by TGF-β, IL-4, and IL-10 (Li et al. 2006; Nguyen et al.1992). Thus the immune system may regulate phagocytes as part of inflammation. So NO might serve as an important inflammatory marker for airways inflammation.

23.2.2 Nasal Lavage Measurement in Sick Building

Damp indoor environments have been associated with nasal and sinus symptoms, but little attention has been given by the health community to their environmental causes, objective correlates, relation to lower respiratory disease, or natural history with environmental interventions. Allergic rhinosinusitis is one of the most common chronic diseases and its worldwide prevalence is increasing. Estimated prevalence ranges between 10 and 50% (Bellanti and Wallerstedt 2000). Many physicians consider allergic rhinitis to be an inconsequential disease, because it is not life threatening. However it is a major source of discomfort and reduced job performance. In one of our recent studies we found the prevalence of nasal symptoms was

66% among farmers but only 1% of them had physician-diagnosed rhinitis. This study's result suggests that the upper airways diseases are prevalent, yet overlooked by health care providers (Akpinar-Elci et al. 2009).

There are two main reasons for scientific interest of nasal responses to harmful agents. First of all, the nose is a target and entry organ for many harmful agents. The nose prevents the entry of harmful agents into the lower airways by using a mechanical and immunological mechanism. Second, the nose is a highly accessible portion of the respiratory tract and may serve as a surrogate tissue for lower respiratory tract responses (Anon 1998).

An estimated annual cost of rhinosinusitis was $2–5 billon in the US in 2003 (Reed et al. 2004). Allergic rhinitis also plays an important role in exacerbating asthma (Bousquet et al. 2003; Passalacqua et al. 2004) and the prevalence of occupational rhinitis with occupational asthma is 76–92% (Siracusa et al. 2000). The similarities between the histology of nasal mucosa and bronchi suggest that inflammation in the nasal mucosa may reflect the inflammatory response in the lower airways (Purokivi et al. 2002a). Thus, prevention of upper airways diseases may be an opportunity to prevent or minimize the severity of lower airways diseases, such as asthma, which will lead to increased productivity in the workforce.

Various methods have been used to collect nasal secretions for the assessment of nasal inflammation. One objective method for evaluating nasal inflammation is nasal lavage, which is an easy, well-tolerated, affordable, and repeatable technique. It is applicable to both field and laboratory studies (Petrick and Slavin 2003).

The following commonly accepted method is used in the field. The catheter is attached to a 10 ml syringe filled with 4 ml of pre-warmed (37°C) saline. A precursor is placed on the bridge of the nose to break up mucus and facilitate fluid recovery. The saline is refluxed 3 times into the nose using the syringe and the majority of the fluid is recovered back to the syringe. The catheter is then removed from the nose and residual fluid is blown gently into the collection dish. The process is repeated on the remaining nares. Fluid is recovered in the collection plate from both nares, is then combined and the volume is measured (Akpinar-Elci et al. 2007a).

Nasal lavage has been widely used in respiratory disease investigations. A study compared different nasal sampling techniques for collecting nasal cytologies and stated that for studies that require repeated sampling, the nasal lavage will be recommended as the best suitable technique to obtain nasal cytologies (Deutschle et al. 2005). Despite these inconsistencies, nasal lavage is still a frequently used technique in field investigations. This technique samples the most superficial aspect of nasal mucosa. Cells sampled include resident epithelial cells and infiltrating inflammatory cells. Fluid and soluble materials sampled include mucus and various inflammatory mediators. Contaminants also include dead cells and bacteria. Nasal lavage can provide information concerning both the health status and recent exposure history of a person (Hellgren et al. 2001). Nasal lavage with measurement of inflammatory markers from the fluid has been used to characterize the effects of various inhalable pollutants on the upper airways.

Table 23.1 summarizes various biomarker measurements in nasal lavage used in sick building related exposure studies. An increased risk of upper airways diseases has been reported to be associated with bioaerosol exposure in building environments. Many recent studies have focused on adverse health effects in the upper airways reported in water damaged and moldy buildings. Stark et al. 2006 reported that cases with previous exposure in a moisture-damaged building had significantly increased IL-4 concentrations in nasal lavage after the *Aspergillus fumigatus* challenge. Their data showed a link between inflammation markers in nasal lavage and experimental *Aspergillus fumigatus* challenge (Stark et al. 2006). In one of our studies, we also found a significant relationship between IL-8 concentration in nasal lavage and work-related flu-like symptoms in occupants of a water damaged building (Akpinar-Elci et al. 2007a). However, another recent study observed no IL-8 concentration change in nasal lavage associated with indoor mold exposure (Ebbehøj et al. 2005). Using nasal lavage for early diagnosis of upper airways inflammation and disease is a promising method, which can help prevent lower airway diseases such as asthma.

23.2.3 Induced Sputum Measurement in Sick Building

Healthy persons might produce about 950 ml. of sputum every day. The sputum is transported slowly and continuously toward the mouth, then swallowed, without the person being aware of the process. Patients with active lung inflammation may easily produce sputum samples simply by coughing, but for many others, in order to collect it reliably and within a reasonable period of time, the sputum secretion must be induced. Sputum induction has been used as a direct and relatively noninvasive method to investigate airways inflammation as a reproducible and valid technique (Lemière 2002; Lemiere 2006; Rytilä et al. 2000). The traditional method used for a subject to reliably produce sputum is to ask them to inhale a 4.5% hypertonic saline for several minutes. After inhalation, they cough up the sputum into a plastic container (Anderson and Brannan 2003). The European Thoracic Society standardized this procedure (Joos et al. 2003). The collected fluid may simply be frozen for later processing for cytokines' measurement, or may be processed onsite when white cell counts and differentials are desired.

Induced sputum has been increasingly used as a biological sample in respiratory disease research (Vlachos-Mayer et al. 2000). Induced sputum measurement shows early airways inflammation in persons exposed to agents known or suspected of causing airways inflammation (Lemière 2002). Induced sputum is especially helpful when there is a need to evaluate the predominant type of inflammatory cell or cytokine. Compared to BAL, induced sputum is a less invasive, comfortable method and is also suitable for screening programs (Fireman et al. 1999). There have been concerns about the safety of sputum induction among uncontrolled asthma patients. However, Vlachos-Mayer et al. (2000) showed that standardized sputum induction could be safe for such patients. Although the use of induced sputum in field settings

Table 23.1 Biomarkers in nasal lavage (NL) and associated building related exposure and health outcomes

Reference	Place/exposure	Biomarkers in NL	Results
Akpinar-Elci et al. (2007a)	Water damaged office building	IL-8, Albumin, MPO, ECP	Significant relationship ECP and IL-8 and work-related flu-like symptoms. High MPO levels were associated with chills and work- related chills.
Bakke et al. (2008)	University building	ECP, Lysozyme, Albumin, MPO	"NAL-lysozyme was associated with ocular, nasal, laryngeal symptoms and indoor environmental perceptions."
Ebbehøj et al. (2005)	Public school building/mold	IL-8, ECP	IL-8 and ECP were not associated with mold.
Hirvonen et al. (1999)	Mold-contaminated school	TNF- α IL-6, NO	"An association between inflammatory markers in the nasal lavage fluid, the high prevalence of respiratory symptoms among the occupants, and chronic exposure to molds in the indoor environment."
Koren et al. (1992)	New building/VOCs	Neutrophil	Neutrophil significantly increased after VOCs exposure.
Lignell et al. (2005)	Moisture-damaged schools/Microbial	NO, IL-4, IL-6, TNF- α	"Reported allergies and repeated respiratory infections were associated with high IL-4 level."
Norbäck et al. (2000)	School buildings	ECP, Lysozyme, Albumin, MPO	"The most consistent findings were observed for formaldehyde, NO_2, and *Aspergillus* spp., related to increase of ECP and lysozyme. The presence of yeast was associated with an increase of ECP and lysozyme."
Purokivi et al. (2002a)	Moisture-damaged buildings	TNF- α, IL-1, IL-4, IL-6, NO	"Inflammatory mediators in NL are not per se a reliable method to evaluate the inflammatory status of the lower airways after exposure to indoor air pollutants."
Purokivi et al. (2002b)	Moisture-damaged buildings	NO	"NO measurements alone are not sufficient to quantify airway inflammation when evaluating subjects exposed to microbes present in moisture-damaged buildings."
Roponen et al. (2001)	Mold-damaged buildings	IL-1, IL-4, IL-6, TNF- α	"IL-4 was significantly higher among all occupants during the working period as compared to that during vacation."
Roponen et al. (2003)	Moisture-damaged buildings/ viable fungi, viable bacteria	TNF- α, IL-1, IL-4, IL-6, NO	"Cytokine levels of subjects with high microbial exposure were slightly increased compared to the subjects with low exposure."

Table 23.1 (continued)

Reference	Place/exposure	Biomarkers in NL	Results
Wålinder et al. (1999)	School building/ dust, cleaning agents	ECP, Lysozyme, Albumin, MPO	"ECP and lysozyme were increased for the subjects in schools with a lower frequency of floor mopping, a lower frequency of desk cleaning, and where wet mopping was used."
Wieslander et al. (1999)	Hospital building/ dampness, mold, VOCs	ECP, Lysozyme, Albumin, MPO	"Increased occurrences of ocular and nasal symptoms and an increased concentration of lysozyme were found in the subjects working in the damp buildings. A relationship between MPO and nasal symptoms was also found."
Wålinder et al. (2001a)	Damp office building	ECP, MPO, Albumin	Exposures in a damp office building may cause an inflammatory nasal mucosal response.
Wålinder et al. (2001b)	School buildings	ECP, Lysozyme, Albumin, MPO	"A pattern of nasal responses: less patent noses and an inflammatory biomarker response could be related to flat roof and a concrete slab fundament, factors that are known risk factors for water leakage, building dampness and possibly microbial growth."

MPO: Myleoperoxidase, IL: Interleukin, ECP: Eosinophilic cationic protein, TNF: Tumor necrosis factor, NO: Nitric oxide has provided a practical and objective monitoring method, there are methodological problems to be addressed. Induced sputum is sampled predominantly from large airways and this may not accurately reflect the inflammation in the peripheral airways (Barnes et al. 2006; Holz et al. 1998). Another potential problem is related to the solubilization of sputum. Solubilization with dithiotheitol disrupts sulphydryl bonds and may modify proteins, which prevents the recognition by antibodies (Kelly et al. 2002). This may be a problem with several cytokines (Barnes et al. 2006).

Studies have investigated the function of biomarkers in the sputum of asthmatic patients and have compared the results from induced sputum and blood (Pizzichini et al. 1997; Jang and Choi 1999; Lemière et al. 1999). Pizzichini et al. (1997) reported that the proportion of eosinophils in sputum is a more accurate marker than the proportions of eosinophils in blood or serum eosinophilic cationic protein (ECP) among asthmatic patients. Lemiere et al. (2006) supported Pizzichini's conclusion in their study. In another study, Leimère et al. (2000) also demonstrated that "induced sputum differential cell counts and IL-5 might anticipate changes in lung functional parameters after exposure to occupational agents in occupational asthmatic subjects."

Induced sputum IL-8 has been studied extensively in environmental and occupational related airways inflammation investigations. In our study among popcorn production workers, we found that sputum IL-8 concentrations were higher in the high-exposed popcorn workers compared to the low-exposed group (Akpinar-Elci et al. 2005). Many epidemiological studies have investigated an association between adverse health effects and exposure to mold or microbes from moisture-damaged buildings. Purokivi et al. (2001; 2002a; 2002b) widely studied induced sputum among occupants of a moisture-damaged and moldy building. They tried to demonstrate a biochemical link between microbial exposure and the large variety of reported respiratory symptoms. Purokivi et al. (2002a) also measured concentration of IL-1, IL-4, IL-6, TNF-α and, NO in induced sputum and nasal lavage at moisture-damaged and reference school buildings and compared the results. They found that NO and IL-4 levels in nasal lavage significantly predicted induced sputum levels. In another study, Purokivi et al. (2001) investigated the association between the respiratory symptoms such as cough, phlegm, sore throat, and the inflammatory mediators interleukin IL-1, IL-4, IL-6, and TNF-α in nasal lavage and induced sputum samples collected from people working in moisture-damaged school buildings (Purokivi et al., 2001). The sampling was performed and the questionnaires were completed at the end of the spring term, at the end of the summer vacation (2.5 months), during the winter term, and after a 1-week winter holiday. "The authors found a significant elevation of IL-1, TNF-α and IL-6 in nasal lavage fluid and IL-6 in induced sputum during the spring term in the subjects from the moisture-damaged school building compared to the subjects from the control building. The exposed workers reported sore throat, phlegm, eye irritation, rhinitis, nasal obstruction and cough in parallel with these findings. The present data suggests an association between microbial exposure, and symptoms as well as changes in pro-inflammatory mediators detected from both the upper and lower airways." (Purokivi et al. 2001). Roponen et al. (2003) compared inflammatory mediators in nasal lavage, induced sputum, and serum of occupants of a moisture-damaged building. They measured concentrations of NO, IL-1, IL-4, IL-6 and TNF-α in induced sputum of the occupants during the working and the vacation periods. All measured cytokines were detectable in the induced sputum samples; however the authors could not find significant differences in cytokine levels between working and vacation periods, between the cases and their controls.

23.2.4 Exhaled Breath Condensate (EBC) Measurement in Sick Building

Exhaled breath condensation (EBC) is another non-invasive method that gathers exhaled breath samples useful for investigating number of different inflammatory biomarkers and oxidative stress. There has been an increasing interest in using EBC, which is an easy and noninvasive technique to sample the airways and is performed repetitively over short intervals between sampling. Collection of EBC is simple; it has no significant adverse side effects, and is well tolerated by participants. Passing exhaled breath through a cold trap collects inflammatory biomarkers. The collected material consists of aerosolized airways lining fluid droplets as well as exhaled volatile compounds and water vapor. Collection devices can be portable; therefore this is a very useful tool for epidemiological and field studies as well as clinical studies (Horváth et al. 2005). Mutlu et al. (2001) acknowledged that "Studies are now being conducted to detect nonvolatile macromolecules present in exhaled breath, including proteins, lipids, oxidants, and nucleotides. Analysis of these nonvolatile substances requires cooling of the expired breath, which results in condensation. These macromolecules represent biomarkers of various pathological processes in the lungs." EBC collection methods, advantages and the potential disadvantages of the technique are summarized in the ATS/ERS Task Force report (Horváth et al. 2005).

EBC analysis might provide indications of ongoing biochemical and inflammatory activities in the lower airways (Hunt 2002). Horváth et al. (2005) stated, "EBC contains a large number of mediators including adenosine, ammonia, hydrogen peroxide, isoprostanes, leukotrienes, nitrogen oxides, peptides and cytokines. One of the current limitations of EBC measurements is the low concentration of many biomarkers, so their measurement is limited by the sensitivity of assays." Cytokine concentrations in EBC might be quantified by enzyme immunoassays including enzyme-linked immunoassays (ELISA) (Akpinar-Elci et al. 2007). The controversy is whether these concentrations actually reflect the levels in airways lining fluid aerosolized in exhaled breath (Effros et al. 2004). In a recent study, Sack et al. 2006 used multiplexed immunoassays to measure cytokine profiles in EBC, which contain only small amounts of cytokines and they successfully detected all investigated cytokines in EBC.

Evaluation of EBC has often been used in asthma studies, COPD and cystic fibrosis. These studies show that EBC could be used to detect airway inflammation, particularly in a severe form of diseases (Baraldi et al. 2003; Bucchioni et al. 2003). In our study, we used EBC to evaluate relationships between airways inflammatory markers and building-related health problems among the occupants of water-damaged building. We measured IL-8 and nitrite in EBC. In this study we investigated 207 non-smoker office workers who complained of respiratory diseases in a water-damaged office building. EBC IL-8 levels were statistically high among workers with work related respiratory symptoms such as cough and in those with physician-diagnosed asthma. EBC nitrite levels were statistically significantly higher in the employees reporting shortness of breath (Akpinar-Elci et al. 2008). To our knowledge, our study is the first and only published study on EBC measurement among the occupants of a water-damaged office building.

EBC is clearly a promising technique for evaluation of airways inflammation. However, further studies on the standardization of results of available EBC methods will be necessary to understand whether EBC evaluation is a valid approach for the assessment of building related diseases (Horváth et al. 2005).

23.2.5 Exhaled and Nasal Nitric Oxide (NO) Measurement in Sick Building

Exhaled and nasal NO measurement is currently the most popular non-invasive marker of eosinophilic airways inflammation in asthma. Standards for this measurement have been published by the ATS and ERS (Anon 2005). Increased levels of exhaled NO in asthma patients in clinical settings have been widely documented, but this technique has rarely been used in field studies. Nasal NO levels are usually very high compared to lower airways NO level. Persons with primary ciliary dyskinesia or cystic fibrosis have low nasal NO levels (Anon 2005). Exhaled and nasal NO measurement is a very valuable tool for epidemiologic investigation and monitoring of inflammatory airways disease. However, it has some disadvantages. Technical factors affect exhaled and nasal NO results. Low exhalation or sampling flow rate and holding the breath increase exhaled NO levels; high exhalation or sampling flow rate decrease exhaled NO levels. Other diagnostic tests such as a sputum induction and spirometry decrease exhaled NO levels. Several factors, such as smoking, are known to increase or decrease exhaled NO levels and nasal NO levels, therefore these confounding factors should be avoided or noted during the pre-test questionnaire (Anon 2005). Smoking status of the person must be seriously considered in the interpretation of exhaled and nasal NO results. Most studies measure and detect exhaled and nasal NO levels by using a chemiluminescence method.

In our previous National Institute for Occupational Safety and Health (NIOSH) health hazard evaluation (HHE) study, we investigated heath problems among occupants of a water-damaged office building (Anon 2003). Of the 68 employees working in the building, 36 (53%) participated in exhaled NO measurement study. The average exhaled NO levels were 6.1 ppb and only one participant had mildly elevated exhaled NO levels. We did not observe any significant change in exhaled NO levels in our repeated measurements between Monday and Friday (Anon 2003).

In another study, we collected exhaled NO and EBC measurements from 224 of the 356 invited employees (62.9%) at the water-damaged building. Since smoking is highly related to exhaled NO measurements, we included only 205 current non-smokers in the analyses. Consistent with the previous literature, exhaled NO levels were higher among participants with hay fever ($p = 0.019$) and significantly lower in those with physician-diagnosed chronic bronchitis ($p = 0.018$) (Akpinar-Elci et al., 2008). During our follow-up measurements, we observed that the prevalence of upper respiratory symptoms remained high. Three years later, we decided to repeat the nasal NO measurements in the same building. Nasal NO levels were low in participants who reported having work-related chills, nasal itchiness, and tiredness symptoms (Akpinar-Elci et al. 2007). According to ATS guidelines low nasal NO should also be considered abnormal (Anon 2005).

Purokivi et al. (2002b) evaluated the value of exhaled NO measurements in determining the airways inflammation among occupants of moisture-damaged school buildings. They did not observe any statistically significant difference in NO levels between study groups. This result suggested that, "NO measurements alone are not sufficient to quantify airways inflammation when evaluating subjects exposed to microbes present in moisture-damaged buildings".

Kolarik et al. (2009) investigated exhaled and nasal NO levels for assessing human response to indoor air pollutants. After exposure, exhaled NO concentrations slightly increased, but nasal NO levels were not affected. As like their conclusion, exhaled and nasal NO measurement might be a possible objective marker of subclinical inflammation in healthy adults exposed to indoor air pollutants.

23.3 Conclusion

In this chapter, we discussed the role of non-invasive airways inflammation assessment methods and their potential applications for evaluation of sick building related health problem.

Identifying and understanding the role of airways inflammatory markers may help to provide new insights into the pathogenesis of inflammatory diseases and for the development a therapeutic modulation. These non-invasive methods are being increasingly recognized as tools for the detection of airways inflammation, which may occur in the absence of changes in pulmonary function and should be considered in studies evaluating relationships between indoor air exposures and adverse health effects. The noninvasive measurement of airways inflammation might provide objective and accurate methods for detecting building related diseases, and are suitable for the monitoring of occupants in water-damaged buildings. Early detection of airways inflammation is critical for prevention of more severe clinical forms of sick building related diseases. Noninvasive assessment of inflammatory markers, in building related disease investigations, is an emerging topic that merits future research. Further studies in this area will help researchers to better understand the causal mechanism of building related health problems.

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Chapter 24
Solving Indoor Environmental Problems: What Can Be Found Out through Individual Measurements?

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24.1 Introduction

Problems with indoor environment cause recurrent complaints from dissatisfied occupants and increase the number of unplanned service and property maintenance visits. Sometimes the problems lead even to illnesses, such as contagious respiratory infections, allergic reactions, or asthma. Unfortunately, corrective actions to improve indoor air quality (IAQ) are often implemented only after occupants develop serious health problems. The slow reaction time prevails also when the causes of thermal discomfort are corrected. In addition, the current policy seems to be that corrective actions are implemented not systematically throughout the building but only in those areas from which the complaints were coming. Thus, much time is wasted and the problem has become serious before corrective measures finally start.

Typically, there is not an isolated problem with the indoor environment, but a cluster of them. Sometimes there are problems with IAQ, such as bad odours, but often the reason is the poor performance of mechanical systems. In addition, in many cases both IAQ and mechanical problems appear in only some areas of the building, complicating the process of locating them (Takki and Virta 2007). Therefore, it is important to determine carefully what kinds of measurements and analyses are needed, and to be aware of what each individual measurement can illustrate. The aim is to collect all of the necessary information cost-effectively in as short a time as possible and make the right decisions for improving the situation comprehensively.

In this chapter, the benefits and limitations of the most common field measurements used in improving indoor environmental quality (IEQ) in office-type environments are discussed.

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24.2 The Basic Approach

Before any technical measurements the nature and magnitude, in addition to the localization, of the indoor environmental problems must be specified. This is best achieved by conducting questionnaires, interviews, or *occupant satisfaction survey*s (OSS). OSS is discussed in more detail in Chaps. 4 and 19 of this book. The survey can be utilised as a diagnostics tool to identify specific problems and their likely causes.

It is recommended that a *health symptom questionnaire*, such as the Örebro MM40 questionnaire (Andersson 1998) be incorporated into the survey in order to link users' health symptoms with indoor environmental quality.

The perceived IEQ and the health symptoms suffered play an integral role in determination of the quality of the building. The complaint areas are defined with the indoor environment perception map that is the product of the survey (Takki and Virta 2007) and localises the problem more exactly to specific floors and façades as well as to specific aspects of indoor environment. With OSS all comments, including free-form ones, can be collected and taken into account in decisions on improvements. *Technical analysis and physical measurements* are then to be conducted in the areas where dissatisfaction and/or health symptom frequencies are the highest, to find the sources of dissatisfaction.

Based on the findings of the occupant satisfaction survey and the results of technical analysis, a *corrective action plan* is implemented. After all necessary corrective actions have been taken, it is important to check that all problems really are solved. This can be done by carrying out a new occupant satisfaction survey (i.e., a '*post-survey*') and limited physical measurements if needed. This should be performed 6–12 months after the corrective actions.

24.3 Technical/Field Measurements

On the basis of the regions and subjects of dissatisfaction (see Table 24.1) revealed by the survey or questionnaire, the next step should be taken by multidisciplinary professionals. Technical/field measurements presuppose a multidisciplinary team of scientists representing at least indoor air quality, building physics, acoustics, and HVAC-system knowledge. The team also needs expertise in various aspects of building services such as lighting, and air distribution.

Often the reporting of specific health problems of a large number of occupants is the first sign of indoor air quality problems. From health symptoms, it is, unfortunately, difficult to draw definitive conclusions as to reasons, because various problems in indoor environment quality can have very similar health effects (see Fig. 24.1).

Table 24.1 The causes identified for dissatisfaction with indoor environment and possible technical/field measurements to choose from to solve them

Area of IEQ dissatisfaction	Typical technical measurements[a]
Odour, Stuffy air	– VVOC/VOC/SVOC levels from air/material samples – CO_2 concentration – Temperature and relative humidity (RH) – PM_{10} and other particulate matter measurements in the air – Dust on surfaces – Air-flow rates (supply and exhaust rates) – Pressure differences (room and surroundings) – Cleanliness of the ventilation system – Micro-organisms from materials – Micro-organisms from air samples – Surface moisture
Irritative agents	– VVOC/VOC/SVOC levels from air/material samples – Dust sampling for fibres – Total airborne dust – Temperature and RH – Air flow rates – Pressure differences (room and surroundings) – Cleanliness of the ventilation system
Unsuitable RH	– RH – Cleanliness of the ventilation system
Too high/low temperatures, Draught	– Air flow – Pressure differences (room and surroundings) – Air flow pattern – Temperature, air velocity, and turbulence intensity
Poor acoustic environment, No sound privacy	– Noise level – Reverberation time – Speech transmission index – Airborne sound insulation between rooms
Poor quantity or quality of lighting	– Light intensity – Luminance factor

[a]Not all measurements are necessarily needed in a successful sampling strategy prepared by IAQ and HVAC system specialists.

24.3.1 Methods to Analyse Indoor Air Quality and Thermal Discomfort

Verification of proper functioning of the ventilation system is one of the key elements when improvements to indoor air quality and thermal comfort are pursued. Here, an HVAC system specialist is needed. Measuring the flow rates (see Figs. 24.2b, c) determines whether the proper amount of outdoor air is reaching the occupants, and if there is balance or unacceptable pressure differences between supply and exhaust air. The HVAC performance should fulfil the design values.

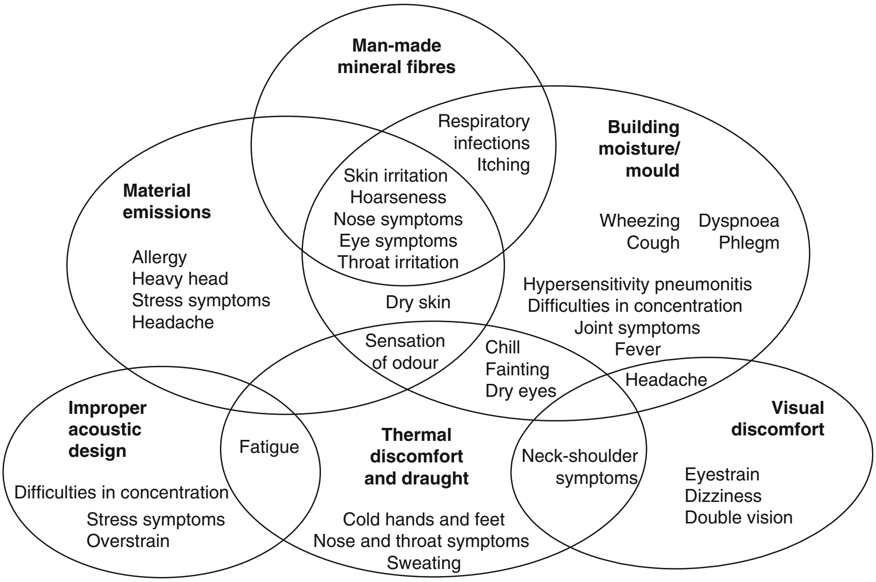

Fig. 24.1 Indoor environment-related symptoms and their possible causes (Schneider and Lundqvist 1986; Hedge et al. 1993; Korpi 2001; Mäkinen-Kiljunen and Mussalo-Rauhamaa 2002; Villberg et al. 2002; Haapakangas et al. 2008; Norbäck and Nordström 2008; WHO 2009; Boyce 2010; d'Errico et al. 2010)

Disturbingly often, the causes of the problems are unbalanced ductwork, diffusers with unsuitable throw patterns, room units operating outside optimal range, or poor operation of room controllers and/or the building management system (BMS). Measuring certain physical parameters (temperature, relative humidity, air velocity, and CO_2 level at the measurement point; Fig. 24.2e) gives information about general air quality and ventilation efficiency in the room.

24.3.1.1 Material Emissions

For volatile organic compound (VOC) measurements and analysis (Fig. 24.2a; Table 24.2), international standards and accredited methods (ISO 16000-1; ISO 16000-6, and ISO 16017-1) facilitate the analysis. Careful sampling strategy should be employed. This includes, for example, not ventilating naturally ventilated rooms for 8 h before sampling. For analysis, laboratories that apply quality management systems should be used.

When the measured VOC levels are lower than the established limit values (such as the time-weighted average (TWA), or threshold limit value) for those compounds, the air quality should be acceptable in terms of VOC types and concentrations. However, indoor air offers a mixture of hundreds of VOCs, and there are no limit values for every one of them. Therefore, the total VOC value (TVOC) is calculated. Interpretation of the TVOC value is not straightforward either. On one hand, a high

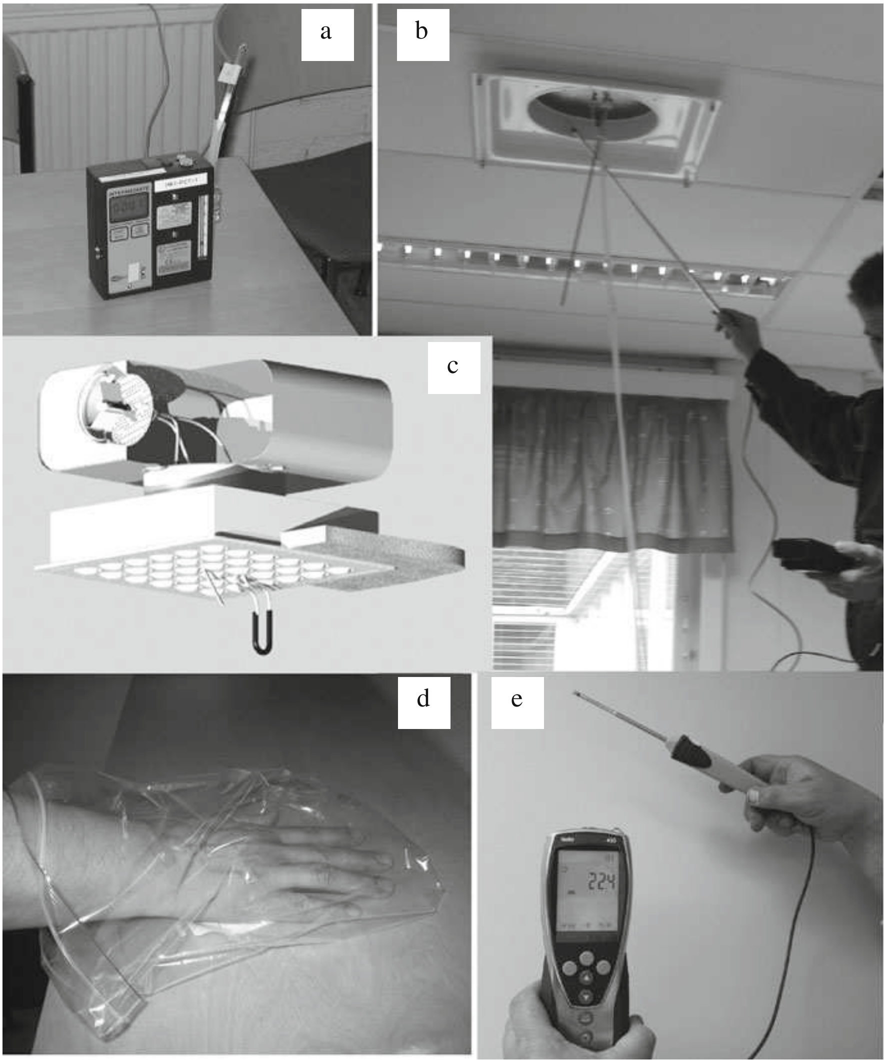

Fig. 24.2 Examples of measurements. **a** Sampling for airborne chemical contaminants. **b** Measurement of airflow. **c** Determination of the supply flow rate via the measurement and adjustment module. The tubes and control spindle are passed through the diffuser. The differential pressure is measured with a manometer. The flow rate is then calculated according to the manufacture's product data. **d** Wipe sampling for man-made mineral fibres. **e** Measurement of temperature and RH

TVOC-concentration may not cause any health symptoms to occupants or present a disturbing smell. On the other hand, a low TVOC-value can be measured in the room while people still suffer from poor indoor air quality caused by a VOC. In these extreme situations, interpretation of the results by a professional is very important.

Table 24.2 Typical measurements to study IAQ problems caused by material and human activity emissions

Air sampling/material emission sampling for chemical contaminants	Interpretation of the result and conclusions
– VOCs in indoor air – VOCs as material emissions (FLEC[a]) – Others, such as PAHs[b], SVOCs[c], ammonia and formaldehyde	– If the sample does not contain 'abnormal' volatile compounds, either there are no (abnormal) chemical emission sources in the space or the space was ventilated just before collection of the samples – The tests help to identify unpleasant odours – They clarify from which materials the divergent result comes (i.e.; they locate the problem) – Indicator compounds for certain moisture-affected material emissions exist (e.g., 2-ethyl-1-hexanol, ammonia, formaldehyde, and 2,2,4-trimethyl-1,3-pentanediol di-isobutyrate) – The list of VOCs present even in a 'normal' air sample is long and requires specialist interpretation of the findings, to avoid false positive and negative conclusions – Elevated concentrations indicate existing problems; normal levels are not always known

[a]FLEC = field and laboratory emission cell; [b]PAH = polycyclic aromatic hydrocarbons, such as benzo[a]pyrene and naphthalene; [c]SVOC = semi-volatile organic compound; includes e.g., plasticisers and flame retardants

Increased levels of some individual VOCs (such as 2,2,4-trimethyl-1,3-pentanediol di-isobutyrate, formaldehyde, and acrolein) are known to cause health symptoms such as eye irritation or asthma (Villberg et al. 2008; Metiäinen et al. 2006; Salonen et al. 2009).

In addition to VOCs, the measurement of certain semivolatiles (SVOCs) may in some cases be advisable. There are recent studies reporting connections between the presence of tributylphosphate (a flame retardant) in floor dust and mucosal symptoms (Kanazawa et al. 2010) and between house dust levels of BBP and DEHP (plasticisers) and allergy symptoms or asthma in children (Bornehag et al. 2004).

Emissions from building materials affect indoor air quality. Material emissions can be measured by means of the field and laboratory emission cell (FLEC). This method is suitable also in field studies when the aim is to identify VOC sources in buildings. Using the FLEC may help in IAQ diagnostics (Nicolle et al. 2009).

24.3.1.2 Man-Made Mineral Fibres

The main sources of man-made mineral fibres in an office environment are damaged sound absorption panels in the ceiling and sound attenuation materials inside the ventilation system (room units, ducts, and air-handling units). Measurement of fiber concentration on the surfaces has a greater ability to detect the presence of fibers than measurement of the fibre concentration in the air (Schneider et al. 1990).

Table 24.3 Methods and measurements to study IAQ problems caused by man-made mineral fibres and dusts

Method: – measurements	Interpretation of the result and conclusions
Settled dust sampling (wipe sampling) for particulate and fibrous contaminants: – Man-made mineral fibres, mould spores, soot, pollen, and asbestos identified with electron microscopy	– If the sample contains any contaminants, further analysis is needed to find pollutant sources – If the sample does not contain any contaminants, the space is clean or surfaces were cleaned less than a week earlier – Only a qualitative result is obtained
Ventilation duct inspection: – Remote-controlled video camera robots	– This determines the condition of ventilation ducts, and locates possible contamination sources in the ducts – It also confirms cleaning needs and records the quality of cleaning

This is why settled dust sampling is useful in identifying mineral fibre exposure (Morawska and Salthammer 2003) (Table 24.3). Vallarino et al. (2003) have proposed a technique to standardise evaluation of fibres in building dust. In addition, sampling should be performed a few days after rigorous cleaning, to verify that the collected dust represents the current situation (Fig. 24.2d). One should bear in mind that for one to be able to say anything about the origin of the fibres in the environment, or to verify that the fibres are MMMF, or to detect also those fibres with the smallest diameter, the analysis must employ a scanning electron microscope, or light microscopy using plane polarised illumination.

On many occasions, a result concerning the composition of a dust sample may be obtained simultaneously with the determination concerning fibrous matter. While it is possible to detect microbial spores in the samples, one cannot reach species or even genus level in microscopic evaluation of a dust sample.

24.3.1.3 Building Moisture and Microbial Contamination

Moisture damage and microbial growth are perhaps the most difficult IAQ problem causing agents to locate and measure. Sometimes the visual signs of moisture are clear and distinct and no microbial sampling is needed to prompt action. But when moisture problems are not as obvious and damage is only suspected, there is not just one method that can detect microbial growth in all conditions (Table 24.4). That is why surface and material samples and sometimes also air samples may be needed. Mould growth can be verified by comparing samples from damaged and undamaged materials. If damage is not visible, mould growth can be found via either settled surface dust samples or air sampling. Air sampling should not be the only method used for collecting information on moisture damage, because of its limitations (Meklin 2002).

Culture-based methods are for the time being a usual means of detecting microbial growth (WHO 2009). However, they possess certain drawbacks. Firstly, no

Table 24.4 Typical methods of studying IAQ problems caused by building moisture and/or microbial contamination in building materials

Method: – measurements	Interpretation of the result and conclusions
Surface moisture measurement: – Locating moist areas in floors, roofs and walls made of homogeneous material	– This provides rapid and non-destructive determination of the moisture content of building materials – It is for preliminary analysis before destructive methods – It is indicative and instantaneous – Interpretation is often demanding
Structural humidity measurement: – The water content of concrete at measured depths	– It determines whether the structure is dry enough – It determines whether the conditions in specific structure are favourable for mould growth – It destroys structures, and the holes drilled may harm the functioning of the structure and enable condensation of moisture
Air sampling for microorganisms/microbial constituents: – Viable fungal and bacterial spores/cells present in the air – DNA-based methods for identification and quantification of microbial genera – General toxicity of airborne dust (e.g., boar sperm motility test) – Other target compounds, such as mycotoxins, β-glucans, toxins produced by actinobacteria, and endotoxins (– Ergosterol, fungal extracellular polysaccharides, muramic acid, and 3-hydroxy-fatty acids)	– Culture-based methods favour and select certain species; while they allow the identification of many species, they do not provide detection of non-culturable and dead micro-organisms, cell debris, and microbial components also having toxic or allergenic properties – If the sample contains higher concentrations of specific species or genera of micro-organisms in comparison to reference samples, further analysis is needed to find pollutant sources – If the sample does not contain abnormal levels/genera of viable fungal spores, the room may be clean, there were no viable spores in the air at the time of measurement, or spores do not germinate on the sampling media – The presence of certain microbial genera may indicate moisture/mould damage, if other conditions are met – For toxicity measurements, extremely high-volume air samples are needed, so the sampling time is on the order of weeks – For non-culture-based methods and means of assessing microbial constituents, reference values for distinguishing damaged from non-damaged buildings or materials are not yet available. These methods are suitable for before–after situations – Many of the newly developed methods are not well validated and remain unavailable commercially

Table 24.4 (continued)

Method: – measurements	Interpretation of the result and conclusions
Surface (dust)/material sampling for micro-organisms/microbial constituents: – (Viable) micro-organisms growing on the surface sampled – All micro-organisms, both viable and non-viable, present in the sample – Direct microscopic examination of a surface – Toxins in the sample – General toxicity of the sample (e.g., boar sperm motility inhibition assay) – DNA-based methods for identification and quantification of microbial genera – Other target compounds, such as mycotoxins, β-glucans, toxins produced by actinobacteria, and endotoxins (– Ergosterol, fungal extracellular polysaccharides, muramic acid, and 3-hydroxy-fatty acids)	– This determines whether the surface or material sampled (with a visible stain, discoloration, etc.) has microbial growth at the sample location – It indicates whether there are abnormal microbial genera/quantities on the surface – Surface sampling may also reveal indoor reservoirs of spores that have not yet become airborne – The presence of biological materials on a particular surface is not a direct indication of what may be in the air – The method requires a parallel sample from a non-suspect reference material for valid interpretation – Cultivation favours certain types of micro-organisms – Non-culture-based methods and methods for assessing microbial constituents are fast, but reference values are thus far lacking. The method is suitable for pre-and post-renovation monitoring – Many of the newly developed methods are not well validated and are unavailable commercially
Thermal infrared imaging: – Air and thermal leakage in structures e.g., windows and external walls – Temperature differences in the structure	– The method detects building/structure abnormalities that result in energy losses – The data produced can indicate possible at-risk structures for cold bridges and moisture condensation

health-based exposure limits have been recommended. Secondly, culture-based methods detect only those viable spores in the air that survive the sampling process and germinate on the sampling media. Lastly, a high outdoor air concentration of microorganisms, certain human activities, and the type of the building can distort the background level of mould spores in the indoor air. For example, old wooden buildings have higher background microbial concentrations than new concrete buildings do (Lignell et al. 2007; Meklin et al. 2005).

There are also new, non-culture-based methods to detect microorganisms. Recent studies demonstrate promising results from DNA techniques such as the quantitative polymerase chain reaction (qPCR) method. Methods based on DNA techniques are not dependent on the viability of the microbes, and they can be designed to work at different levels of specificity, detecting a whole group of microbes, a genus, or for example, a biosynthetic gene (Rintala 2003; Lignell 2008; WHO 2009). For now, the disadvantages of these rapid methods include the lack of reference values and the need for special expertise. Therefore, interpretation of the results is difficult.

Determination of microbial constituents, such as mycotoxins, β-glucans, toxins produced by actinobacteria, endotoxins, ergosterol, fungal extracellular polysaccharides, muramic acid, and 3-hydroxy-fatty acids is also among the new methods. Most of these tests lack validation and reference values for the time being (WHO 2009; Kärkkäinen et al. 2010; Hyvärinen et al. 2006).

Finding at-risk or moisture-damaged structures may require surface moisture measurements, structural moisture measurements, and/or thermal infrared imaging performed by a building physics specialist (Table 24.4).

24.3.1.4 Thermal Discomfort and Draught

Typical methods for studying thermal discomfort and draught are presented in Table 24.5. Performing the technical analysis at the site typically takes a few days and requires an HVAC specialist.

When it comes to thermal conditions, the analysis concentrates on the locations of heat loads and heat losses, and on the functioning of ventilation, heating, and cooling systems. If the problem is draught, it is important to study the air flows in the room with the help of, for example, smoke visualisation. In areas where the air quality is of concern, the focus is on the efficiency of ventilation in the room and on the pressure differences between rooms. Verifying the cleanliness of the air-conditioning systems and inspecting the air-conditioning devices are also important.

Problems in thermal comfort are often related to badly performing ventilation and heating systems. Typically, problems with HVAC systems' settings, such as operation times of air-handling units as well as air and water temperatures, and in operation of building management system are found. Sometimes thermal discomfort is caused by the lack of cooling or heating capacity in the building, or that the occupants and building maintenance personnel are unacquainted with the usage and operation of the building management system.

Solving draught problems via air velocity measurements specified in international standards (e.g., ISO EN 7730 (2005) and ASHRAE Standard 55 (2004))

Table 24.5 Typical field analysis methods for studying thermal discomfort

Methods: – measurements	Conclusions
Trend logs for the building management system: – Room air temperature and CO_2-concentration in the room – Primary air-flow rate and duct pressure – HVAC-system set values	– The problem may stem from system failures in the building management system, in air-handling units (AHUs), or in other system components – There may be large variations in room conditions caused by, for example, a broken sensor, closed/stuck valve, broken fan, or released fire damper – The wrong setpoints may be in use
Airflow visualisation using smoke: – Air diffusion in the space – Air-flows between spaces – Pressure difference between spaces – Air tightness of windows	– This determines the air movements in the space – It clarifies reasons for draught in the occupied area – e.g., terminal unit, cold window surface, infiltration, or pressure difference between spaces – It assesses the operation of the terminal unit
Room conditions' measurement: – Local air temperature, air velocity, CO_2-concentration and relative humidity – Window and other surface temperatures	– The method determines room conditions at the time of measurement – The result depends on the actual measurement timing (i.e., heat loads in the space, supply air condition (cooling or heating), sunshine, etc.)
Measurement and audit of HVAC-system parameters: – Local air-flow rates in ductwork branches and at terminal units – Water-flow rates in heating and cooling systems – The condition of all HVAC-components	– This determines whether the ductwork and pipes are in balance and operating at the design values – It determines whether the system components, such as AHUs, fans, filters, condensation drains, and valves, are clean and in good condition
Thermal infrared imaging: – Tightness of windows to air and heat – Air-conditioning room unit operation (e.g., chilled beam and radiant ceiling) – Window surface temperature (Note: measurement is difficult because of reflections)	– This determines the air-tightness of window structures – It identifies too low or too high surface temperature of window or other surfaces – It provides information on the operation of room units and their management system – It gives information on system failures in pipework and the BMS

is challenging. These standards specify the draught rating (DR) value – i.e., the percentage of people dissatisfied because of draught. The draught rating is a function of local air temperature, local mean air velocity, and local turbulence intensity. Recent studies indicate that this model should also take into account the length of exposure, activity level, and velocity directions (Griefahn et al. 2000; Toftum et al. 1997; Melikov 2005). The revised versions of both standards include a diagram for estimating the air speed required to offset an increase in temperature. Also, the possibility of controlling temperature at the individual level is important for occupant satisfaction (Toftum and Melikov 2000).

When air flow is measured in a non-occupied room, it is difficult to identify possible draught. The velocity field at a given moment depends on the number and the location of heat sources and on the primary air conditioning. Occupant and solar load as well as air-flow rates and the supply air temperature of terminal units vary all the time in the space. This is why the velocity field is not stable and the flow pattern will change with the load conditions. In many cases, thermal plumes dominate air movement by creating large eddies in the room (Kosonen et al. 2007).

Consequently, solving draught problems requires professionals who are well aware of the operation of terminal units and behaviour of thermal plumes and air movements in the space. This is why this phenomenon is easier and faster to visualise with smoke instead of through measurement of local velocities and temperatures.

24.4 Conclusions

Identifying and locating the reasons behind unsatisfactory indoor environment quality is a challenging task. This is because typically the problems are caused by several coexisting factors. Poor indoor air quality can originate from various elements, such as microbial growth, unprotected or damaged man-made mineral fibre surfaces, or chemical emissions from materials. Also, imbalance of supply and exhaust air often causes IAQ problems. At the same time, there may be poor air distribution in the room, or problems in controlling the heating system might cause thermal discomfort and draught.

The occupant symptom profile on its own is seldom adequate to lead the indoor air experts to the right track. Instead, the areas where occupant dissatisfaction is the highest serve better for cost-effective targeting of the methods and measurements. For example, an expert relying on only one type of measurements (let's say, surface moisture, airborne micro-organism, or smoke tests) rarely succeeds in improving the indoor environment holistically. There is neither a systematic sampling strategy to follow nor a panacea with respect to what samples to take, since the range of things to measure is vast and cases vary. On the whole, choosing the right technical measurements and solving indoor environmental problems require multidisciplinary skills, with at least IAQ, building physics, and HVAC-system specialists working together. This chapter presented discussion of the pros and cons of typical field measurements to solve indoor environment problems.

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Chapter 25
Sick Building Syndrome from a Medical Perspective-Symptoms and Signs

Berndt Stenberg

25.1 Introduction

In 1982, the World Health Organization (WHO 1983) expert group defined 'Sick building syndrome, SBS' mainly on the basis of reports from the Scandinavian countries and the US. This definition is still in widespread use and includes the following list of general, mucosal and skin symptoms and signs (Table 25.1).

This definition however, is not an accepted clinical syndrome but rather a list of symptoms often perceived by persons working or residing in buildings with indoor air quality problems. Consequently, SBS has been interpreted differently by various investigators. For example, skin symptoms are often excluded by Anglo-American investigators (Kreiss 1989). Berglund et al. (1992) have suggested criteria for the definition of SBS including specific symptoms and signs, and odour or taste sensations, combined with requirements for the prevalence of symptomatic inhabitants within the building. They specified that the cause must not be exposure to a single agent. These criteria however have never been validated and have not come into general use.

Table 25.1 Prevalent symptoms reported by occupants of buildings with indoor air quality problems (WHO 1983)

Sensation of dry mucous membranes and skin	Wheezing
Eye, nose and throat irritation	Non-specific hypersensitivity
Erythema	Mental fatigue
Itching	Headache
High frequency of airway infections	Nausea
Cough	Dizziness
Hoarseness	

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Clinical studies of SBS are sparse; indeed, it is sometimes stated that SBS has no clinical signs (Welch 1991; Lachapelle 2000). One Swedish study is of particular interest, however, as it is one of very few studies that focuses on reactions in children and because it is one of the studies upon which the WHO list of SBS symptoms is based. At clinical examination dry and erythematous skin on the face and extremities, conjunctivitis and nose symptoms were more frequently found among children in day care centers with indoor air quality (IAQ) problems compared with control buildings (Stockholms-undersökning 1982).

25.2 Symptoms and Signs

In this section we describe the range of symptoms and signs that have been reported in the literature and discuss any associations. Overall, SBS symptoms appear to be more prevalent in women than in men; this may be the result of different exposures or different constitutional and personality traits (Stenberg and Wall 1995; Brasche et al. 2001a).

25.2.1 Skin

In an earlier study of skin reactions in patients referred to a dermatological department as a result of symptoms perceived in workplace buildings with IAQ problems (Stenberg 1989), facial erythema, rosacea, scaling of scalp, ears and face, urticaria and 'itching folliculitis' were most common.

In the first published follow-up study of SBS patients referred to hospital (Edvardsson et al. 2008), the most common skin symptoms noted at the primary investigation in the hospital clinic were facial erythema and body itch. At follow-up, facial erythema was the most common skin symptom.

In their review of skin reactions related to the indoor environment, Ring et al. (2001) discuss findings from the German ProKlimA project, which compared questionnaire-reported symptoms with medical observations and measurements of skin sebum content and the hydration of the stratum corneum. Individuals characterised by low sebaceous secretion and/or low stratum corneum hydration reported significantly more skin complaints (Brasche et al. 2001b; 2004).

In a case referent study of SBS, two personal factors were found to be significant risk indicators after adjustment for atopy: photosensitive skin and a strong 'stinger test' reaction (Stenberg et al. 1994). As the study was cross-sectional it was not possible to assess which came first, the SBS symptoms or the 'stinger' reactivity.

25.2.2 Eyes

Dry and irritated eyes are common symptoms in individuals working or living in buildings with IAQ problems, according to the WHO list referred to in Table 25.1

(WHO 1983). Eyes problems were investigated in early epidemiological and clinical SBS studies. For example, foam formation at the inner eye canthus, which may reflect the condition of the tear film, has been found to be lower among office workers compared with a control population and negatively correlated with symptoms and signs of dryness of the eyes (Franck and Skov 1989). Eye symptoms were studied in 'The Danish Town Hall Study'. In people suffering from work-related eye symptoms, signs of dryness, such as low Break Up Time (BUT) and corneal erosions, were noted (Franck 1986; Skov et al. 1990).

Since these early studies, eye symptoms and signs have been extensively investigated and reviewed. A model has been suggested in which blink frequency, destabilisation, and break-up of the eye tear film may explain eye symptoms among office workers in terms of occupational, indoor climate and personal risk factors (Wolkoff et al. 2003). Methods for investigating eye symptoms in relation to IAQ factors have also been extensively discussed (Kjaergaard 2001; Rohr 2001). Although blink frequency has been used as an outcome in several experimental studies (Klenø and Wolkoff 2004; Klenø et al. 2005) there is good evidence that BUT is the sign most strongly associated with reported SBS symptoms related to the eyes (Brasche et al. 2001b; Kjaergaard 2001; Rohr 2001). BUT is a measure of tear film stability and can be measured either by fluorescein staining of the eye to make visible, and thus enable measurement of the time from a blink until the tear film breaks (Norn 1986), or by recording the time the subject can keep their eyes open without pain, when focussing on a fixed point (self-reported BUT). There is a good correlation between self-reported BUT and the standard method (Wyon and Wyon 1987). Because fluorescein itself can have an effect on tear film stability, a non-invasive tear film break up time (NIBUT) has been developed (Mengher et al. 1985).

Using CO_2 as an irritant to determine the threshold for eye irritation, increased susceptibility has been found in subjects reporting SBS symptoms (Kjaergaard et al. 1992). The same study found that the CO_2 threshold was related to skin irritation sensitivity assessed as response to lactic acid smeared on the cheek.

25.2.3 Upper Airways

WHO lists dry mucous membranes and nose irritation as typical SBS symptoms (WHO 1983). Clinical studies of the upper airways in subjects suffering from SBS symptoms are lacking. Perceived nasal obstruction is a symptom that can result from inflammation of the nasal mucosa and is often an effect of mucosal swelling. Changes in mucosal swelling and nasal patency can be studied by computed tomography, magnetic resonance imaging, rhinostereometry, or acoustic rhinometry (Malm 1997). Other functional measures include rhinomanometry and nasal peak flow measurements. The clinical or research question is the decisive factor in the choice of method.

Acoustic rhinometry is a convenient method to use in environmental studies. This approach has been used in recent studies on the effects of the indoor environment on the nose. Decreased nasal patency has been observed in subjects in schools with low air exchange rates (Wålinder et al. 1998) and low cleaning frequency (Wålinder et al. 1999). Rhinostereometry is a more complicated method, which may explain why it has not been widely used in field studies. It can be combined with histamine challenge to measure nasal hyperreactivity (Hallen and Juto 1993). This method was used in a study of tenants living in buildings that were identified as being 'sick'. The tenants were prone to histamine induced hyperreactivity, whether they reported symptoms from the upper airways or not (Ohm et al. 1997). This method has also been used to track an exposed population, recording changes in hyperreactivity over time (Rudblad et al. 2002).

25.2.4 Lower Airways

Even though the WHO list of SBS symptoms (WHO 1983) includes a number of lower airways symptoms (hoarseness, cough, airway infections and wheezing), such symptoms are reported less consistently than ocular problems and mucous membrane irritation (Mendell 1993; Menzies et al. 1993; Hodgson 1995). Typically, the lower respiratory tract seems unaffected by exposure to inadequate IAQ when assessed using standard procedures such as spirometry and the methacholine test (Muzi et al. 1998). There are a few exceptions such as a Swedish study which demonstrated a decrease in forced vital capacity (FVC) during work among teachers in a school where there were problems with damp and mould (Dahlqvist and Alexandersson 1993).

Symptoms of the lower airways are prominent in many studies of the potential health risks associated with building dampness. Other SBS symptoms from the WHO list have not been included in many of these studies. For this reason it is not clear whether the respiratory symptoms in such situations are separate from SBS or just one of a group of symptoms or a syndrome of which only the respiratory symptoms have been studied. Building dampness studies have been summarised in two reviews (Bornehag et al. 2001; 2004) which describe evidence that dampness is a risk factor for respiratory symptoms (cough, wheeze and asthma) in both atopic and non-atopic individuals. These reviews also suggest an association with other symptoms such as tiredness and headache.

25.2.5 General/Systemic Symptoms and Signs

Although general or systemic symptoms, such as headache and fatigue, may cause anxiety in affected individuals and also be associated with subjective loss of productivity, there have been no systematic attempts to characterise such symptoms (Hodgson 2001). Fatigue, headache and difficulties concentrating are prevalent symptoms reported by individuals living or working in buildings with IAQ problems (Mendell 1993; Edvardsson et al. 2008) but are also often reported in the general population (Eriksson and Stenberg 2006). Nausea and dizziness are rarely reported and the association between IAQ and these symptoms has been questioned in a recent study (Glas 2010).

25.3 Laboratory Findings

The use of biomarkers in SBS research has been reviewed by Norbäck and Wieslander (2002) and Norbäck (2009). Analyses of tear fluid are very rare. There are, however, reports of an increased number of conjunctival polymorphonuclear leucocytes after exposure to *n*-decane (Kjaergaard et al. 1989) and increased albumin content in tear fluid after exposure to a mixture of volatile organic compounds normally found in buildings (Thygesen et al. 1987).

A number of studies involving analyses of nasal lavage fluid (NAL) have been undertaken. There are many potential biomarkers, including tryptase, albumin, lysozyme, eosinophilic cationic protein (ECP), and myeloperoxidase (MPO). Other biomarkers that have been monitored in NAL include TNF-alpha, IL-1beta, IL-6, IL-8 and prostaglandin E(2). Nitrate and nitrite (as markers of nitric oxide formation) and antioxidants have also been measured in NAL. The biomarkers reflect different pathogenic mechanisms of reactions in the mucosa (Norbäck and Wieslander 2002).

Most studies of biomarkers in NAL have involved experiments with exposure to single chemicals such as ozone and formaldehyde. Relevant field studies of biomarkers associated with IAQ factors are few. Increases in lysozyme and ECP in NAL were recorded in subjects in schools with low cleaning frequency (Wålinder et al. 1999). Increased lysocyme and ECP was also associated with higher indoor levels of formaldehyde and nitrogen dioxide (Norbäck et al. 2000). In a longitudinal study, a move to an office recently painted with water-based paint was related to an increase in lysozyme and ECP in NAL (Wieslander et al. 1999a). There are also data indicating that exposure to micro-organisms or building dampness influences the nasal mucosa. ECP, MPO and albumin were all increased in subjects in buildings with pronounced microbial growth in the fabric of the building (Wålinder et al. 2001). Dampness in the floor construction of two geriatric hospitals and the presence of 2-ethyl-1-hexanol in indoor air were both associated with increased lysocyme in NAL (Wieslander et al. 1999b). Teachers in Finland working in a school building where mould was present had higher levels of TNF-alpha, IL-6 and NO in NAL than did the unexposed controls. The biomarker concentration returned to normal levels (i.e. those recorded in the controls) during the summer vacation (Hirvonen et al. 1999).

Bronchoalveolar lavage (BAL) is not used much in IAQ research probably because symptoms associated with the lower airway are not as prominent as upper airway symptoms among those living or working in problem buildings. An examination of BAL was undertaken in patients referred to Helsinki University Hospital due to symptoms suspected to have been caused by long-term exposure to water damage in the home or workplace. It was concluded that exposure to water damage caused a significant change in the cellular composition of BAL (lymphocytosis) and a decrease in the number of CD19 cells in blood (Wolff et al. 2009).

A non-invasive method for analysing respiratory inflammatory response is to study biomarkers in exhaled breath condensate (EBC) (Gibson et al. 2000). In a study of workers reporting respiratory conditions in a water-damaged office building, EBC interleukin-8 (IL-8) levels were significantly increased in workers with respiratory symptoms (Akpinar-Elci et al. 2008).

To date, laboratory analyses of the blood have not contributed much to the diagnosis of SBS, and there are no specific blood tests associated with reported SBS symptoms. Recently, however, signs of oxidative stress measured as urinary 8-hydroxydeoxyguanosine has been found to be related to indoor air pollution (Lu et al. 2007a,b).

25.4 Clinical Course/Prognosis

While some reviews have stated that SBS is characterized and even defined by the relief of symptoms when the affected person leaves the building (Welch 1991), others, even among the early descriptions of the syndrome, have pointed out the gradual onset and long duration of symptoms (Akimenko et al. 1986; Redlich et al. 1997). There are no studies supporting the statement that SBS symptoms always resolve immediately after exposure ceases. There is, however, evidence for long-lasting symptoms in a study showing slowly decreasing mucosal hyperreactivity, years after the subjects had worked in a school with moisture problems (Rudblad et al. 2002). Other studies show that symptoms persist for at least a proportion of those affected. A follow-up study of the prevalence of work-related SBS symptoms among office workers reported a decrease in symptom prevalence soon after moving to a building with a better ventilation system. Three years later, however, nearly half of the symptom prevalence remained (Bourbeau et al. 1997). In a follow-up study of SBS patients, it was shown that symptoms deceased over time. Nearly half of the patients claimed that symptoms were more or less unchanged after 7 years or more, despite actions taken (Edvardsson et al. 2008).

25.5 Differential Diagnoses

Persistent SBS symptoms such as those in the studies discussed above are sometimes attributed to environmental factors other than ‘sick buildings’. Nethercott et al. (1993) are among those who consider persistent SBS symptoms to represent multiple chemical sensitivity (MCS).

Since the 1980s the phenomenon of MCS has attracted great interest and has been discussed in numerous publications. Cullen (1987) defines MCS as “an acquired disorder characterized by recurrent symptoms, referable to multiple organ systems, occurring in response to demonstrable exposure to many chemically unrelated compounds at doses far below those established in the general population to cause harmful effects. No single widely accepted test of physiologic function can be shown to correlate with symptoms”. Alternative but similar major diagnostic features have been suggested. The current knowledge of MCS is extensively reviewed in a textbook (Ducatman 2005), while similarities between SBS and MCS are discussed by Miller and Ashford (2001).

Because of the non-specific nature of many symptoms appearing in the office environment, psychological factors are often suggested as causes for the complaints. They may even be used as an excuse for incomplete investigations (Faust and Brilliant 1981). In a textbook of occupational dermatology SBS is described in the following way: “SBS… refers to epidemics of subjective symptoms (itching and burning sensations) without any clinically visible signs, which occur in the work environment. This situation can be related, for instance, to low relative humidity but may also represent a mass psychogenic illness” (Lachapelle 2000).

Findings from 19 episodes of probable mass psychogenic illness (MPI) investigated by the National Institute for Occupational Safety and Health (NIOSH) have been summarised by Boxer (1985). Some symptoms typical of MPI are common to SBS; skin symptoms were, however, not reported. Signs suggestive of MPI, such as relatively severe symptoms of sudden onset, conversion symptoms and recurrences in affected individuals when they congregate, make it possible to separate this phenomenon from real indoor air problems (Boxer 1985).

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Chapter 26
Improvement of the Illumination Levels Combined with Energy Savings for a Residential Building

Sabah A. Abdul-Wahab and Syed Uzair Ahmed

26.1 Introduction

Lighting is related to both general satisfaction in the indoor environment and the comfort of visual performance (Drahonovska 2005). Poor lighting design can cause health problems and is likely to irritate, distract, and produce lethargy. Inadequate lighting can affect the mental performance of occupants (Mendell et al., 2002). This may contribute to building-related illness, which have clearly identifiable causes, or to other adverse health effects. As the eyes are the most important working tool across a wide spectrum of jobs and professions, then they have to function in an appropriate lighting environment (Drahonovska 2005). Eye work under inappropriate lighting can be a very obvious cause of sick building syndrome (SBS), producing eye discomfort, eye strain and fatigue (Morris and Dennison 1995; Drahonovska 2005).

World Health Organization (1983) has defined SBS as a medical condition in which people in a building suffer from symptoms of illness or feeling unwell for no apparent reason. The symptoms of SBS are causing discomfort and a sense of being unwell rather than a distinct illness. While specific causes of SBS remain still unknown, it is often attributed to the poor indoor air quality (Jones 1999). The most common symptoms of SBS are sore throat, fatigue, lethargy, dizziness, lack of concentration, respiratory irritation, headaches, eye irritation, sinus congestion, dryness of the skin (face or hands), and other cold, influenza, and allergy type symptoms (Spengler and Chen 2001). These symptoms may occur singly or in combination with each other. Mendell et al. (1996) reviewed the findings of 32 studies conducted between 1984 and 1992 that considered 37 factors potentially related to office worker symptoms. He prepared a summary of reported relationships between symptom prevalence and environmental measurements, building factors, workplace factors, and job or personal factors.

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The symptoms of SBS lead to increase employee sick days and reduce the performance of occupants in buildings (Fisk 2000; Mendell et al., 2002). Wallace et al. (1993) pointed out that SBS symptoms may have a greater impact on public health and cost to the economy than some major diseases due to widespread absenteeism and lowered productivity amongst affected people. For example, it has been estimated that the annual cost of headaches amongst the employees of the US Environmental Protection Agency may be as high as $2 million (Jones 1999). Fisk (2000) estimated potential annual savings for the United States between $43 and $258 billion. Other studies have reported similarly high economic costs (Mendell et al., 2002; Seppänen 1999; Brightman et al., 2008).

The installation of appropriate lighting levels was found to reduce the incidence of SBS. Sterling et al. (1983) noted a reduction in eye symptoms by varying both the quantity of ultraviolet light and the ventilation. Wilkins et al. (1989) noted a decrease of the incidence of eye-strain and headache by more than 50% in a group of office workers by using solid state high frequency ballast which resulted in illumination with a reduced fluctuation. It is also possible that visual stress plays a part in the development of eye irritation and headache, for example through the lighting level, insufficient contrast, excessive brightness and glare.

Occupant's satisfaction with lighting may vary with illuminance and with the characteristics of the lighting system (Katzev 1992). In any given office environment, occupants should be able to see easily, comfortably and accurately. The illumination level required to achieve these results will vary, depending on the given activity taking place and the characteristics of the occupant. For most spaces and environments, the perceived quality of light in any situation depends on the type of activity or task being undertaken, the age and eyesight of workers, and the visual difficulty of the task being carried out. Conventional white fluorescent lighting is likely to cause eyestrain and headaches (Wilkins et al., 1988; 1989; London Hazards Centre 1990). Inadequate illumination, glare, flicker and lack of contrast can also cause tiredness, dry and gritty eyes and headaches (Vince 1987).

Several reports have claimed that the ultraviolet light emission from fluorescent lamps can react with various pollutants in the air creating a photochemical smog which acts as a toxic irritant (Wilkins et al., 1989; Stone 1992). However, Morris and Dennison (1995) pointed out that more research is needed to ascertain whether ultraviolet light emission has any role to play in sick building syndrome.

The quality of the indoor environment depends significantly on several aspects of lighting (Veitch and Newsham 1998) including the illuminance (intensity of light that impinges upon a surface), the amount of glare, and the spectrum of the light (Veitch and Newsham 1998; Fisk 2001). There is evidence that a decrease in the amount of flicker in light, i.e., the magnitude of the rapid cyclic change in illuminance over time, may be associated with a decrease in headache and eyestrain (Wilkins et al., 1989) and with an increase in worker performance (Veitch and Newsham 1998). Lighting characteristics influence the quality of vision, and can have psychological influences on mood and on perceptions about the pleasantness of a space (Tiller 2001).

In general, lighting levels in offices need to be of a quality that provides an environment in which it is easy to see, so that tasks can be safely performed without eyestrain (Brown 2006). During typical working hours, lighting inside offices tends to rely on a combination of both daylight from windows and an artificial lighting. The quality of artificial indoor lighting is a function of the types, locations and number of luminaires, and the optical characteristics of indoor surfaces, such as their spectral reflectivity and color (International Performance Measurement & Verification Protocol 2001). It is important to note that the greatest scope for increased productivity lies with improvement in lighting quality rather than in the provision of higher illuminances. As a general rule, the lighting system should be designed and installed to effectively reveal the task(s) and to provide safe and comfortable visual environments (Cooperative Research Centre for Construction Innovation 2008).

Artificial light is generated through the conversion of electrical energy into visible radiation. In office buildings, artificial lighting is considered the second major consumer of electricity after air-conditioning. According to Krarti (2003), 30–50% of the electricity consumption in office buildings is used to provide lighting. Moreover, heat generated by lighting contributes to additional thermal loads that need to be removed by the cooling equipment. Therefore, any reduction in the lighting systems will be significant (Al-Nakib 2003). By having an understanding of the lamps, ballasts, luminaries and control options available today as well as the techniques used to develop efficient lighting, lighting can be produced so that it is energy efficient, cost effective and yields a better quality of light (Ali et al., 2009).

Lighting design should respect the size, height and depth of a room, the number of desks or workplaces, the type of work, color and surface quality and the geographical orientation of the building (especially windows). The choice of the main components of lighting design (both sources and system) strongly depends on these variables (Drahonovska 2005). There are many organizations that publish recommended-practice documents, codes, and standards that attempts to codify good lighting practice. Organizations that have a role in regulating lighting practice around the world, along with their internet website address and self-described mandate can be found in Tiller (2001).

In recent years, there have been many new developments in the lighting industry, in both technological equipment and approaches to lighting design (Ali et al., 2009). One objective of these technological developments in the lighting industry has been the improvement potential in lighting efficiency, thus a reduction in energy consumption and costs. Various technologies used in this regards are listed by Ali et al. (2009).

Even in university offices, housing and laboratories, complaints are often voiced regarding the poor quality of lightening. Faculty and students have observed that intensity of the light affects their activities and may make the environment uncomfortable. Due to these reasons, residents of faculty and student houses are in need of efficient and comfortable lighting environment to provide a better working and living indoor environments.

In this chapter, DIALux lighting software was selected to study the improved illumination level and energy saving for a selected faculty house in the SQU campus. This was done with the support of Philips lighting equipments saved in DIALux database. The proposed lighting system will provide a comfortable environment as well as an efficient lighting system for the people living in the house.

26.2 Linkage Between Lighting and Human Performance

The quality of lighting in a space is a key element in the comfort, health, and productivity category of green building. Effective lighting can enhance the mood, energy, and effectiveness of people using the space. Light also affects people's circadian rhythms, an important factor in maintaining health sleep cycles (Armstrong and Walker 2006).

National Electrical Manufacturers Association (NEMA 1989) pointed out that lighting has at least the theoretical potential to influence performance directly, because work performance depends on vision, and indirectly, because lighting may direct attention, or influence arousal or motivation. Several characteristics of lighting (e.g., illuminance, amount of glare, and the spectrum of light) may theoretically affect work performance (Fisk 2001).

It is expected that performance of work that depends very highly on excellent vision, such as difficult inspection of products, will vary with lighting levels and quality. The published literature, while limited, is consistent with this expectation. For example, Fisk (2001) mentioned that Romm (1994) reports a 6% increase in the performance of postal workers during mail sorting after a lighting retrofit that improved lighting quality and also saved energy. A review of the relationship between lighting and human performance (NEMA 1989) provides additional examples, such as more rapid production of drawings by a drafting group after bright reflections were reduced.

26.3 DIALux Lighting Software

DIALux is lighting design software that can be used to design technical lighting and lighting planning. It can be applied for the professional lighting calculations to determine all the lighting parameters for indoor and outdoor lighting systems for various environments. The software can provide clear and precise results according the latest regulations in the indoor architecture field. It allows applying textures and working with a wide range of furniture, which can be simply modified and saved for a future project.

The software was developed by the DIAL-German Institute of Applied Lighting Technology. It includes the product information of all the lighting companies in its database. The program provides the lighting designers the opportunity of limitless design. The program includes the products of all the lamp producers in its database to permit its use by all lighting designers and to provide different points of view (Ekren et al., 2007).

There are many versions of the DIALux program. DIALux includes the armature and lamp information from many companies, such as Philips, Osram, SURYA, AEG, Endo, Dextra, Simes, Luxonic, SEAE in its database (Ali et al., 2009). Hence, the program helps to measure the necessary lighting level and finds out the number and type of the armature.

Being a simulation program, DIALux supports many room shapes, such as rectangular, square, polygon, L shaped or the shapes designed by the user, and allows the user to choose from among those shapes. The program, which supports the addition of more than one piece of furniture to the place, also takes into consideration factors such as lighting level, reflection and glitter which can be seen on the furniture (Ekren et al., 2007).

To run DIALux software, the following data are required:

1. Space data (i.e., width, length, height)
2. LUX of the space

Then the redesign of the lighting system is achieved through:

1. Power consumed by the selected luminaire.
2. Number of luminaires and their locations.

26.4 Materials and Methods

26.4.1 Procedure

The exiting lighting system for each space of the house is first calculated. The DIALux software is then run for each space of the house. For each space, the redesigning of the lighting system is tested with different luminars. The redesigning of the lighting system is repeated until obtaining the lighting system that complies with allowable LPD value and at the same time fulfilling the recommended illuminance level for that space. Therefore, the following two points are taken into account when higher efficient lighting systems and lower energy cost are required:

- Increasing the lux level to reach the required standards.
- Reducing energy consumption for the lighting system that complies with allowed LPD value.

For example, in the case of dining rooms, the DIALux software is run with the target of 200 lx (i.e., recommended lighting intensity for dining rooms). The redesigning of the system will be examined with different luminars until the lighting system that complies with allowed LPD value for the dining room (1.105 W/m^2) is obtained and at the same time fulfilling the recommended lighting requirement for the space (200 lx).

26.4.2 Description of the Test House

The test house under consideration is a two-story building that was constructed in 1986. The ground level consists of a kitchen, dining room, bathroom, store and a living room. The top level contains three bed rooms and two bathrooms. The floor plan of ground floor is shown in Fig. 26.1, whereas the floor plan of first floor is shown in Fig. 26.2. Although the building includes car parking area, bathrooms and staircase area where the lighting equipments are installed, they were not considered in the redesigning effort since residents do not stay in them for a prolonged time. The area of each spaces considered in this chapter is calculated and shown in Table 26.1.

26.5 Results

The existing lighting system throughout the house generally consists of tungsten tube luminaires of 60 W rating (Table 26.2). The on/off switching is operated manually from wall-mounted switches in each room. The existing lighting power densities (LPD) for each space in the house under consideration are calculated and shown in Table 26.2. It can be seen that the kitchen is lit by luminaires with two 60 W tungsten lamps and by luminaires with 2 ft fluorescent lamps, each consumes 10 W. The total power consumption is 140 W.

In the living room, there are 3 luminaries. They are tungsten bulb type, each consumes 60 W. The total power consumption is 180 W. In the dining room, there are 2 luminaries. They are tungsten bulb type, each consumes 60 W. The total power consumption is 120 W.

The existing lighting system of the 3 bed rooms is similar to that of the dining room. The existing total lighting loads of all spaces of the house are 800 W. The LPD (Watt/ft^2) for each room/space was calculated based on the total area of the space and total power consumption.

Working on a green building project from lighting perspective also needs the compliance of standards. According to ASHRAE/IESNA Standard 90.1-2004 a complete, hardwired lighting system, to be efficient, should be installed with the lighting power density (LPD) requirements shown in Table 26.3. Comparison of the calculated LPD with the LPD allowance for the various spaces of the house is also given in Table 26.3. Looking at Table 26.3, it can be seen that the existing LPD values for kitchen, dining and living rooms are less than the allowable LPD. However, the house residents expressed the feeling that the light intensity in these spaces is not adequate. Hence, the lighting systems do not fill the spaces lux requirement.

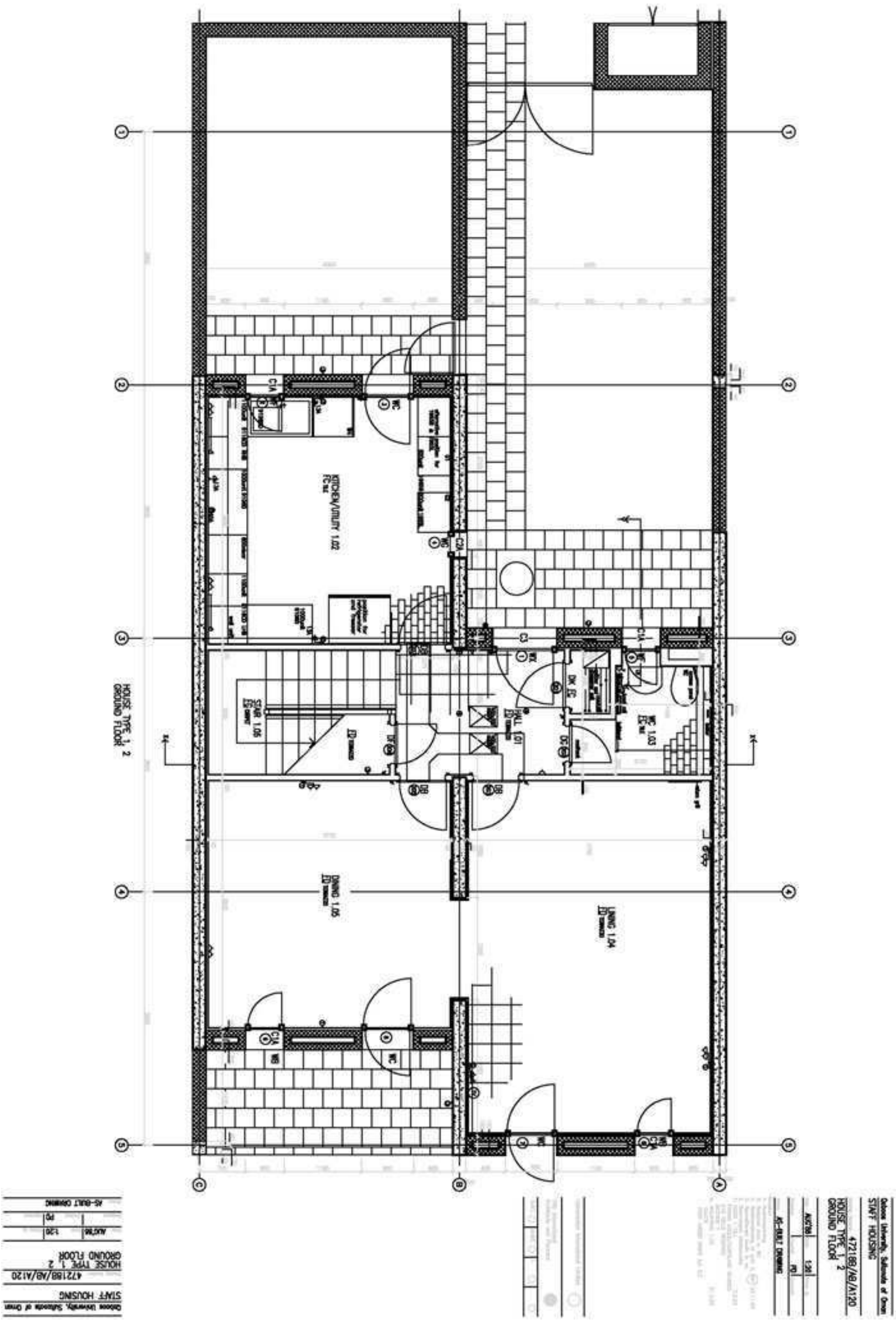


Fig. 26.1 Floor plan of ground floor

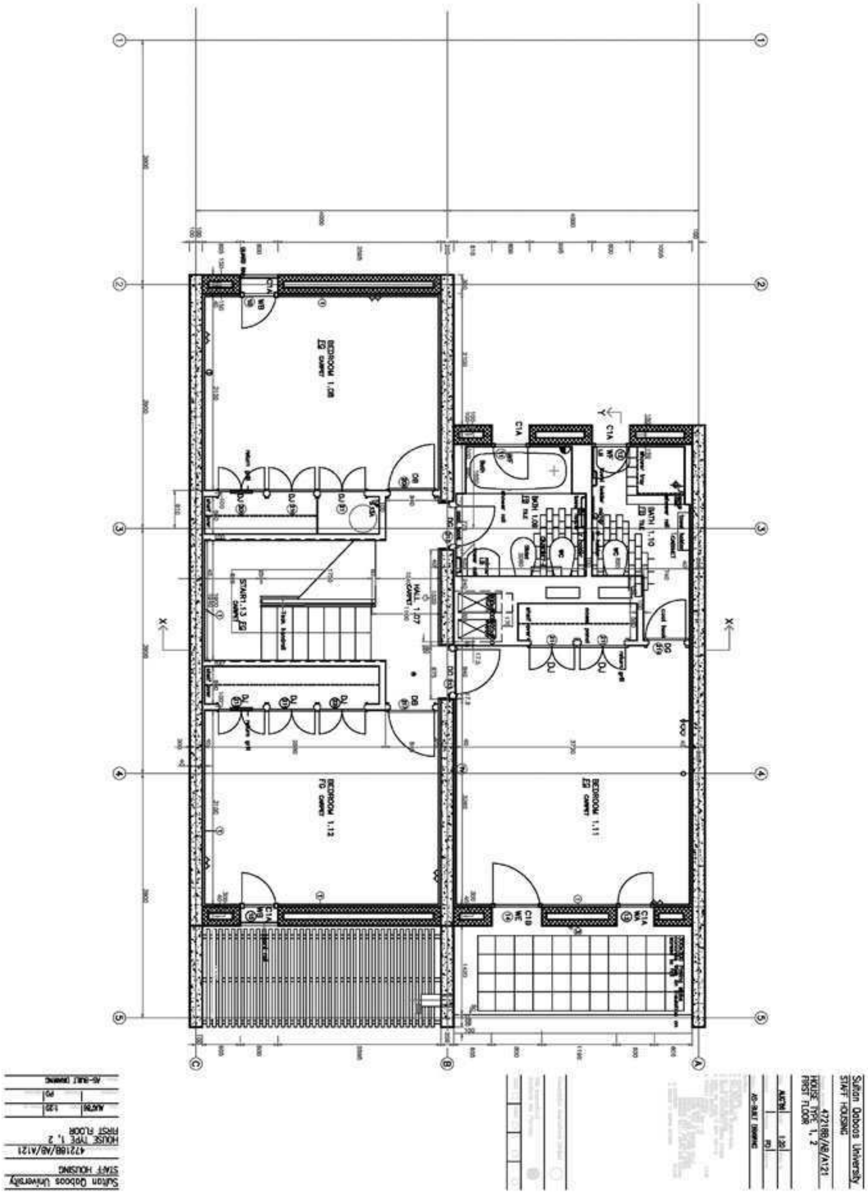


Fig. 26.2 Floor plan of first floor

As for the three bedrooms, the calculated LPD is greater than the LPD allowance. Thus, the lighting systems for all the spaces of the house required to be redesigned. The redesigned system should not only fulfill the Lux requirements for each space but also operate under the allowed LPD limits. Redesigning includes the

Table 26.1 Area of the various spaces of the house

No.	Space	Dimensions	Area
1.	Kitchen	3.80 m × 3.72 m	14.136 m^2 (152.2 ft^2)
2.	Dining room	3.80 m × 3.72 m	14.136 m^2 (152.2 ft^2)
3.	Living room	3.72 m × 5.52 m	20.534 m^2 (221.03 ft^2)
4.	Bed room (1.08)	3.10 m × 3.72 m	11.532 m^2 (124.13 ft^2)
5.	Bed room (1.12)	3.10 m × 3.72 m	11.532 m^2 (124.13 ft^2)
6.	Master bed room	3.72 m × 4.105 m	15.27 m^2 (164.37 ft^2)

Height of each space is 2.81 m

Table 26.2 Type of existing luminaire together with the calculation of the existing lighting power density

No.	Space	No. of luminaire	Type of luminaire	Total power consumption W	Area of space ft^2	LPD[a] (Calculated) W/ft^2
1.	Kitchen	4	2 Tungsten bulb type, each consumes 60 W 2 one feet fluorescent tube lamps, Each consumes 10 W	140	152.2	0.92
2.	Dining room	2	2 Tungsten bulb type, each consumes 60 W	120	152.2	0.79
3.	Living room	3	They are tungsten bulb type each consumes 60 W	180	221.03	0.81
4.	Bed room (1.08)	2	They are tungsten bulb type each consumes 60 W	120	124.13	0.97
5.	Bed room (1.12)	2	They are tungsten bulb type each consumes 60 W	120	124.13	0.97
6.	Master bed room	2	They are tungsten bulb type each consumes 60 W	120	164.37	0.73
	Total lighting load			800		

LPD[a] is the lighting power density = (Total power consumption/Area of the space)

consideration of better luminary and its right placement so that required lighting level could be achieved with minimum number of luminaries. To this effect, the DIALux software is used to redesign the lighting system according to the recommended lighting intensity (LUX). The recommended lighting intensity values depend on the type of the space as shown in Table 26.3.

When redesigning the lighting system for the spaces of the house, the first question to be addressed is "What lighting levels are needed?". Luminous flux of a light

Table 26.3 Comparison of the calculated LPD with the LPD allowance for the various spaces of the house

No.	Space	Calculated LPD W/ft^2	Allowable LPD (before reduction) W/ft^2	Allowable LPD (after 15% reduction)[c] W/ft^2
1.	Kitchen	0.92	2.0[a]	1.7
2.	Dining room	0.79	1.3[a]	1.105
3.	Living room	0.81	1.09[b]	1.1
4.	Bed room (1.08)	0.97	0.5[b]	0.5
5.	Bed room (1.12)	0.97	0.5[b]	0.5
6.	Master bed room	0.73	0.5[b]	0.5

[a]Values are taken from: http://nyserda.org/sclp2/technicalguide/design/targets.asp
[b]Values are taken from: http://lpd.ies.org/cgi-bin/lpd/lpdhome.pl or http://lpd.ies.org/cgi-bin/lpd/ShowSpaceTypes.pl
[c]This reduction is used for the optimization of energy performance for lighting power

Table 26.4 Allowable LPD with the recommended LUX levels for the various spaces of the house

No.	Space	Allowable LPD (after 15% reduction) W/ft^2	Recommended LUX levels[a] lumens/ft^2 or lx
1.	Kitchen	1.7	500, 300 (gen)
2.	Dining room	1.105	200
3.	Living room	1.1	500, 100 (gen)
4.	Bed room (1.08)	0.5	50
5.	Bed room (1.12)	0.5	50
6.	Master bed room	0.5	50

[a]Boer and Fischer (1978)

source incident per unit area of a surface and measured in Lux (lx) is referred to as Lighting Level. The recommended lighting levels (lx) with respect to space types are shown in Table 26.4. These values were given in the IESNA Handbook and in many other lighting books.

The change in LPD values requires redesigning of the lighting system of each space. Redesigning includes the consideration of better luminary and its right placement so that required lighting level could be achieved with minimum number of luminaries. Each space of the building is considered and redesigned separately. The results of the redesigning by using the DIALux software are shown in Table 26.5.

It can be seen that the redesigning reduced the LPD values as required in compliance with the ASHRAE Standard. Based on these results, a comparison of the redesigned LPD and he existing LPD resulted in the reduction of lighting power consumption by 34.15% (526.5 W compared to 800 W). Details of the reduction

Table 26.5 Results of the DIALux software

No.	Space	Total pieces	Designation	Power per piece W	Total power W	Designed LPD W/ft^2
1.	Kitchen Area = 152.2 ft^2	7	2 Philips centura 2 TCS160 1xTL-D58W/840 CON L1 (1.000) 4 Philips eW cove powercore BCX410 1x5-LED-HB/NW-4200 (1.000) 1 Philips X-tendolight TCS398 SI 1xTL-D36W/840 CON M2-A (1.000)	66.5 4.5 42.5	193.5	1.27
2.	Dining room Area = 152.2 ft^2	4	Philips arano TWS640 1xTL5-24 W/840 HF AC-MLO (1.000)	28.0	112.0	0.74
3.	Living room Area = 221.03 ft^2	2	Philips centura 2 TCS160 1xTL-D36W/840 CON L1 (1.000)	42.5	85.0	0.38
4.	Bed room (1.08) Area = 124.13 ft^2	1	Philips finess TCS198 1xTL-D36W/840 CON L1 (1.000)	42.5	42.5	0.34
5.	Bed room (1.12) Area = 124.13 ft^2	1	Philips finess TCS198 1xTL-D36W/840 CON L1 (1.000)	42.5	42.5	0.34
6.	Master bed room Area = 164.37 ft^2	2	Philips X-tendolight TCS398 WH 1xTL-D18W/840 CON L1 (1.000)	25.5	51.0	0.31
	Designed total power consumption				526.5	

Table 26.6 Comparison between the existing LPD and designed LPD together with the allowable LPD and designed lux

No.	Space	Existing LPD W/ft^2	Designed LPD W/ft^2	Allowable LPD (after 15% reduction) W/ft^2	Designed lux
1.	Kitchen	0.92	1.27	1.7	500
2.	Dining room	0.79	0.74	1.105	200
3.	Living room	0.81	0.38	1.1	100
4.	Bed room (1.08)	0.97	0.34	0.5	50
5.	Bed room (1.12)	0.97	0.34	0.5	50
6.	Master bed room	0.73	0.31	0.5	50

in LPD values for each of the spaces are shown in Table 26.6. Comparison is also made with the allowable LPD and the designed lux values.

LPD and lux values for each of the individual rooms were obtained as follows:

1. Kitchen: Seven pieces were used with a total power of 193.5 W (Table 26.5). They produced a designed LPD of 1.27 W/ft^2 which is lower than allowable LPD (1.7 W/ft^2). The associated design lux is 500.
2. Dining room: Four pieces were used with a total power of 112.0 W (Table 26.5). They produced a designed LPD of 0.74 W/ft^2 which is lower than allowable LPD (1.105 W/ft^2). The associated design lux is 200.
3. Living room: Two pieces were used with a total power of 85.0 W (Table 26.5). They produced a designed LPD of 0.38 W/ft^2 which is lower than allowable LPD (1.1 W/ft^2). The associated design lux is 100.
4. Bed rooms (1.08 and 1.12): For each bedroom, one piece was used with a total power of 42.5 W (Table 26.5). It produced a designed LPD of 0.34 W/ft^2 for each room which is lower than allowable LPD (0.5 W/ft^2). The associated design lux is 50 for each bedroom.
5. Master bed room: Two pieces were used with a total power of 51.0 W (Table 26.5). It produced a designed LPD of 0.31 W/ft^2 which is lower than allowable LPD (0.5 W/ft^2). The associated design lux is 50.

The IsoLux maps for each space are given in Figs. 26.3-26.7. The red element shown in these figures shows the lighting equipment position. The gradients with different numbers along them represents the IsoLux lines along which the value of Lux is constant but the lux values changes as we move to another line. The numbers along the lines outside the space is the scale representing the dimensions of the room. The scale is read in meters.

Figure 26.3 shows the Isolux map for kitchen. For kitchen, it was required to maintain the value of 500 lx. Although the lux values are not 500 throughout the space, it was tried to maintain the required Lux in the working region (i.e., in the center region) where main kitchen related activities are performed.

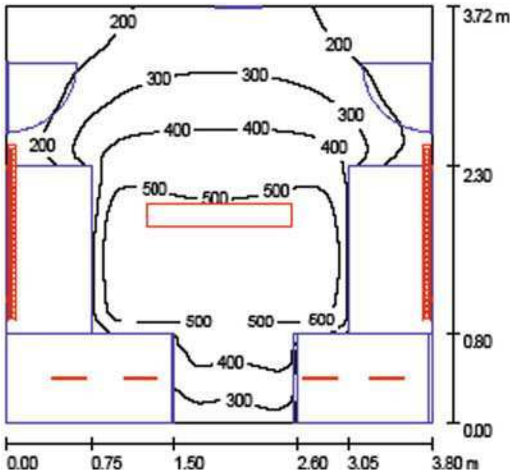


Fig. 26.3 Isolux lines for kitchen

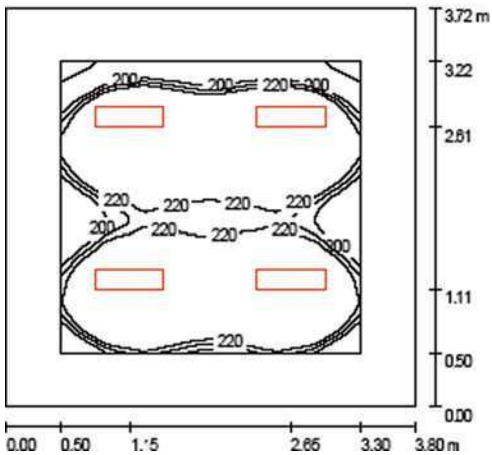


Fig. 26.4 Isolux lines for dining room

Figure 26.4 shows the isolux map for dining room. In this space, the working area is limited by setting its boundary 0.5 m away from the walls. This was done because the working area in this room is the area over the dining table which centered over the room floor. In this room, it was required to maintain 200 lx. It can be seen from the map that the required working area is maintaining the required Lux value.

Figure 26.5 illustrates the isolux map for living room. For living room there are two requirements for Lux values: 100 lx and 500 lx. The selection of the required value depends on the use of the space. For example, if the living room is being used for just sitting and resting purpose, then 100 lx is enough. On the other hand, if the living room is used as studying, then the value of 500 lx should be maintained. In the

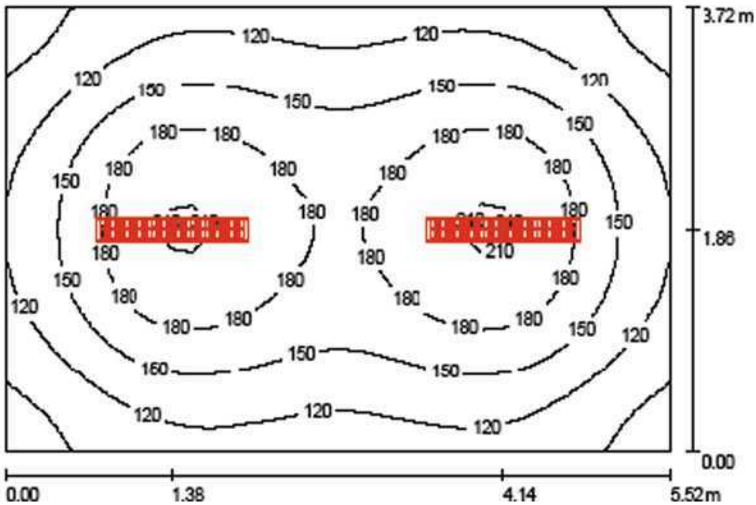
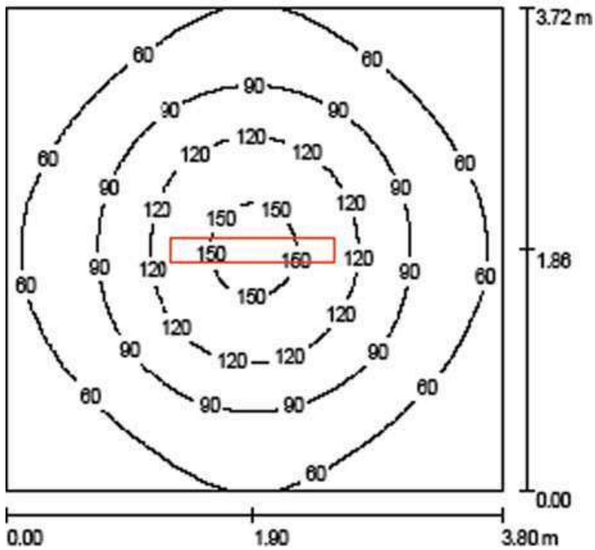


Fig. 26.5 Isolux lines for living room

Fig. 26.6 Isolux lines for bed room 1.05 and 1.02



studied house, the living room is used for just sitting. Looking at Fig. 26.5, it can be observed from the map that the maintained lux value is greater than the required value while being in the allowed LPD value (100 lx).

Figures 26.6 and 26.7 represent the isolux maps for the three bed rooms. The two bed rooms 1.05 and 1.02 are same in size therefore the lighting system design for

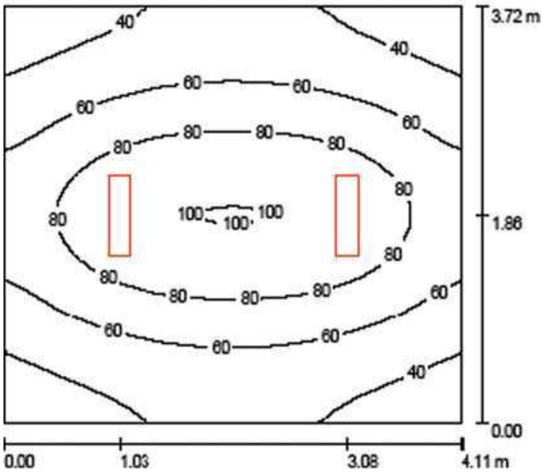


Fig. 26.7 Isolux lines for master bed room

the two is exactly the same (Fig. 26.6). Bed room 1.11 is a little larger in size so its lighting system design is different (Fig. 26.7). However, the requirement of Lux values and the allowed LPD values for all the three bed rooms are same because of being of the same type. The required Lux value here is 50 lx. It can be seen that this value is maintained in all the bed rooms while being in the allowed LPD values.

26.6 Conclusions

The study was undertaken to assess the design and actual performance of lightening in a typical house in Muscat. The study also aimed at attempting to increase the lighting quality and to decrease the electricity consumption in an existing residential house at the campus of Sultan Qaboos University. It has been shown that existing lighting system of the spaces of the house may be redesigned with the help of DIALux lighting program.

In this case, improvements were made to the luminaires themselves which had resulted not only in better lighting quality but also in reduced electricity consumption. Power consumption was 800 W for the existing lighting system. The improvements resulted in considerable savings in the electricity used for lighting purposes. The power consumption for the proposed lighting system is 526.5 W, which represents a power reduction of almost 34% in lighting. Other than energy saving, improvement in the lux illumination level is also achieved.

Verification of the results of modeling and testing the accuracy of the model is required. This can be carried out by actual installation of equipment and measurement of the lux values.

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Chapter 27
Passive Methods to Address the Sick Building Syndrome in Public Buildings

José A. Orosa and Armando C. Oliveira

27.1 Introduction

The sick building syndrome (SBS) was originally defined by the World Health Organization (WHO 1989) as the occurrence of an increased prevalence of non-specific symptoms among populations in determined buildings (Thörn 1998).

Some of the common symptoms are eye, nose and throat irritation; mental fatigue; headaches; nausea; dizziness and skin irritation; lethargy; irritability; and lack of concentration, which appear to be linked with the occupancy of certain workplaces (Hedge et al. 1996; Raw et al. 1996; Gupta et al. 2007).

It is difficult to detect SBS, as its exact definition depends on the method used to determine it (Raw et al. 1996). While the usual medical syndrome constitutes a group of signs and symptoms which present a "clinical picture of diseases" in individuals, the SBS is considered to occur when one or more common, non-specific symptoms, are present at a prevalence that exceeds the normal prevalence expected in the population of a building. Therefore, proposed individual diagnostic procedures are vague, and there is no consensus on what may or may not constitute a sick building.

It appears that the main criteria for diagnosis are the exclusion of other conditions together with the improvement of symptoms when the patient is temporarily removed from the workplace (Thörn 1998).

Once SBS is diagnosed for an indoor ambience, one must detect its causes and try to correct the syndrome. It is important to recognize that SBS is based on prevalence data which describe symptom patterns at the level of the building and not necessarily at the level of the individual (Hedge et al. 1996).

In particular, parameters such as fleece factor, air temperature, total suspended particles, job stress, mechanical ventilation, illumination (James and Bahaj 2005), dust and noise were analysed and related with SBS symptoms (Thörn 1998).

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DOI 10.1007/978-3-642-17919-8_27,

Finally, if the symptoms of SBS appear at work and disappear when away from work, then it is important to analyse all these parameters at the workplace.

After discussing the conclusions of recent research works on SBS, the main parameters that are typically analysed to address the SBS will be summarised. These parameters were classified into objective and subjective parameters. In particular, importance will be given to building internal coverings as a tool for reducing mechanical ventilation control, the presence of VOCs and for controlling indoor air relative humidity and, finally, to the perception of indoor air quality.

27.2 Objective Parameters

Recently, a large number of studies have attempted to relate the SBS symptoms to measurable parameters of indoor air, such as temperature and relative humidity. The objective of these studies was to control these parameters to prevent the symptoms.

However, before analysing their conclusions, some questions have to be answered. For example, should we employ natural or mechanical ventilation for preventing SBS? Further, if SBS is detected, should we control the indoor ambiences or correct the heating, ventilating and air conditioning system (HVAC)? The answers to these questions are presented in the following sections.

27.2.1 Should We Employ Natural or Mechanical Ventilation?

To answer this question, some recent studies were analysed (De Magalhaes et al. 2009). In these studies, defective ventilation was considered to be responsible for the symptom prevalence, and it was corrected without effect (Thörn 1998).

In particular, researchers showed that symptoms were more prevalent among those workers who occupied air-conditioned buildings than among those in naturally ventilated buildings. For example, in De Magalhaes et al. (2009), a higher prevalence of work-related upper respiratory symptoms and tiredness was observed in a sealed building with HVAC system than in a naturally ventilated building.

From this research, it can be concluded that the air passes through several potential sources of contamination (ducts, humidifier, chiller, etc.) in air-conditioned buildings and this might be the reason for higher prevalence of symptoms, whereas in naturally ventilated buildings, ventilation depends solely on operable windows and doors (Hedge et al. 1996). Therefore, one can conclude that preference should be given to the construction of naturally ventilated buildings and, when this is not possible, the use of HVAC systems must be minimized.

27.2.2 How to Detect SBS?

To detect the SBS, one may employ objective or subjective methods. The values of several physical environmental parameters (such as air temperature, globe temperature, air velocity, carbon monoxide and ozone concentration) measured using objective methods failed to show any significant relationship with SBS (Hedge et al. 1996).

Despite a linear relationship between CO_2 concentration and SBS (Gupta et al. 2007), it does not necessarily imply that CO_2 is the only influencing parameter affecting the SBS score in a building. However, CO_2 acts as an indicator or marker, which likely indicates the presence of indoor air pollutants. The concentration of CO_2 in a building may lie within ASHRAE standard limits, but the occupants may still complain about symptoms of SBS.

Even though objective detection can be measured in an automatic way, subjective detection methods were found to present better results. These methods are based on the information reported by the occupants themselves, such as SBS health symptoms (WHO 1989); therefore, the reports by occupants were found to cover a greater number of parameters.

27.2.3 Corrective Parameters: HVAC System or Building Design?

As shown before, buildings with mechanical ventilation show a higher prevalence of SBS symptoms than natural ventilated ones, and the methods for detection are defined. Next, we must define an effective way for detecting and preventing SBS symptoms.

Hence, HVAC parameters were analysed with respect to the presence of SBS symptoms (Kolari et al. 2005), and importance was given to duct cleaning and the percentage of fresh air. For example, it was noticed that air duct cleaning did not have a significant effect on measured air quality. The most significant improvement in work environment factors due to duct cleaning was related to stuffy "bad" air and work-related nasal symptoms. Strong and significant correlation was found between dust deposition and the prevalence of nasal symptoms before duct cleaning.

After duct cleaning, the prevalence of the nasal symptoms was found to be lowered (Kolari et al. 2005). Furthermore, despite the fact that non-problematic office buildings were analysed in this case study, the particle mass concentration, TVOC, CO_2 and fungal spore concentrations were clearly below stipulated values, both before and after duct cleaning and re-balancing of the ventilation system.

Another parameter that must be analysed is the percentage of fresh air that enters the building. One must remember that the main purpose of the ventilation system is to deliver fresh supply air to spaces occupied inside the building and guarantee a high quality of indoor air in modern buildings.

In this sense, previous studies have reported a decrease in dust deposition and microbial count in inner duct surfaces, as well as the total concentration of volatile organic compounds (TVOC) (Kolari et al. 2005). As a consequence of this ventilation, the air movement during ventilation was considered to be an important factor for measuring the indoor air quality (Haghighat and Donnini 1999). The higher the perceived air movement, the greater is the satisfaction with indoor air quality (IAQ).

The last factor related with ventilation is the study of pollution sources that must be removed to improve the perceived air quality in the building, which is polluted by building materials and also building materials plus bio-effluents, because the chemical and sensory pollution loads in the buildings were reduced.

Recent research works (Wargocki et al. 2002) showed that the improvement in air quality obtained by reducing the pollution load by 2–2.5 times was similar to that obtained by increasing outdoor air supply rate by three times.

For example, in Assimakopoulos and Helmis (2004), by following certain activities in the building e.g. cleaning, improving ventilation conditions, restriction of smoking, pollutant concentrations dramatically dropped in all areas; furthermore, the employees did not complain of any sick building symptoms.

After analysing the objective parameters and its corrective methods, it should be noted that SBS is still an unsolved problem; the suspected objective cause factors were encountered only in 25% of the cases (Hedge et al. 1996), and often SBS health problems continue to remain even when the suspected factors have been removed.

Thus, it may be concluded that the SBS is not only related with objective parameters but also with subjective parameters such as job satisfaction and perception of IAQ, which will be analysed in the next section.

27.3 Subjective Parameters

27.3.1 Job Stress

Although research studies repeatedly showed that SBS symptoms are more prevalent among workers in air-conditioned offices than among those in naturally ventilated offices, most of these studies also found stronger associations between a variety of organizational, occupational, and personal variables and symptoms, than between these parameters and environmental conditions (Hedge et al. 1996).

This study is a clear example of the fact that subjective parameters significantly influence the occurrence of SBS symptoms, especially at the workplace. Furthermore, in previous studies, it was concluded that parameters such as type of job can influence the SBS perception.

For example, workers who used their computers for 6 or more hours reported more SBS symptoms than non-users (Gupta et al. 2007). From these results, it may be concluded that each SBS perception must consider the subjective parameters, particularly the type of job.

27.3.2 Perception of IAQ

Recently, it has been observed that the occupants usually self-reported SBS health symptoms; therefore, these reports can be employed as a tool to detect the SBS. For example, in the case of the Athens Air Traffic Control Tower (ATCT), sick syndrome episodes were reported by the employees (Assimakopoulos and Helmis 2004).

These symptoms, expressed as job satisfaction, were positively related with office air quality, ventilation, work area temperature, and ratings of work area environment in recent research studies (Haghighat and Donnini 1999).

Another way to express this relationship is by means of the workers' productivity. In recent studies, workers were asked to indicate the extent to which their work was disrupted by each of the environmental conditions and SBS symptoms.

Results showed that inappropriate thermal conditions, both too warm and too cold, inadequate ventilation, specially a lack of perceived air movement and sensation of stale air, distracting noise, and glaring/lighting, highly disrupted the work (Hedge et al. 1996).

In general, all these results suggest that SBS is not a simple environmentally-induced disorder that is caused by exposure to air polluted by combustion gases, volatile organic compounds, dust and particulates, or simply poor ambient conditions.

27.3.3 Control of Subjective Parameters by Questionnaire

On the basis of the previous results, it was concluded that using questionnaires is an effective method to detect and control subjective parameters. These questionnaires must consider the objective parameters such as indoor air temperature and subjective parameters such as job stress. Furthermore, this is the only tool that effectively quantifies the subjective situation of each occupant.

Recent studies reported the following elements of SBS questionnaire design:

1. The layout of the questions related to symptoms.
2. The wording used to establish whether the symptoms are building related.
3. Small differences in the symptoms listed on the questionnaire and the description of these symptoms;
4. The frequency scale used to record the occurrence of symptoms and discomfort (Raw et al. 1996)

These research works concluded that a questionnaire using separate questions to report building-related symptoms is a better method of collecting symptom data than a questionnaire using a response table (Raw et al. 1996).

Another conclusion obtained was that two-thirds of the questions can also become redundant within the separate questions format, which will make answering easier and quicker for those with few symptoms, allowing plenty of space to report those symptoms that occur. Note that the same questionnaires were employed in the previous studies with adequate results, for example, the MM-40-FIN questionnaire that assesses the perceived indoor environment and work-related symptoms before and after duct cleaning.

Finally, in this type of questionnaires, some indices called Percentage of Dissatisfied persons with local thermal comfort (PD) and indoor air acceptability (Acc) were employed.

These indices were employed (Simonson and Salonvaara 2000) for defining the effect of materials on controlling indoor air temperature and relative humidity. These indices were employed to define the effect of permeable coverings in public buildings, which will be discussed in the following sections.

27.4 Permeable Coverings as a Realistic Solution

At this point of SBS analysis, we are ready to understand the future tendencies in SBS prevention based on building design. In particular, it is well known that in many cases, the main reasons for SBS is the inappropriate envelope design, the misuse of the building by the inhabitants and the combination of indoor–outdoor pollution sources (Assimakopoulos and Helmis 2004).

Recent studies (Orosa and Baaliña 2008; 2009; Orosa and Oliveira 2009a) showed the feasibility of permeable internal coverings for reducing the need of mechanical ventilation and for controlling indoor ambience.

These passive methods are gaining popularity, because they are energy conscious and environmentally friendly. However, there is very little published data on mass transfer between building envelopes and indoor air. Furthermore, permeable coverings can improve the subjective perception of an indoor ambience by controlling some objective parameters such as indoor air relative humidity and temperature, improving the reduction of SBS symptoms. They also have positive consequences, like energy savings. All these relationships will be analysed next.

27.4.1 The Public Building

To study permeable coverings as a possible solution for SBS, 25 typical Spanish office buildings were monitored during 1 year. All the offices have the same internal activity and periods of work, which began a few minutes before 9:00 and finished at 14:00, in the summer and winter seasons.

Their wall structure is the same (Fig. 27.1); it comprises an external covering of marble, concrete, brick, air barrier, polystyrene, brick, concrete, as well as one internal covering. The only difference is that the internal covering has been experimentally classified into three different groups, according to their permeability level: permeable, semi-permeable and impermeable coverings. Permeable coverings are made of materials such as paper or plaster; semi-permeable coverings are made of wood or plastic; and impermeable coverings are mainly made of glass.

These coverings have been selected because they are found in abundance in each office building, despite that fact that other materials are present in that environment.

All offices have two clearly differentiated zones: the workers' zone and the clients' zone. The workers' zone is the region where employees serve the clients located in the clients' zone, and both these zones are separated by a safety glass (Fig. 27.2).

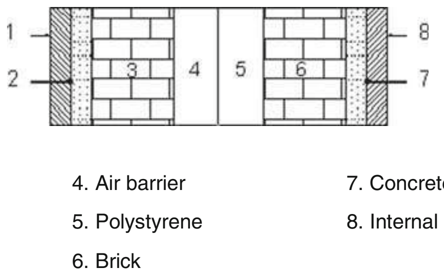

Fig. 27.1 Wall structure

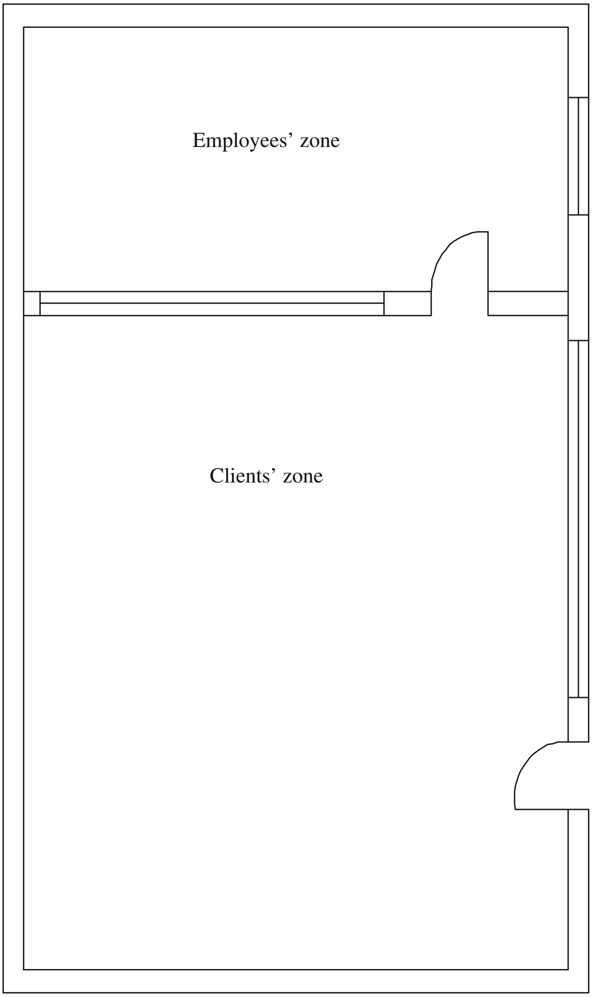

Fig. 27.2 Offices' zones

27.4.2 Objective Parameters Controlled by Permeable Coverings

27.4.2.1 Control of Indoor Air Relative Humidity

The main objective of the first study was to show the effect of internal wall coatings on indoor air conditions by means of indoor air parameters. Measurements were taken from the 25 office buildings during different seasons of the year, with a time frequency of 10 min for each variable of temperature and relative humidity.

To analyse the data, a One Way Anova statistical method was applied (Orosa and Oliveira 2009a) to define the moisture-buffering capacity of permeable coverings during the unoccupied period.

Results showed that in offices with permeable coverings, the indoor partial vapour pressure is higher during winter and lower during the summer. These offices have the most permeable internal coverings, which are similar to paper, and allow humidity to pass through the building structure.

An opposite behaviour was found in impermeable offices, where indoor partial vapour pressure was higher during the summer and lower during the winter. In summary, one may confirm that permeable coverings tend to decrease and increase partial vapour pressure in summer and winter seasons, respectively.

Permeable coverings increased the partial vapour pressure, thereby improving environment acceptability and local thermal comfort for the first few hours of occupation, despite using an air barrier and less permeable coverings than other authors. Therefore, permeable coverings have been proved to be a real solution as a passive control method; they are also energy saving, as discussed next.

In the same study, it was demonstrated that permeable coverings improve indoor conditions even if an air barrier and less permeable coverings such as wood are used.

It was also confirmed that during a long-term study, internal permeable coverings maintain their regulatory property, as a result of the existence of more than 4 h of excessive indoor humidity before the studied period.

Finally, these results confirm the studies of Simonson and Tuomo (2000), but this effect is extended for more than 2 weeks after a change in weather conditions.

27.4.2.2 Control of Indoor Ambience: Control of VOCs

Recently, an airtight envelope has become popular in the design of office buildings. It is used for reducing the heating and cooling loads. Maintaining an adequate IAQ for such airtight buildings totally depends on mechanical ventilation systems (Gupta et al. 2007).

Despite this, further analyses of the results showed that the central ventilation system is not sufficient for the building needs; as a result, in some areas VOC pollution sources were developed, either because of cleaning negligence or because of the type of construction material used (Assimakopoulos and Helmis 2004).

The reduction in peak concentrations of formaldehyde and VOCs in indoor air, when the sources of these compounds are within the room, depends not only on emission and ventilation rates, but also on sorption/desorption rates to/from the surfaces of the rooms (Seo et al. 2009).

During the periods of building occupation, when the temperature is higher, the emission of VOCs from materials is favoured. In addition, it is possible to wait for a regulating effect of permeable coverings on VOCs, so that they are adsorbed during the occupied period and released when the air is cleaner, thereby allowing an improved quality of indoor air.

With the objective of quantifying this effect, a few studies have examined measurements related to the reduction in concentration of VOCs, such as toluene using activated carbon. Their results have demonstrated that sorptive building materials are fairly effective in reducing VOC concentration in rooms, an effect that can be expected in practice (Seo et al. 2009).

In these studies, the sorption saturation value and/or lifetime of the sorption capability of sorptive building materials were investigated.

Results showed that they have a long-lasting VOC-reduction performance; therefore, these materials are an interesting tool to control indoor air quality with energy savings.

27.4.3 Subjective Parameters Controlled by Permeable Coverings

Some recent studies have concluded that symptoms were more prevalent among workers occupying air-conditioned buildings than in naturally ventilated buildings.

In studies in mechanically ventilated buildings (Cheong et al. 2006), an extensive investigation of Perception of Indoor Air quality (PAQ) and SBS, with a displacement ventilation (DV) system in the tropics, has been conducted. The results demonstrated that thermal gradient had an insignificant impact on PAQ, SBS and their corresponding PDs.

Despite this, the data showed reports of thermal problems, especially under extremely warm conditions, which were the most common components of perception of poor indoor air quality. Furthermore, it was found that dry air sensation, irritations and freshness decreased with an increase of the room air temperature. One possible reason is that average values of absolute humidity and enthalpy at breathing level increased with the room air temperature (Cheong et al. 2006).

On the other hand, despite the fact that odour intensity and PD were insignificantly affected by room air temperature, it was found that PD and some complementary parameters, such as dry air sensation and irritations, decreased with an increase in the room air temperature.

The opposite effect was obtained in the case of air freshness. Air freshness decreased with an increase in the room temperature; therefore, if the air temperature is low, the air inside the room is considered to be fresh (Cheong et al. 2006).

Considering previous studies (Simonson and Tuomo 2000; Orosa and Baaliña 2008), moist air indices were employed for evaluating the expected percentage of dissatisfied and the indoor air acceptability (Orosa and Baaliña 2009). Once the daily evolution of these two indices was obtained, it was possible to conduct a deeper analysis of the effect of permeable coverings on indoor ambience, and define the main periods of the day during which coverings present a higher activity.

Results showed that indoor coverings exert an influence on the indoor environment and PAQ for a long-term, and that it is especially important during the last hours of unoccupation periods, the consequences of which can be appreciated in indoor air acceptability and the percentage of dissatisfaction during the first hours of occupation.

On the other hand, when analysing the influence of humidity on acceptability, it was concluded that it is higher than thermal parameters' influence. This effect on indoor air acceptability was especially high in summer mornings; thus PD_{IAQ} in offices with permeable coverings showed 25% of dissatisfaction. In winter, this effect was reduced, because of low indoor temperatures in all offices.

27.4.4 Energy Savings

As a continuation of previous studies, the possibility of energy savings was analysed. In Orosa and Oliveira (2009a,b), the energy savings of internal permeable coverings, due to the reduction in ventilation needs, was quantified, particularly regarding the peaks of consumption during the first hours of occupation. Energy savings were observed when the air change rate was analysed. The results showed that the sorption of water vapour in the porous envelope has a greater effect on indoor humidity than ventilating the room with 0.5 ach. This result complements the previous research on estimating the effect of hygroscopic materials on energy consumption in buildings.

These works showed the possibility of reducing the heating and cooling energy consumption while using hygroscopic materials along with well-controlled HVAC systems. Using permeable coverings is an energy advantage, because these materials allow achieving better indoor conditions during the first hours of occupation, which is interesting with regard to the reduction in energy consumption peaks during the morning (Orosa and Oliveira 2009b).

27.5 Conclusions and Future Research Work

Further studies must be conducted to investigate the real effect of building materials on indoor air quality, thermal comfort and energy savings, and also on how to implement or substitute the current HVAC systems with this type of passive method.

Above all, it is necessary to identify one method for selecting the value of materials' properties (constants), the active (effective) thickness and the internal covering to achieve the best indoor conditions with the least maintenance.

These results confirm the studies of Toftum et al. (1998) and allow, with a more intelligent design, energy savings in indoor air renovation, especially during the initial hours of indoor occupancy.

To attain this objective, new techniques (Ellis and Mathews 2002), such as computer design tools, should be developed in close co-operation with building designers. In general, the requirements for new design tools are as follows:

- The tool should be simple and easy to use.
- It should provide default values for unknown variables.
- Time required to learn and use the software must be as short as possible.
- Output should be simple yet informative.
- It should use a language familiar to designers.
- The tool must be verified and tested by designers.
- New tools should make provision for easy data transfer between different design tools.

Adequate software will allow, with a more intelligent design, the saving of energy in indoor air renovation. Furthermore, these software tools must consider parameters such as the adaptive opportunities on thermal comfort responses and the effect of internal coverings on other climatic regions.

Finally, software tools also help in preventing future SBS problems. New techniques must be analysed; for example, a porous hedge in front of the building (Chang 2006; Seo et al. 2009) or occupant's concienciation about effect of habits on indoor ambiences.

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Chapter 28
Ventilation and the Air Ion Effect in the Indoor Building Environments: Impact on Human Health and Wellbeing

Milos Nedved

28.1 The Air Ion Effect and Its Applications – An Overview

Why are modern, well equipped hospitals still plagued with the range of cross infection? How do killer viruses like Legionnaires' disease spread, undetected, through air-conditioning systems to meticulously clean wards?

The cause is clear and the remedy simple. The spread of Legionnaires' disease and other forms of infection can be traced directly to a lack of negative ions in the atmosphere.

Tests have shown that a negative ion depleted atmosphere is a breeding ground for bacteria. Increasing the concentration of negative ions would stop germs from travelling and create a semi-sterile environment. This could be done quickly and cheaply, by placing negative ion generator in any air conditioning system.

The problem was the same in many offices and factories. Even some of the symptoms attributed to the extended use of computer screens were in reality the fault of the working environment atmosphere.

Ions are particles of air that have either a positive or negative electrical charge. In natural environments they are produced to maintain a healthy ratio but in an artificial environment of air conditioning, electrical equipment, fluorescent lighting and even synthetic clothing the balance can be seriously affected. Each re circulation of air through the air conditioning system reduces the concentration of negative ions.

Negative ions present in air are, most frequently: CO_3^-, O_2^- or O_2^- $(H_2O)_n$, where each of them carrying one negative charge (–). Positive ions are usually present in the form of N_2^+.

The factors having a major influence on air ion indoor levels are:

- ducted air conditioning (refrigerated)
- static electricity

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- smoke and dust contamination
- high density of people

Positive ions are formed by friction between either solid surfaces, or between a solid surface and the flow of air. In a modern building, such friction is responsible for a very substantial decrease in negative ion concentration.

The following data (Table 28.1) give a good idea of the likely concentration of negative and positive ions in the air in various environments.

It is not only the ion imbalance, which creates discomfort for the people, but mainly the reduced negative ion level. For example, pain can be reduced by the presence of negative ions in air, since the level of serotonine hormone which transmits pain, is reduced. Negative ions also reduce histamine levels, what could have pronounced impact on various allergies. In summary, air ion imbalance causes imbalance of a number of important biochemical constituents of a human body.

Because viruses and microbes can only be transmitted by attaching themselves to solid, positively charged airborne particles the introduction of negative ions prevents the germs travelling. To support this case we can cite examples of studies carried out around the world.

Most burns wards in Californian hospitals are now equipped with negative ion generators. All have reported a dramatic fall in the incidence of infection and up to 70% cut in recovery time for burns victims. The North-Eastern hospital in Philadelphia has installed a special negative ion chamber for burns cases. Patients placed in the chamber are reported to be free of pain or greatly relieved after a much shorter period of time than was the case without negative ions supply. Just as impressive are the results of studies carried out in the workplace.

Some years ago the author was called in to advise an English company which had moved its office staff to new air conditioned premises. Naturally, they had expected improved staff moral, fewer absentees and higher productivity. The opposite was the case. Staff complained of headaches, dizziness and nausea, and there was general discontent. After the installation of a negative ion generator there was a significant improvement in all these symptoms.

Table 28.1 Concentration of negative and positive ions in the air in various environments

	Concentration in 1 ccm of air	
Environment	Positive ions	Negative ions
Clean mountain air	2,500	2,000
Rural environment	1,800	1,500
Typical urban environment (mildly polluted)	600	500
Light industrial plant area	400	300
Modern office environment	200	150
Closed moving vehicles	100	50

During his research into the ion phenomena, the author of this article measured the concentration of negative ions in various parts of the 8 storey administrative building in Perth, housing around 1,600 people. Complaints included some throat, dizziness, rashes, headache and other flu-like symptoms, with consequent low output and low working morale. The management suspected low oxygen levels, and perhaps higher dust concentration in certain sections of the building. Whilst the oxygen concentration fluctuated between 19 and 20% by volume, the nuisance dust concentration was well below 0.5 mg/m^3. But, as expected by the author, the negative ion concentration was very low, varying between 60 and 140 throughout the building. The remedial measure suggested by the author was quite simple – to increase the fresh air intake to the air conditioning system. Within several days, most occupants of the building experienced marked relief. The negative ion concentration measured (with 20% fresh air intake in each cycle of recirculation of air) was then between 240 and 460 ions in 1 cm^3 of air.

A booklet produced by the British Automobile Association already some years ago warned motorists of the dangers of too many positive ions, after several studies revealed that a motor vehicle's electrical system, heater and air conditioner, all produce only positive ions while pollution and exhaust fumes destroyed negative ions. Drivers were consequently overdosed by an excess of positive ions causing fatigue, drowsiness and lack of concentration. The Association had therefore recommended the use of a car negative ion generator.

So with all the evidence supporting the use of negative ion generation how much is now happening worldwide? Though conclusive studies have been conducted in a number of countries, it takes time to convince the authorities and the medical profession. But we are now getting very positive feedback and encouraging inquiries from doctors and from business and industrial managers who can see the cost benefit of maintaining a healthy working environment, both in human and monetary terms.

The tests had also shown that negative ion generators could be beneficial to people with breathing problems such as asthma. Could negative ions be the cure for our modern-day ills? In this context it is necessary to admit, that not all the people are sensitive to the ion effect to the same extent. From the research studies carried out in the United States, United Kingdom, Germany and Switzerland it follows that:

- 25% of all people are very much affected by ion imbalance.
- 25% of people are not affected at all.
- 50% of people are affected in varying degrees.

The symptoms of ion imbalance include:

- sleeplessness
- migraine
- pain in joints
- headaches
- laryngitis
- respiratory problems

- increase in mortality (Observed in Switzerland and Germany, when dry winds depleted of negative ions were blowing)
- increase in crime rate
- increase in traffic accidents frequency (Switzerland: 2.5 times increase when dry wind depleted of negative ion was blowing)
- suicides (as above)

Please note that dry winds are deprived of negative ions, since by friction between the air flow and the ground positive electrostatic charge is generated. This leads to discharge of negative ions in air.

People in a high proportion of the Perth (capital of Western Australia) metropolitan area would experience some tiredness or at least some unpleasant feeling whilst a dry easterly wind deprived of negative ions is blowing. On the other hand, sea breeze which is high on negative ions (these are formed when the wind comes into contact with water surface) brings substantial relief to most people.

On the basis of the above it is possible to understand why most people feel much more comfortable in indoor premises cooled by the evaporative systems as compared with refrigeration systems.

It appears from all the relevant studies and observations that the atmosphere in which we live and work makes around three quarter of individuals to complain of discomfort within their work room environment or actually precipitate complaints of illness. The concentration of negative ions appears to be one of the major atmospheric factors responsible for this. The modern office environment in which many computer operators work is usually deficient in negative ions for a number of reasons, and computer operators and users work in a particularly negative ion depleted micro-environment near to the unit, because of the positive electro static charge on the screen surface.

The author of this chapter, in his research into the negative ion effects, has measured the concentration of negative ions in the breathing zone of the computer operators, as well as the concentration of negative ions as a function of distance from a computer screen. The results of these measurements have shown the concentration of negative ions in the computer operators' breathing zone being around 50–60 ions in 1 ccm of air. This was in the well ventilated room with average concentration 1,050 negative ions in 1 ccm of air.

The above data explain, why only those who work very closely to the screen might develop some problems. People watching a TV from a distance of several meters breathe the air which is not depleted of negative ions any more. The introduction of artificially generated negative ions can significantly improve the subjective rating of the environment and of the subjects own feeling of comfort and well-being. In addition negative ions significantly reduce the complaint rate of illness, particularly headache, nausea, dizziness and skin rashes.

Increased concentration of negative ions also improves certain types of psychological and psychomotor performance. The generation of negative ions could be a cheap addition to the computer workstation and could bring about major improvements in job efficiency, health and comfort. Other applications of negative ionization of air would include:

- increasing mental alertness and concentration (e.g. for machine operators and drivers)
- accelerated healing of burns and wounds
- dust, smoke and pollen control (increased concentration of negative ions in air leads to the precipitation of dust and smoke)
- improving transportation safety
- other medical applications, such as asthma or infections control

It should be mentioned in this context that ions should not be considered in isolation of the many atmospheric, environmental, architectural, biological psychosocial and ergonomic factors that all contribute in a complex and interrelated way to determine an individual's health and well being at work.

The effectiveness of negative ions effects appears to be reduced at high temperatures and high humidity. However negative ions have a particularly beneficial effect at night and could contribute in reducing the health problems and discomfort associated with shift work.

Small and medium sized negative ion generators are widely available in most countries around the world. Over the last 10 or 20 years, their price has dropped significantly in real terms therefore such generators can be seen as a cost efficient control strategy for a number of serious problems.

28.2 Physics Related to the Air Ion Phenomenon, and the Negative Ion Effect Impact on Human Health and Wellbeing

Air ion complexes are unstable, changing their composition by transient association and disassociation as the original ion moves into the air. Small air ions have a lifespan in clean air ranging from small fractions of a second to several seconds.

While cosmic rays and solar radiation provide much of the energy for ion production, there are other sources of energy such as radiation from compounds such as radon in the soil.

And even the disintegration of water droplets in waterfalls can lead to ion formation. Near a waterfall, the fine spray contains a considerable concentration of negative air ions. There have been actual measurements in locations near waterfalls demonstrating negative air ion concentrations of in the order of tens of thousands negative ions per cubic centimeter of air.

Tens of thousands, possibly even hundreds of thousands of passengers using the Singapore airport, were able to feel refreshing atmosphere near the man made waterfalls in the transit lounge.

It might seem difficult to understand that positive and negative ions exist simultaneously in air because of the tendency of the positive and negative charges to neutralize one another. But, in clean unpolluted mountain air the typical concentration of positive and negative ions is between 2 and 3,000/cm^3 of air, the positive to negative ratio of 1.2–1.

This apparently surprising coexistence next to each other is possible owing to the vast numbers of neutral molecules separating the charged ions. For every one ion in air there are quadrillions of electrically neutral molecules. When oppositely charged small air ions collide, they neutralize one another. Various electrical fields also can deplete air ions attracting and transporting them to surfaces where, upon contact, the ions give up their charge and cease to exist.

The concentration of air ions in all circumstances is extremely low; even in a room containing an operating ion generator; only one air ion exists for each 10,000 billion of electrically neutral ordinary molecules of air.

Well known facts are that even very small electrical currents and voltages can significantly influence a wide variety of physiological processes. For example, it has been documented that very tiny and very brief electrical current-just a fraction of 1/1,000,000 of ampere at a frequency of 4 Hz for just 3/10,000 of a s-to the smell sensors of a fish would substantially affect the behavior patterns of the fish.

On the basis of such evidence it is not difficult to understand that small air ions can bring about biological responses because of the minute currents they transmit to an organism.

Some 50 years ago, the drive for improved understanding how air ions can affect human physiology led to the establishment of the Air Ion Research Laboratory at the University of California. The Laboratory had built sophisticated facilities for exposing bacteria, protozoa, plants, insects, and small animals to measured concentrations of small air ions in a controlled microenvironment.

Human subjects have not been used in this targeted research, because they cannot be maintained under completely controlled conditions for prolonged periods. Another reason was that it is difficult with humans to exclude the placebo effect – that reactions will be influenced by the very fact that a study is going on.

Out of the work in the Air Ion Research Laboratory several hundred of pioneering scientific reports have been published. They have described biological effects of negative ions ranging from the destruction of microorganisms and the stimulation of plant growth to changes in brain and blood levels of a very important nervous systems hormone serotonin.

It has been proven beyond any doubt that small negative air ions have a lethal effect on a wide variety of moulds and bacteria, including such dangerous microorganisms as those responsible for cholera and typhoid fever.

Plant growth studies have confirmed the previous hypotheses that atmospheric electricity enhances the rate of growth of various plants, among them, barley, lettuce, oats, and peas. It has also been found that air stripped of ions inhibits plant growth and causes the plant to die.

Many studies have focused on the effects of ions on serotonin. Serotonin is a potent nervous system hormone. It has a wide range of physiological activity. It is, among other things, an important neurotransmitter-or message carrier-in the brain.

In one of the studies it has been observed that small positive air ions increase the level of serotonin in the mouse brain and blood while small negative air ions decrease it. These ion induced changes in serotonin levels, which were later confirmed by other investigators, led the researches to formulate the serotonin hypothesis of air ion action. That it is the change in serotonin levels which accounts for many of the biochemical and physiological changes that result from exposure to abnormal concentrations of positive or negative ions.

Experiments demonstrating the action of air ions in killing microorganisms, stimulating plant growth and altering the concentration of serotonin in blood and brain always involve electromagnetic fields generated by the ion generating equipment. The researchers were therefore faced with an ancillary question: Are air ions, as distinct from the electromagnetic field biologically active?

To solve this problem, the researchers grew large populations of barley seedlings in ion-depleted atmosphere under controlled conditions. Then the air ions generated by a radioactive element were introduced. The ions produced a statistically valid increase in growth rate; an identical electromagnetic field did not. This clear indication that small negative air ions were responsible in this particular case for increased growth rate does not exclude the possibility that electromagnetic fields in other cases can be also biologically active.

Laboratory investigations, for the most part, have been searches for possible examples of living forms, tissues or tissue components which respond to air ions. Other studies have pinpointed some specific effects of ions in plant-such as increasing plant production of iron-containing enzymes, altering iron metabolism or handling, raising the rate of oxygen consumption, and increasing the essential metabolic activity of chloroplast in photosynthesis and starch formation.

It has also been found, that the silkworm responded to negative and positive ions with increased larval growth and accelerated formation of important enzymes. Negative ions have been found to lower tissue levels of hormone serotonin in mice and rats, while positive ions raise the levels.

It has also been found that air ions are capable of influencing the course of certain diseases. Positive ions adversely affect *the* survival rate for influenza and for bacterial pneumonia in mice, whilst ion-depleted air has shown the same effect on mice infected with influenza virus.

28.2.1 Some Significant Examples of How the Ion Effect Can Influence Human Health and Wellbeing

Hippocrates, who was frequently described as the world's "Father of Medicine," pointed, in the fifth Century B. C. to certain winds as having a negative influence on the people. He observed that the winds which passed over mountains to reach cities disturbed the air people breathe and the bodies of people were than endangered by diseases.

The first suspicion that these so-called "winds of ill repute" (for example the Foehn in Germany and Switzerland, and the others) might involve air ions was raised in 1901, when a direct connection between the adverse effects of these winds on a large proportion of people who were weather sensitive, and the presence of increased concentration of positive ions in the air have been observed and documented.

At Hebrew University, the researchers have accumulated extensive clinical and biochemical evidence that the excessive concentration of positive ions seriously affects serotonin levels, just as it had been found to be the case in the Californian experiments with mice. They have also pinpointed a variety of endocrine gland effects and have also established that such disorders can be managed by increased negative ion concentration in air as well as with serotonin-blocking drugs.

Some British studies of students clustered in lecture rooms and classrooms have shown that negative ion depletion brings with it tiredness, loss of attention, discomfort, and headache. Restoration of ion concentrations to normal levels reversed these effects.

Another research completed some 30 years ago, in a meticulously controlled investigation, has found that "air ions have bio psychological influences," clearly influencing mood and serotonin levels in people.

In several countries, physicians were successful in the utilization of the potential value of air ions in treating a wide spectrum of disease. Despite the uneven quality of these attempts the results were sufficiently promising to establish air ion treatment in several countries under the supervision of competent physicians associated with medical schools or reputable hospitals.

In the former Soviet Union, researchers used, with a lot of success, air ion therapy in asthma. In the Argentine, the research team of physicians used air ion therapy in depression and anxiety disorders. In Denmark, researchers have used air ion generators in providing healing environments for patients suffering from asthma and hay fever. In the UK, the researchers have established that inhalation of negative ions enriched air successfully cut short attacks of certain types of headaches and migraine. In Romania, the team of physicians used negative air ions in the treatment of duodenal ulcers. In the United States, the team of pioneers in American air ion research, found air ions useful in treating patients suffering from burns. Particularly important was the findings that the people in control studies exposed to high concentrations of negative air ions for 16 h a day over a period of 2 months have exhibited no abnormal physiological or biochemical changes, thus demonstrating the fact that no harm to the human organism results from high negative ion concentrations.

28.3 Indoor Air Quality and Its Control

Industrialization, urbanization, and streets congested with polluting traffic have certainly created huge and well known pollution problems. In addition to that, there is another increasingly significant factor which has been largely unrecognized by the general public, indoor air pollution. Ultimately, it will be the professions of designers and engineers which will have to assume the responsibility for correcting and controlling this important aspect of the indoor environments in all new and many existing structures.

Small respirable particles (particle size range between 0.5 and 7 μm) in air suspension are continuously circulated by air currents until they are eventually trapped by adhesion to solid surfaces or eliminated by air exchange. The modern architectural trends toward smaller, more space-efficient rooms which limit air currents, as well as the use of impermeable synthetic structural materials, inhibits these clearance mechanisms.

Nowadays people are living and working in environments dictated by economy and fashion, which have been developed by science and technology for our changing life styles under the pressures of urbanization. This is having far reaching negative effects on the health and wellbeing of the people, and we need to employ modern science and technology to rectify these problems for the sake of our own wellbeing and that of our future generations.

28.3.1 Health Hazards

Airborne particles of primary concern to human health and wellbeing in indoor building environments are:

- Bacteria
- Mould spores
- Viruses
- Toxic chemical molecules or aggregates
- Pollens
- Organic toxins

In addition to the above there are the larger sets of particles present in the air, to which the smaller ones attach themselves; these include dust, hair, synthetic fibers and other particles. However, unlike the outdoor environment where wind and thermal air currents are powerful factors in distributing large and small particles alike, the smaller sizes are of chief concern in normal indoor environments because they tend to remain in suspension in the air longer and tend to penetrate further into the human pulmonary system.

It had been established a long time ago, that the only reason a particle remains in suspension is because it carries an electrical charge which is acted upon by similar electrical charges. They are in the state of continuous electrostatic suspension, held in space by electrostatic forces which are of greater magnitude than gravity. They are repelled from walls and other surfaces having a like charge, until their charge is neutralized.

It is also known that friction between any two dissimilar substances creates electrostatic charges of opposite polarities on each. In a typical home or office interior, the friction of air currents against the wall, ceiling, floor, and furnishings made of most synthetic and all metal surface materials, extracts some weakly bonded electrons; this builds up positive charges on these surfaces, creating positive electrostatic fields which attract negatively charged particles (ions) and repel the positive ones.

Where resistance in the earth to ground path is too high to permit these cumulative positive charges to be neutralized through current flow, or where the ambient concentration of negative ions attracted to the charged surfaces is not sufficient to neutralize them at an equal rate, the positive charge on the surface of many common materials can build up to the magnitude of several hundred volts.

Under these conditions, it can be seen that this mechanism is capable of maintaining positively charged particles in air suspension indefinitely, where their concentration continues to increase cumulatively, as more are added, unless they are exhausted by air exchange systems or experience discharge of their positive charge.

On the basis of our understanding of the electrodynamics of indoor air pollution problems in which the sources cannot be eliminated effectively, a set of solutions can be developed.

If the positive charge on the particle which holds it in air suspension is neutralized, gravity becomes the dominant force acting on the particle which, falling through the progressively diminishing resistance of Brownian motion, will be precipitated to the floor. Alternatively, if the particle charge was reversed, the particle would quickly precipitate by attraction to an oppositely charged surface, such as a wall or ceiling, to which it will adhere indefinitely until overtaken by another electrostatic event.

In normal fresh air, one or both of these processes go on continuously within adequate concentrations of highly mobile small air ions. These are continuously colliding with oppositely charged pollutant particles which are much larger and less mobile, and neutralize the particle charges to initiate precipitation. This is why the pollution problem was rarely serious in the large, old fashioned, high-ceilinged, well ventilated, exterior rooms with plenty of window area as natural light and radiation continuously recreate the short lived air ions.

In modern indoor environments, dependent upon re circulated air, the natural process of ion neutralization and solid particle precipitation is seriously impeded by abnormally low ion concentrations, particularly of negative ions. This negative ion depletion effect is due to two groups of factors commonly found in artificial environments, each of which contributes incrementally to this basic cause of progressive indoor pollution. The following lists describe the major factors, most of which are in existence in modern, air sealed indoor environments.

(*a*) *Architectural factors*

- Forced air ventilation ducts, which acquire high positive charges from air friction and neutralize negative ions in passage.
- Synthetic structural materials and surfaces.
- Inadequate or no natural light to regenerate ion populations.
- Low ceilings of 3 m or less and interrupted design (rather than long straight line) of walls, which impede convection current circulation of air.
- Electronic precipitation filters which trap out all ions.
- Effective air-sealing (non opening windows, and efficient insulation).

(*b*) *Indoor furniture, equipment and people factors*

- Computer and television screens, which carry high positive charges, are major factors in depleting the negative ion population where and when they are used.
- Synthetic carpets, curtains, office division screens and hard surfaces.
- Electrical equipment and appliances, fluorescent lamp fixtures, fans, and blowers.
- Metal and plastic furniture.
- Tobacco smoke particles which attract and neutralize negative ions at a very high rate.
- Synthetic clothing and shoes.
- Overcrowding of rooms (people absorb negative ions and exhale positive ions).

In view of the ever increasing of these factors in the modern society and modern buildings, there is an urgent need to develop and implement suitable control strategies against the negative effects the above listed factors are having on our indoor building environments.

28.3.2 Indoor Air Control Technologies

28.3.2.1 Negative Ionization of Air

The problem of negative ion depletion, and the consequent degradation of the natural process of ion discharge and solid particle precipitation in indoor environments, can be reversed by negative ionization of air; this involves the installation in each room to be controlled, of a negative ion generator capable of continuously producing adequate quantities of small negative ions.

A centralized negative ion generation system is less effective, since negative ions introduced into the air duct system are almost immediately attracted to the interior surface of the duct and neutralized.

28.3.2.2 Ventilation

Definition

Ventilation is defined (in ASHRAE Standard 62.1 and the ASHRAE Handbook) as the process of changing or replacing air in any space to provide high indoor air quality (to control temperature or to remove moisture, odors, smoke, excess heat, dust, airborne bacteria, carbon dioxide and to replenish oxygen). Ventilation is used to remove unpleasant smells, introduce fresh air, to keep interior building air circulating, and to prevent stagnation of the interior air.

Air Composition and Human Needs

A person working hard breathes about 40 l of air per minute, consumes about 2 l of oxygen and exhales about 1.7 l of carbon dioxide. A sleeping person consumes only about one-tenth of this amount.

If the oxygen concentration is reduced to 17% a healthy person can still work but will breathe a little faster and deeper. Symptoms of dizziness, buzzing in the ears, rapid heart beat and headaches appear at 14% oxygen concentration. Life can be supported at an oxygen concentration of 13% provided the air is kept moving and the person is at rest.

Carbon dioxide acts as a stimulus to help regulate breathing. During heavy work, the amount of carbon dioxide released in the lungs increases and this stimulates faster and deeper breathing. When the atmospheric carbon dioxide concentration increases to 3% the breathing rate doubles. At 5%, breathing rate is quadrupled and breathing is very labored. Higher percentages cause violent panting and severe throbbing in the head but providing that oxygen is still present, the concentration of carbon dioxide has to rise significantly to cause death.

The human body continuously produces heat derived from the consumption of food. This maintains an internal body temperature of 37°C but the body cannot store heat. Increase in exertion or work increases the amount of heat produced and this is dissipated by physiological processes regulating heat loss from the skin. In a cool environment heat loss is fairly rapid but in hot surroundings the body may gain heat, and then has to dissipate this together with the heat of any activity. Air movement helps by evaporating perspiration from the skin.

When a person is seated at rest, his/her heat output is around 115 W. A person doing very light work has a typical heat output of 140 W. During light industrial bench work the heat output is around 235 W, and during heavy manual labor the heat output is around 440 W.

The body gives off water by perspiring at rates which vary according to the need to dissipate heat. Perspiration rates around 75 mg/s of sweat are common during physical activity. Perspiration which soaks into clothing or is mopped off the face does not contribute to heat regulation. The rate of heat loss from the body is governed by the perspiration evaporation rate which in turn is governed by air movement, relative humidity and temperature.

Air movement is needed in workplaces to remove bacteria and odors produced by human existence. Respiratory bacteria are spread by coughing and sneezing which spread bacteria laden droplets over considerable distances. These infectious droplets remain floating in the air unless removed by ventilation.

Body odors arise from organic substances in the air, which increase when personal hygiene is deficient. Body odors are generally regarded as undesirable pollution. Human activity such as smoking increases the pollution of air, particularly of stale air. To control tobacco smoke may require a ventilation rate of five times that needed if smoking did not occur.

Solar radiation from the sun can be transmitted through walls, roofing and windows, increasing building internal temperatures. In winter this may be desirable but in summer it can produce unpleasant working conditions. Glass incorporated in roofing is almost transparent to solar radiation and can transmit around 950 W/m^2 from direct sunlight.

Air Movement for Human Comfort

When air movement in occupied spaces is less than 0.075 m/s it generally causes a feeling of air stagnation and above 0.4 m/s it is felt as an unpleasant draught. To maintain comfort conditions in the workplace it is generally desirable to maintain an air movement between 0.1 and 0.3 m/s.

Dilution Ventilation

Excess heat, odors and contaminants can often be controlled via dilution or replacement with outside air. In humid climates there is a need to remove excess moisture from ventilation air. The concentration of airborne contaminants in the workplace can be reduced by introducing large quantities of fresh air. Natural ventilation is not reliable and when materials are used which could cause a health hazard, mechanical ventilation is usually necessary.

Dilution ventilation is generally used to:

- Dilute to safe concentrations the less toxic substances, and the removal of smoke, steam and unpleasant odors.
- Dilute airborne contaminants which have escaped from local exhaust systems.
- Dilute flammable vapors which may be generated within enclosed or partly enclosed spaces.

When flammable vapors and dusts are present, safe practice is to ensure that their concentration does not exceed one-fifth of the lower explosive limit.

Dilution ventilation is not generally a reliable method of controlling hazardous emissions from processes because the concentration of the contaminants is only rarely evenly distributed throughout the room air. For this reason, dilution ventilation is only suitable when the following conditions are met:

- There must be no risk of fire or release of flammable vapors; or of exposure to harmful concentrations of atmospheric contaminants.
- The toxicity of the contaminant must be low.
- The rate of release of the contaminant must be low and not from a point or localized source; that is, release points must be well spaced throughout the area.
- The sources of release must be far enough away from the workers' breathing zones to ensure that adequate dilution occurs between the release point and the workers' breathing zones.

As dilution ventilation requires a much greater volume of air than a local exhaust system to achieve the same degree of control, this method is only suitable when the amount of contaminant released into the workplace air is small, otherwise the very large air quantities required will be neither practical nor economic to provide. Because of these factors, dilution ventilation is rarely used as the major means of controlling airborne dusts and fumes in industry, but is the most common method for air quality control in buildings.

Air Movement in Dilution Ventilation

There are three basic means of mechanically controlling air flow for dilution ventilation.

- By supply and exhaust fans

This is the preferred method, and the sole one applicable for large buildings, with approximately equal quantities of air being supplied and exhausted by two fan systems. Slight excess exhaust is appropriate if there is a possibility of contaminating adjoining areas. Cooling or heating of the inlet air is easily accomplished to provide comfort conditions and the incoming air may be filtered to control dust.

- By supply fan only

This method is applicable when contaminant release points are scattered throughout the work area. The' possibility of exposure to pockets of high concentration of contaminant is less likely than with exhaust ventilation only, as air supplied under pressure ensures better circulation and dilution. Sufficient permanent outlets must be provided to permit the supplied air to escape freely after circulating through the contaminant release zones. Cooling or heating of the inlet air is readily accomplished and all air entering may be filtered to control dust.

- By exhaust fan only

This method is applicable where contaminants are released in fixed areas of the work environment and where the exhaust outlets can be located nearby. Adequate openings to admit fresh replacement air must be provided. Cooling or heating, and filtering of the fresh replacement air would be difficult in this setup.

Ventilation Rate

The ventilation rate is usually expressed by the volumetric flow rate of outside air being introduced to the building. The typical units used are cubic feet per minute (CFM) or liters per second. The ventilation rate can also be expressed on a per person or per unit floor area basis, such as CFM/p or CFM/sq.ft, or as air changes per hour. For residential and office buildings, which mostly rely on filtered fresh air supply, the common ventilation rate is the number of times the whole interior volume of air is replaced per hour, and this is referred to as air changes per hour (ACH). ASHRAE (American Society of Heating, Refrigeration and Air-Conditioning Engineers; the world leading professional body in the field of ventilation and air-conditioning) now recommends ventilation rates dependent upon floor area in addition to CFM/person.

In 1973, in response to the 1973 oil crisis and conservation concerns, ASHRAE Standards 62-73 and 62-81 reduced required ventilation from 10 CFM per person to 5 CFM per person. This reduction in fresh air supply was subsequently found to be a primary cause of sick building syndrome. Current ASHRAE standards (Standard 62-89 and 62-2001) state that appropriate ventilation guidelines are 20 CFM per person in an office building, and 15 CFM per person for schools. In commercial environments with tobacco smoke, the ventilation rate will range from 25 CFM to 125 CFM per person.

Air Change Rate

For most residential and office buildings, schools etc., the ventilation rate expressed in air changes per hour-ACH is in the range between 4 and 10. Air change rate per hour can be expressed in Imperial Units as:

$$\mathrm{ACH} = 60\ q/V$$

where: q = fresh air flow through the room in cubic feet per minute; V = volume of the room in cubic feet; Air change per hour can be expressed in SI Units as:

$$\mathrm{ACH} = 3,600\ q/V$$

Where: q = fresh air flow through the room in cubic meters per second; V= volume of the room in cubic meters

Safe Discharge of Exhaust Air

Industrial exhaust systems should discharge outside and above the building so that the discharged air does not re enter that building or other nearby buildings or occupied spaces. The aerodynamic wake of a building typically extends to 125% of the building height above ground so the exhaust points should be above this height. The dispersion pattern around an air discharge point can frequently be severely influenced by adjacent structures and where this is likely to be the case; special studies such as wind tunnel modeling may be needed in the design stage.

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Chapter 29
Sick Building Syndrome and Indoor Environmental Quality in China – A Review

Yufeng Zhang and Xiuling Ji

29.1 Introduction

The term Sick Building Syndrome (SBS) is used to describe situations in which building occupants experience acute health and comfort effects that appear to be linked to time spent in a building. SBS is usually indicated by the complaints of symptoms from building occupants associated with acute discomfort, e.g. headache; eye, nose, or throat irritation; dry cough; dry or itchy skin; dizziness and nausea; difficulty in concentrating; fatigue; and sensitivity to odors. The cause of the symptoms is not known and most of the complainants report relief soon after leaving the building. SBS is related to indoor environmental parameters, such as ventilation rate and concentrations of chemical or biological contaminants. The work on indoor environmental quality and SBS in China started in the 1950s of last century, including the surveys and studies on the health effects of indoor environments, the standards and norms, and the status surveys in national scale. The status of the work on SBS in China is reviewed through the above aspects.

29.2 Surveys and Studies on Health Effects of Indoor Environments

Surveys and studies on health effects of indoor environments is the base for knowing the status of SBS, understanding the inner mechanisms of the health effects and establishing the relevant standards and norms. It is very difficult to perform the surveys and studies for that various factors may affect human health and lots of contaminants can exist in indoor environments with low level of concentration. Compared with the rapidly developing applications and the real problems found in

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actual environments, the studies on health effects of indoor environments are relatively slow and late, which can not make timely responses in terms of complete explanations of the problems and valuable guidance of the potential technologies for solving the problems. Fortunately, the national invests on scientific researches and the numbers of researchers are rapidly increasing recently in China, and more and more surveys and studies are expected to be done, which are believed to provide the solid base for the understanding, prevention and control of SBS.

There are three main streams in the surveys and studies in China: the health effects of air-conditioned (AC) environments, the health effects of indoor air environments and the subjective assessments of indoor air quality, which are reviewed and summarized in the followings.

29.2.1 Health Effects of AC Environments

Air-conditionings were first occurred in industrial buildings in China for the technical requirements of productions, and the health effects of AC environments became one of the main focuses of early studies. The work can be classified into two stages: field surveys and mechanism studies, and the former are to provide primary observations and the latter is to discover the cause-and-effect relationships through epidemiological, toxicological and statistical approaches.

29.2.1.1 Field Surveys

It was reported early in 1984 that the workers in the AC factories in electronics industry often complained the symptoms of dizziness and exhaustion, which was expected to be well studied (Liu 1984). Thereafter, lots of field surveys have been performed in various AC buildings and the main results are reviewed as followings.

The people working or living in AC environments for a long-time are usually selected as test group, and those working or living in naturally ventilated (NV) environments with similar physical conditions are selected as control group. The field surveys consist of environmental measurements, questionnaires and medical tests. The environmental parameters often measured are air temperature, relative humidity, ventilation rate, concentrations of respirable particles, CO_2 and bacteria, noise and lighting. The questionnaires include professional and medical history, complainant of uncomfortable symptoms in current environments and disease report. The medical tests are mainly immunity tests and some surveys include productivity or neurobehavioral tests.

Zeng et al. (1986) investigated 1,183 workers in AC factory and found that the prevalence of cold reached 58.4% and the complaints of aches on shoulder, elbow, waist and knee and fatigue were very common, which were reported by the test group significantly more than the control group. Peng et al. (1988) investigated 1,121 workers in AC workshop in 1988 and reported that the CO_2 concentration, the prevalence of SBS like headache, dizziness, insomnia, memory loss, cough, bellyache and lumbago and the prevalence of upper respiratory illness, menstrual abnormality and dysmenorrhea were significantly higher in AC environments while compared with those in NV environments. Long et al. (1988) focused on the female workers in AC environments and found more complaints of symptoms of dysmenorrhea, arthralgia, cough, stomachache and larger numbers of WBC in blood in the test group. Pu et al. (1988) studied 409 waiters in AC environments in restaurants and found that they reported more symptoms of irritancy, sleepiness, dizziness, angina, stomachache and bellyache and negative ion concentration in their ambient air was lower.

Huang et al. (1990) found in a survey of AC restaurants that the CO_2 and negative ion concentrations were lower and the prevalence of symptoms of dry mouth, fatigue, dizziness, irritancy, sleepiness, headache and memory loss was higher while compared with the NV restaurants. Pu et al. (1992) investigated 135 waiters in AC restaurants and obtained the similar result with their previous study that is higher prevalence of symptoms of irritancy, fatigue and sleepiness and lower concentration of negative ion. They also made neurobehavioral tests and found that the test group was worse than the control group in terms of reaction time, sensitivity and visual retention.

Huang et al. (1996) investigated 200 female workers in sealed AC workshop and found that their prevalence of menstrual abnormality was high and the prevalence increased with the working time in AC environments. Cao et al. (1998) performed neurobehavioral tests on 144 workers in AC factories and reported stronger reactions in strain, anxiety, gloom, indignation, fatigue and perplexity, longer reaction time and more mistakes in test group. Su et al. (1999) found in their survey of 145 waiters in AC restaurants that their prevalence of symptoms of dizziness, irritancy, fatigue, sleepiness, muscle ache and catching cold was higher and their performances on reaction time, sensitivity, visual retention and digital decoding were worse than the control group, and the negative ion concentration in the ambient air was lower than NV environments.

Song et al. (2001) investigated 225 wokers in AC restaurants and found that the prevalence of some symptoms changed with exposure time in AC environments and the prevalence was higher for longer exposure time. In the same year, Yang and Lu (2001) conducted a survey on 68 workers in AC offices and reported that the ventilation rate was inadequate and the concentrations of contaminants were much higher than NV offices, and the prevalence of SBS such as headache, fatigue, sleepiness, respiratory (cold, snuffle, cough and dry throat) and eye (eye ache, lacrimation and photophobia) irritations and lumbago was higher and the contents of lysozyme and IgA in saliva were lower in test group. They concluded that a long-time working in AC environments could have adverse effects on human's immune functions.

Zhang (2002) conducted another survey on 160 workers in AC offices, and they found significantly higher prevalence of SBS in the test group except for headache. Liang et al. (2004) found in a survey on 523 workers in AC offices and workshops that the prevalence of SBS like dizziness, fatigue, sleepiness, catching cold and uncomfortable throat in AC environments were significantly higher than that in NV environments, even when the environmental parameters in both environments met the requirements of the national standards. Jiang et al. (2008) conducted neurobehavioral tests on 86 workers in AC environments and their results showed that while compared with the control group, their scores are higher on negative sentiments and lower on positive sentiments, and their reaction times are longer and digital decoding is worse. Meanwhile, they found higher CO_2 and formaldehyde concentrations in AC environments.

29.2.1.2 Mechanism Studies

The field surveys provide the primary observations on the health effects of indoor environments, and meanwhile, many researchers attempted to explain the mechanisms of the effects and determine the key factors and the acceptable environmental conditions by using epidemiological, toxicological and statistical approaches.

Yao et al. (1994) conducted tests of cerebral blood flow on 233 workers from AC factories and hotels. They found that the long-time exposure in AC environments had adverse effects on cerebrovascular system and induced more abnormities in cerebral blood flow. They also indicated that the symptoms found in AC environments such as headache and dizziness may be relevant to the variation of cerebral blood flow. Chen and Yu (1999) selected 120 healthy female workers working in AC environments for more than 2 years as the test group, and divided them into two sub-groups according to the negative ion concentrations of their ambient environments, and found through immune function tests that a long-time exposure to low concentrations of negative ions could reduce the content of IgG in blood.

Xu et al. (2002) conducted immune function tests on 90 workers in AC environments and found that the CO_2 and formaldehyde concentrations were higher and the negative ion concentration was lower in AC environments. The contents of IgG, IgM, IgA, C_3 and C_4 in the blood of the test group fell within the normal ranges, but significantly lower than those of the control group. They concluded that the low negative ion concentration in AC environments could have adverse effects on immune functions. Zu et al. (2003) obtained the similar results in their studies on 87 workers.

Shang et al. (2005) and Bei et al. (2005) investigated the possible factors inducing the uncomfortable symptoms in AC environments in summer by using epidemiological and statistical approaches. They classified the symptoms usually reported into 12 categories (eye irritations, nose irritations, dry throat and mouth, irritancy, cough, dry or itchy skin, fatigue or sleepiness, anxiety, dizziness or headache, nausea, difficulty in concentrating and others) and the illnesses into 7 categories (cough, cold, pneumonia, asthma, allergic rhinitis, skin allergies, heat stroke), which were included into the questionnaires reported by 2,620 workers from hotels, restaurants and offices. The subjects were systematically divided into four groups according to their using of air-conditioning: AC workplace and home, AC workplace, AC home and NV group (control group). They found in their investigations that the prevalence of most of the symptoms and illnesses was significantly higher for the test group and the differences closed twofold for six symptoms. It was shown by multivariate logistic regressions that 11 symptoms had positive correlations with "Using air-conditioning both in workplace and home" and all kinds of symptoms and illnesses were relevant to "Using air-conditioning both in workplace and home"

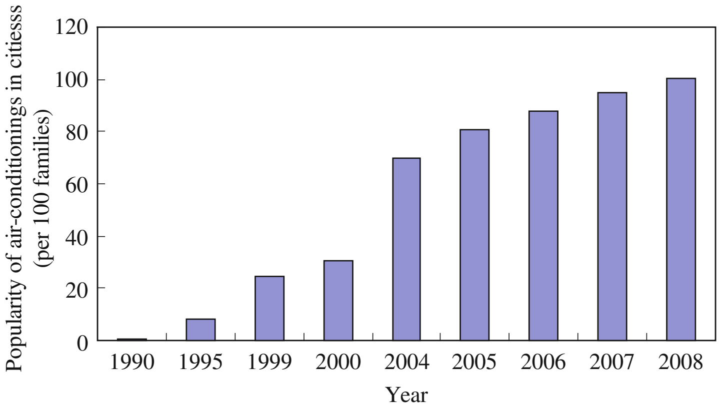

Fig. 29.1 The increase of popularity of air-conditionings in China (China National Bureau of Statistics 2009)

most closely, and then "Temperature is low in workplace" and "Air is not fresh", and then "Education background", "Working pressure" and "Do not like the job". The further analysis show that "Using air-conditioning both in workplace and home", "Air is not fresh", "Working pressure" and "Do not like the job" were independent from each other and would be the important factors for the health effects.

The above mechanism studies indicate that the negative ion concentration may be an important factor for the health effects, and cerebrovascular and immune function tests may be helpful for the discovery of mechanisms, and the various symptoms and illnesses are caused synthetically by multi-factors. The large temperature difference between indoor and outdoor and the heat or cold stress produced by the difference is proposed as another factor for the health effects in other studies (Zhu et al. 2001). The mechanisms of the health effects of AC environments are still on going and needed more systematic and basic research work.

The surveys and studies in early stage follow closely with the primary applications of air-conditionings. By contrast, the popularity of air-conditionings has been raised promptly with the recent economic development (Fig. 29.1), however, the surveys and studies seem not to catch up and progress slowly and lately. Meanwhile, the research conditions for the comparisons of test and control group are gradually disappearing and the relevant health problems are becoming more and more serious due to the widespread air-conditionings in buildings. More work is needed to be done timely to guide and advance the healthy AC environments and buildings in China.

29.2.2 Health Effects of Indoor Air Environments

The studies on health effects of indoor air environments in China started in the 1970s of last century (Qian and Dai 2006). At that time around 50% populations used coals and biomass fuels at home and the indoor air pollutions caused by Chinese cooking were very common, therefore, the early studies were focused on the health effects of the pollutants from combustion, smoking and cooking. One of the most important studies is the project "Pollutions of coal combustion and lung cancer in Xuanwei", which obtains the dose-response relationship between Benzo(a)pyrene and lung cancer mortality through more than 10 years' investigations and provides a solid base for the national standards on Benzo(a) pyrene (Liu 2002).

Since the late 90's, the focus of studies has changed from the indoor air pollutants in high concentration, short exposure time and heavy effect to those in low concentration, long exposure time and light effect, which include formaldehyde, VOC, respirable particles, radon and biological pollutants. The following presents a brief review of those studies.

29.2.2.1 Formaldehyde (FA)

Health effects of FA can be studied through investigations of workers or subjects exposed to environments with FA. Wei et al. (2002) reported that the male workers working in the workplace with FA concentration of 0.341 mg/m^3 had lower contents of IgG in blood. Ying et al. (1999) exposed twenty-three non-smoking students to 0.39–0.68 mg/m^3 of FA for a period of 8 weeks (3 h × 3 times each week) during anatomy classes. Significant increase was found in the percentage of CD_{19}, while significant decrease was observed in CD_3, CD_4 and CD_8 with a $p < 0.01$ after FA exposures. Increase in the ratio of T_4/T_8 was also observed with statistical significance after exposure. It was concluded by the authors that FA could have adverse effects on immune functions. Liu et al. (1998) reported in their investigations on 4,875 workers that the prevalence of gastric cancer for the group exposed to FA was 97.13/10^5, which was higher than that for the control group (33.46/10^5) and they indicated that FA might be a risky factor for gastric cancer. Wang et al. (1997) reported that 80 workers exposed to FA for 12 years had significantly higher frequencies of micronucleated cell in peripheral lymphocyte than the control group. Other studies (Li et al. 2007; Lv et al. 2001; Ren 2005; Wang et al. 1990; Yu et al. 2000; Zhang 2009; Zhang et al. 1999) investigate homes, public buildings and furniture shopping centers and find that the health effects of FA are mainly irritations of eye, nose and throat with the symptoms of cough, chest tightness, sleepiness, fatigue and irregular menstruation.

Health effects of FA can also be studied through toxicological experiments on animals. Yi et al. (2000) and Xie et al. (2003) studied the FA toxicity on germ cells of male mice. They injected FA into mice for 5 days and found that the number of sperm decreased, the sperm activity weakened and the sperm deformation ration increased after injections. Liu et al. (2003b) studied the oxidation damage effects of gaseous FA on organs of mice. The mice were treated by various doses of FA visa inhalation for 72 h and the superoxide dismutase (SOD) activities of 5 organs (brain, lung, heart, liver, and kidney) were measured. They found that SOD activity in liver decreased significantly ($p < 0.05$) after inhalation of 1.2 mg/m^3 FA, and the SOD activities in liver, kidney and lung decreased significantly after inhalation of

3.7 mg/m^3 FA. Wen et al. (2001) reported that FA could suppress the humoral and cellular immunity and macrophage function of mice.

29.2.2.2 Radon

The radon concentration is high in the traditional caves in the west-north area of China and the health effects of radon may be serious for the local inhabitants in that area. Wang et al. (2002) studied the lung cancer risk in Pingliang and Qingyang in Gansu province in China. 1209 lung cancer patients diagnosed during 1994–1998 were selected as the test group and 1968 healthy persons were selected as the control group. The surveys on both groups were conducted by using questionnaires and radon detectors, which were placed in all houses occupied for more than 2 years by the subjects. The mean radon concentration was 230.4 Bq/m^3 for the test group and 222.2 Bq/m^3 for the control group. Lung cancer risk was found to increase with radon level significantly ($p < 0.001$). Based on a linear model, the excess odds ratio (EOR) at 100 Bq/m^3 was found to be 0.19 (95%CI: 0.05, 0,147) for all subjects. They concluded that indoor radon exposures would increase lung cancer risks.

29.2.2.3 Biological Pollutants

The studies on biological pollutants started in the 1950s of last century. Xu (1956) reported a study on chigger and scrub typhus in 1956. Zhang et al. (1961) investigated the pollutions in classrooms in 1961 and found that the increases of CO_2, dust and bacteria concentrations resulted in the tension or disorder of temperature regulation, reduced learning effects, increased fatigue and absent rate for children.

In the recent 10 years, lots of studies were conducted in public places due to their high density and large mobility of people, complex sources of biological pollutions and serious health problems. Liu and Shen (2003) investigated the public entertainment places in Yinchuan in 2003 and found that the concentrations of bacteria and streptococcus hemolyticus were higher than the limits of the national standards in 1.5 and 2.4 times respectively. They also found that the people in the places complained of chest tightness, memory loss, dermatitis and decreased vision. Zhu et al. (2007) conducted a survey on asthma patients and found seasonal variations of IgE, s-IgE, s-IgG1, s-IgG2, s-IgG4 and breeding density of dust mites in their bedrooms. They indicated that the specific antibodies of asthma patients might be related to the breeding density of dust mites in their bedrooms. Fang et al. (2000) indicated in another study on asthma patients that the prevalence of asthma was relevant to the density of dust mites.

Other studies (Chen et al. 2001; Jiang et al. 2009; Liao et al. 2005; Peng et al. 2000; H. Shen et al. 2008; Xu et al. 2008; Zhou et al. 2004) investigated the *Legionella* bacteria in various kinds of public buildings (hotels, cinemas, hospitals, subway stations, shopping centers, office buildings and restaurants) and found high prevalence of the Legionnaire's disease. The existing studies on biological pollutants in China are mostly focused on the concentrations of bacteria and epiphyte, and the number of studies on the health effects of biological pollutants is relatively small (Zhao et al. 2009).

29.2.2.4 Integrated Effects

Except for the studies on the health effects of a single pollutant, some studies are focused on the integrated effects of various pollutants in indoor air environments in various kinds of actual buildings. Some examples are presented as followings. Li et al. (1995) conducted a field survey on shopping centers and found markedly higher concentrations of CO_2, dust, H_2S, oxygen consumption and bacteria in the air environments and larger number of T-Lymphocyte, smaller content of lysozyme and worse performance on neurobehavioral functions in the test group. Ma (2006) investigated the offices just decorated and found that the concentrations of formaldehyde, NH_3, benzene, toluene and xylene were high in the indoor environments 2 months after decoration, which were 0.447, 0.857, 0.460, 0.424 and 0.630 mg/m^3 respectively. The workers in the offices reported more complaints of symptoms such as irritations of eye, throat, skin and nose, cough, asthma, headache, loss of appetite and itchy skin than the control group, and the prevalence of the symptoms was found to be correlated positively with the concentrations of formaldehyde, NH_3, benzene, toluene and xylene, and negatively with the time after decoration. Dong et al. (2005) reported in their survey in nursery and primary schools that the prevalence of cough, expectoration and asthma for children was 9.48, 4.82 and 1.33%, and the prevalence increased with the number of smokers in family, and the prevalence was relatively high for the children whose families have been decorated in recent 3 years. Wang (2008) conducted a survey on indoor air environments in dormitories and found that the students living in a room presence of mold/damp spots, pets, cockroach or passive smoking had a higher prevalence of asthma and damp and mold were risk factors of asthma.

It is worth to mention that some researchers attempted to determine the dose-response relationship for a single indoor pollutant by using controlled human exposure experiments. Yang et al. (1999; 2000) and Chen et al. (2000a, b) established a climate chamber to study the effect of FA on eye illness and they obtained the relationships between concentration of FA and sensory intensity of eye irritation and eye blinking frequency.

29.2.3 Subjective Assessments of Indoor Air Quality

Shen (1997; 2002) introduced a subjective assessment method of indoor air quality by referring to ASHRAE and WHO standards and guidance in the 1990s of last century, which includes the acceptability votes of indoor air quality and the reports on various symptoms. Lots of indoor air quality surveys have been conducted in many cities thereafter, and those surveys provide the primary information on the status of SBS in buildings. The main results are reviewed as followings. Shen et al. (1996)

confirmed the existence of SBS in offices in Shanghai by reporting that the mean acceptability of indoor air quality was only 45.2% and over one third of the occupants reported the symptoms of fatigue, dizziness, headache, dry mouth and eye and catching cold. Pan et al. (2000) investigated the indoor air quality in shopping centers in Shanghai in 2000 and found that in some spaces of the shopping centers the temperature and CO_2 concentration were high and the ventilation rate was low, and the percentage dissatisfied of occupants was higher with indoor air quality (35%) than light or sound environments. We et al. (2001) analyzed the survey data of offices in Shanghai by using grey system incidence theory and indicated that the respirable particles and bacteria were the main factors for the dissatisfied indoor air quality.

Pan et al. (2003) conducted an indoor air quality survey in seven office buildings in Shanghai and the results show that the percentage dissatisfied with indoor air quality (more than 20%) is higher than that with other environmental qualities. Liu et al. (2003) performed a survey in office buildings in Shenzhen and found that meeting the requirements of national standards could not satisfied most of the occupants and the percentage dissatisfied with indoor air quality was 25% for long-time occupants and 51.9% for visitors. SBS was believed to be caused by the poor indoor air quality by 44% of subjects. Tian et al. (2004) investigated the indoor air quality in underground shopping centers in Dalian and reported that the air temperature was high and the ventilation rate was low, and the prevalence of symptoms of headache, fatigue, asthma, dry eye was 27, 29, 8 and 29% respectively. Pei et al. (2006) reported in their survey on shopping centers in Guangzhou that the main indoor pollutants were respirable particles, TVOC and ozone, and the percentage dissatisfied with indoor air quality was 22.64%, and the mainly reported SBS were the symptoms of angina, dry eye, sleepiness, fatigue and itchy skin.

29.3 Standards and Norms

Based on the surveys and studies on health effects of indoor environments and the references of international standards and guidance, several national standards and norms related with indoor environments and SBS were published successively to prevent, evaluate and control the SBS in buildings.

29.3.1 Indoor Air Quality Standards

The "Regulations for Hygienic Management of Public Places" was promulgated by the State Council of China in 1987 and the "Hygienic Standard for Public Places" was promulgated by the Ministry of Health of China in 1988. In 1996, several hygienic standards for public places were promulgated together by the General Administration of Quality Supervision, Inspection and Quarantine and the Ministry of Health of China with the following codes and titles.

GB 9663-1996, Hygienic Standard for Hotel
GB 9664-1996, Hygienic Standard for Public Place of Entertainment
GB 9665-1996, Hygienic Standard for Public Bathroom
GB 9666-1996, Hygienic Standard for Barber Shop and Beauty Shop
GB 9667-1996, Hygienic Standard for Swimming Place
GB 9668-1996, Hygienic Standard for Gymnasium
GB 9669-1996, Hygienic Standard for Library, Museum, Art Gallery and Exhibition
GB 9670-1996, Hygienic Standard for Shopping Centre and Book Store
GB 9671-1996, Hygienic Standard for Waiting Room in Hospital
GB 9672-1996, Hygienic Standard for Waiting Room of Publictransit Means
GB 9673-1996, Hygienic Standard for Public Means of Transportation
GB 16153-1996, Hygienic Standard for Dining

The limits on CO_2, FA, respirable particles and bacteria concentrations in the above standards are listed in Table 29.1. Several hygienic standards for indoor pollutants were promulgated by the Ministry of Health of China since 1997 and Table 29.2 shows their codes, titles and limits.

It can be seen by comparing Tables 29.2 and 29.1 that the limits on carbon dioxide and respirable particles are strengthened and more indoor air pollutants are included in the standards in Table 29.2. The first national indoor air quality standard was promulgated in a systematical and complete form in 2002 by the General Administration of Quality Supervision, Inspection and Quarantine, the Ministry of Health and the State Environmental Protection Administration of China. The standard provides the requirements of indoor air environments (Table 29.3) and the

Table 29.1 The limits in the hygienic standards

Place	CO_2 (%)	FA (mg/m^3)	Respirable particles (mg/m^3)	Bacteria (cfu/m^3)
Hotel in three–five stars	0.07	0.12	0.15	1,000
Bar, teahouse and coffee house	0.15	0.12	0.20	2,500
Cinema, concert hall and ballroom	0.15	0.12	0.20	4,000
Beauty shop	0.10	0.12	0.15	4,000
Library, museum, art gallery	0.10	0.12	0.15	2,500
Gymnasium	0.15	0.12	0.25	4,000
Shopping centre and book store	0.15	0.12	0.25	7,000
Exhibition	0.15	0.12	0.25	7,000
Waiting room in hospital	0.10	0.12	0.15	4,000
Dining place	0.15	0.12	0.15	4,000
Waiting room of train	0.15	0.12	0.25	7,000
Waiting room of airplane	0.15	0.12	0.15	4,000
Cabin of train	0.15	–	0.25	4,000
Cabin of airplane	0.15	–	0.15	2,500

Table 29.2 Hygienic standards for indoor air pollutants in China

Code	Title	Limit
GB/T 17093-1997	Hygienic standard for bacteria total in indoor air	4,000 cfu/ m^3
GB/T 17094-1997	Hygienic standard for carbon dioxide in indoor air	0.10% (2,000 mg/m^3)
GB/T 17095-1997	Hygienic standard for inhalable particulate matter in indoor air	0.15 mg/m^3 (daily average)
GB/T 17096-1997	Hygienic standard for nitrogen oxides in indoor air	0.10 mg/m^3 (daily average)
GB/T 17097-1997	Hygienic standard for sulfur dioxide in indoor air	0.15 mg/m^3 (daily average)
WS/T 182-1999	Hygienic standard for benzo(a)pyrene in indoor air	0.1 $\mu g/100\ m^3$ (daily average)
GB/T 18202-2000	Hygienic standard for ozone in indoor air	0.10 mg/m^3 (hourly average)
GB/T 18203-2000	Hygienic standard for streptococcus hemolyticus in indoor air	36 cfu/m^3
GB 18468-2001	Hygienic standard for P-dichlorobenzene in indoor air	1.0 mg/m^3 (daily average)

relevant testing methods and is suitable for residential buildings and offices. The built environments in other buildings can be designed or evaluated according to it as well.

It can be seen by comparing Tables 29.2 and 29.3 that the requirements on some indoor air pollutants are raised and more potential indoor pollutants are included in the Indoor Air Quality Standard.

29.3.2 Hygienic Norms For Air-Conditioning and Ventilation Systems

Air-conditioning and ventilation systems are the main sources of indoor air pollutions and causes of SBS in buildings, and the Ministry of Health of China promulgated three hygienic norms in 2006 to strengthen the managements of air-conditioning and ventilation systems in public places (Ministry of Health of China 2006).

The "Hygienic Norm for Air-conditioning and Ventilation Systems in Public Places" prescribes the requirements and testing methods for the hygienic conditions of air-conditioning and ventilation systems in public places and its main content is summarized as followings.

Legionella bacteria should not be detected in cooling and condensing water and ventilation rate should meet the requirements in Table 29.4. Air supply should meet the requirements of Table 29.5. Inner surface of air ducts should meet the

Table 29.3 The requirements of indoor air quality standard (GB/T 18883-2002 2002)

No.	Category	Parameter	Unit	Limit	Note
1	Physical	Temperature	°C	22–28	Cooling season
				16–24	Heating season
2		Relative humidity	%	40–80	Cooling season
				30–60	Heating season
3		Air speed	m/s	0.3	Cooling season
				0.2	Heating season
4	Chemical	Ventilation rate	$m^3/(h \bullet person)$	30[a]	
5		Sulfur dioxide SO_2	mg/m^3	0.50	Hourly average
6		Silicon dioxide NO_2	mg/m^3	0.24	Hourly average
7		Carbon monoxide CO	mg/m^3	10	Hourly average
8		Carbon dioxide CO_2		0.10	Daily average
9		Ammonia NH_3	mg/m^3	0.20	Hourly average
10		Ozone O_3	mg/m^3	0.16	Hourly average
11		Formaldehyde HCHO	mg/m^3	0.10	Hourly average
12		Benzene C_6H_6	mg/m^3	0.11	Hourly average
13		Toluene C_7H_8	mg/m^3	0.20	Hourly average
14		Xylene C_8H_{10}	mg/m^3	0.20	Hourly average
15		Benzo(a)pyrene B(a)P	ng/m^3	1.0	Daily average
16		Respirable particles PM_{10}	mg/m^3	0.15	Daily average
17		TVOC	mg/m^3	0.60	Average in 8 hours
18	Biological	Bacteria	cfu/m^3	2,500	Depended on devices[b]
19	Radioactive	Radon Rn	Bq/m^3	400	Annual average (action level[c])

[a] Requirement of ventilation rate ≥ limit and requirements of other parameters except for temperature and relative humidity ≤ limit.
[b] See addenda D of the standard.
[c] Actions are recommended to be done to decrease the concentration of radon while the limit is reached.

Table 29.4 Hygienic requirements for ventilation rate

Place		Ventilation rate ($m^3/(h\bullet person)$)
Hotel	three-five stars	≥ 30
	one-two stars	≥ 20
	no stars	≥ 20
Dining place		≥ 20
Cinema, concert hall and video hall		≥ 20
Recreation hall and ballroom		≥ 30
Bar, teahouse and coffee house		≥ 10
Gymnasium		≥ 20
Shopping centre and book store		≥ 20
Cabin of train and ship		≥ 20
Cabin of airplane		≥ 25

Table 29.5 Hygienic requirements for air supply

Parameter	Requirement
PM_{10}	$\leq 0.08\ mg/m^3$
Bacteria	$\leq 500\ cfu/m^3$
Epiphyte	$\leq 500\ cfu/m^3$
Streptococcus Hemolyticus	Not detectable

requirements of Table 29.6. Air purifiers should not emit any pollutants in principle and should meet the requirements of Table 29.7. Air purifiers should meet the requirements for their performances in Table 29.8.

The "Hygienic Assessment Norm for Air-conditioning and Ventilation Systems in Public Places" prescribes the assessment methods for the new, reconstructed,

Table 29.6 Hygienic requirements for inner surface of air ducts

Parameter	Requirement
Dust	$\leq 20\ g/m^2$
Pathogenic microorganisms	Not detectable
Bacteria	$\leq 100\ cfu/cm^2$
Epiphyte	$\leq 100\ cfu/cm^2$

Table 29.7 Hygienic requirements for air purifiers' emissions

Parameter	Emission
Ozone	$\leq 0.10\ mg/m^3$
Ultraviolet radiation (in a distance of 30 cm)	$\leq 5\ \mu w/cm^2$
TVOC	$\leq 0.06\ mg/m^3$
PM_{10}	$\leq 0.02\ mg/m^3$

Table 29.8 Hygienic requirements for air purifiers' performances

Item	Condition	Requirement
Resistance	Normal air supply and return	≤ 50 Pa
Purification efficiency for particulates	Once through	$\geq 50\%$
Purification efficiency for microorganisms	Once through	$\geq 50\%$
Performance for long time	After 24 hours' continuous working	Decrease in efficiency < 10%
Disinfection	Once through	Sterilization rate $\geq 90\%$

extended or running air-conditioning and ventilation systems in public places. Two kinds of hygienic assessment: preventive (for design and verification) and regular assessment, and their purposes, references, contents, technical requirements and reports are provided in details in the norm. The "Cleaning Norm for Air-conditioning and Ventilation Systems in Public Places" prescribes the cleaning methods for the main parts of air-conditioning and ventilation systems in public place, which include the technical requirements, performances and security for cleaning process, agency and devices.

29.3.3 Other Standards and Norms

Several standards and norms on building materials and constructions have been published to prevent and control the indoor air pollutions. The "Code for Indoor Environmental Pollution Control of Civil Building Engineering" (GB 50325-2001) prescribes the requirements for building materials (inorganic non-metallic main materials for buildings and decoration materials such as artificial wood, coating, adhesive and water treatment agent), survey and design (site investigation on soil radon concentration and material selection), constructions and verifications to control the concentrations of radon, formaldehyde, ammonia, benzene and TVOC, which is applicable for the new, reconstructed or extended civil buildings.

Other standards on building materials are listed below.

GB 18580-2001, Indoor Decorating and Refurbishing Materials – Limit of Formaldehyde Emission of Wood- Based Panels and Finishing Products

GB 18581-2001, Indoor Decorating and Refurbishing Materials – Limit of Harmful Substances of Solvent Coatings for Woodenware

GB 18582-2001, Indoor Decorating and Refurbishing Materials – Limit of Harmful Substances of Interior Architectural Coating

GB 18583-2001, Indoor Decorating and Refurbishing Materials – Limit of Harmful Substances of Adhesives

GB 18584-2001, Indoor Decorating and Refurbishing Materials – Limit of Harmful Substances of Wood Based Furniture

GB 18585-2001, Indoor Decorating and Refurbishing Materials – Limit of Harmful Substances of Wallpaper
GB 18586-2001, Indoor Decorating and Refurbishing Materials – Limit of Harmful Substances of Polyvinyl Chloride Floor Coverings
GB 18587-2001, Indoor Decorating and Refurbishing Materials – Limitations of Harmful Substances Emitted From Carpets, Carpet Cushions and Adhesives
GB 18588-2001, Limit of Ammonia Emitted from the Concrete Admixtures
GB 6566-2001, Limit of Radionuclides in Building Materials

In summary, a primary standard system has been established in China for indoor air environments and SBS, which includes the standards and norms on indoor air quality, air-conditioning and ventilation system, building materials and constructions, and prescribes the requirements for indoor environmental parameters, design and operation of air-conditioning and ventilation systems, harmful substances of decorating and refurbishing materials and pollution control of building engineering. Though the standards and norms are needed to be improved based on the scientific researches and large-scale surveys in future, the standard system has advanced to a large extent the improvements of indoor air environments and the solving of SBS problems in buildings. An effective way is to revise and improve the standard system continuously during practical applications.

29.4 Status Surveys

Many status surveys in relatively large scale have been done in China based on the published standards and norms with the purposes of knowing the current status of indoor air environments in buildings and providing basic information for the further studies and standards. Most of the surveys are still on going and the primary results are reviewed as followings.

29.4.1 Indoor Air Quality

29.4.1.1 Formaldehyde (FA)

Table 29.9 shows the survey data on FA concentration in built environments in nine cities in China. The failure rate on FA concentration is lowest in Shenyang and highest in Guangzhou and the average rate for all nine cities is 82.8%, which means the FA pollutions in indoor environments are serious.

In 2009 an inspection on blockboard was performed by the General Administration of Quality Supervision, Inspection and Quarantine of China. Totally 122 kinds of products from 10 areas were tested with a passing rate of 96.5%. The main problems found were high FA emission and inadequate bending strength. Compared with the previous inspections since 2005, the problems with FA emission

Table 29.9 FA concentrations in built environments in nine cities in China (Jiang and Zhang 2009)

City	Sample	Range of concentration (mg/m^3)	Average concentration (mg/m^3)	Failure rate (%)
Huangshi	59	0.04–2.96	0.56	86.4
Zhengzhou	250	0.02–2.42	0.38	74.5
Tianjin	200	0.03–5.02	–	87
Guangzhou	562	0.02–1.81	0.25	94
Xi'an	30	0.04–0.54	0.29	88
Fuzhou	43	0.06–2.67	–	81
Chengdu	128	0.05–0.28	0.15	82
Wuhan	50	0.07–1.6	0.08	81
Shenyang	44	0.00–3.85	0.84	71

had been greatly reduced in 2009 with an improvement of 9.4% on passing rate of FA emission and 36.2% on that of product quality.

29.4.1.2 Biological Pollutants

There are many reports on bacteria concentrations in indoor environments in various areas of China. The general trend is the concentration is higher in summer (vs winter), morning and evening (vs noon), and public places (vs residential buildings) (Zhang 2001). The bacteria concentration is less than 5,000 cfu/m^3 in homes with good conditions and higher than 10,000 cfu/m^3 in homes with bad conditions (Zhou et al. 1986). The bacteria concentration is about 13,699 cfu/m^3 in the indoor environments in northern rural buildings and 31,331 cfu/m^3 in southern buildings mixed with livestock (Shi et al. 1987). The bacteria concentration is less than 2,500 cfu/m^3 in the operating rooms in hospitals (Tan and Lu 1989; Yan and Xu 1989) and more than 10,000 cfu/m^3 in the crowded and sealed waiting rooms (Shun et al. 1989; Zhang et al. 1987).

29.4.1.3 Radon

Ren (2001) made a statistic on the radon concentrations in China based on the published literature before 1994 and the results are shown in Table 29.10.

Figure 29.2 shows the indoor and outdoor radon concentrations in different areas of China. The areas with higher indoor radon concentrations are Fujian, Shanxi and Hunan, and those with lower concentrations are Jilin and Tibet. It was estimated that the effective exposure of radon and its progeny was 0.84 mSv, in which 0.7 mSv was for indoor and 0.14 mSv was for outdoor.

The indoor radon concentrations change seasonally and diurnally in China (Fig. 29.3). The concentrations in spring are highest and the diurnal variation is 1.96, 4.91, 2.93 and 1.51 for spring, summer, autumn and winter.

Table 29.10 The radon concentrations in China (before 1994) (Ren 2001)

Place	Radon concentration		Progeny concentration		Balance factor	Stay factor
	Sample	Average (Bq/m^3)	Sample	Average (mWL)		
Indoor	9,967	23.7	5,428	3.67	0.47	0.77
Outdoor	4,287	12.6	–	–	0.59	0.23
Underground	1,080	373	–	–	0.43	–

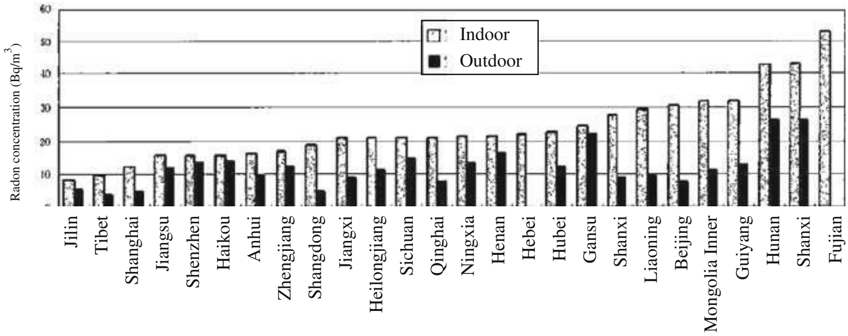

Fig. 29.2 Indoor and outdoor radon concentrations in different areas of China (Ren 2001)

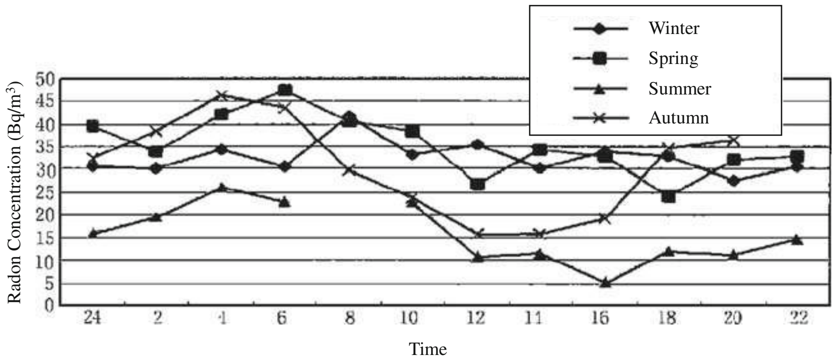

Fig. 29.3 Seasonal and diurnal change of indoor radon concentrations in China (Ren 2001)

Lin et al. (1992) investigated the indoor radon in various buildings in Beijing. Their study shows that the indoor radon comes from building bases, materials and outdoor air with a proportion of 56.3%, 20.5% and 20.5% respectively and the proportion from fuels and water is less than 3%.

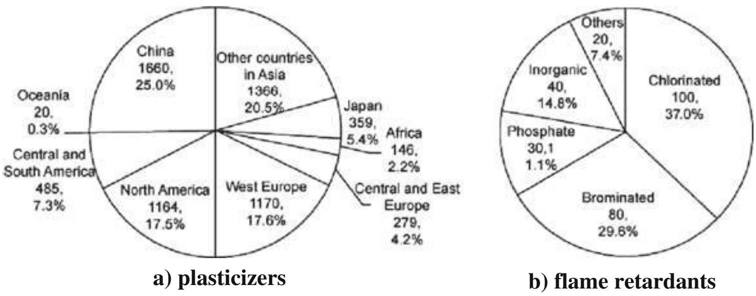

Fig. 29.4 Consumption of plasticizers in the world and production of flame retardants in China in 2006 (Wang et al. 2010). (**a**) plasticizers, (**b**) flame retardants

29.4.1.4 SVOC

Figure 29.4 indicates that China consumed 25% of plasticizers in the world as the biggest consumer (Tao and Liang 2008) and produced 260 kt flame retardants in 2006 and the growth rate of average annual consumption of flame retardants was over 20% in China as 4 times that of the whole world from 2002–2004 (Wang et al. 2010).

China produces and consumes great amounts of pesticides, in which mosquito coil, aerosol, electric mosquito-chip, electric mosquito liquid, and other pesticides account for 45.5%, 31.9%, 8.5%, 2.7% and 11.4% respectively (Jiang and Wang 2006). The production and consumption of coal in China is the highest in the world. 1.67 billion tons was produced in 2003, accounted for 33.5% of that in the world, and the coal combustion provided 36% of annual civilian energy in China (Wang 2005). The production and consumption of cigarettes is also very high in China. Field measurements showed that both Chinese cooking, coal combustion and cigarettes can produce vast quantities of PAHs (Chen et al. 2004; Du et al. 2006; See et al. 2006).

Wang et al. estimated the PAEs exposure for different groups of people in China by using the dust-concentration of PAEs found in 10 houses in China (Shen et al. 2008), and the airborne (gas-phase and particle-phase) and dust-phase concentrations recorded in 30 houses in Germany (Shen et al. 2008), and the human behavior characteristics provided by the USEPA (1997). The results are shown in Fig. 29.5.

29.4.2 Air-Conditioning and Ventilation Systems

In 2004 a national inspection on air-conditioning and ventilation systems in nearly 1,000 buildings was performed by the Ministry of Health in China and the report of the inspection shows that around half of the samples are heavily polluted with high concentrations of dust, bacteria and epiphyte and the passing rate is only 6% (Ministry of Health in China 2004). The report was achieved considerable attentions from governments, managements and researchers, and lots of field surveys were

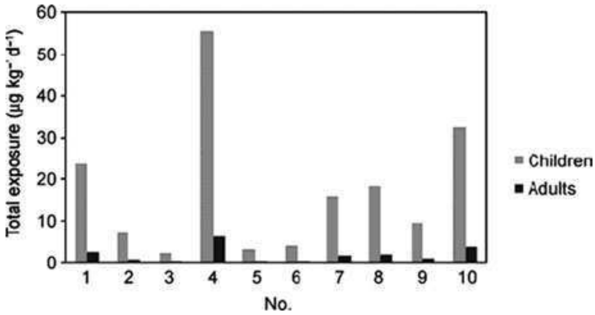

Fig. 29.5 Total exposure of adults and children to DEHP (Wang et al. 2010)

Table 29.11 Distribution of the samples

Area	Beijing	Shanghai	Tianjin	Anhui	Shangdong	Liaoning	Guangdong	Zhejiang
Sample size	139	84	32	360	238	266	96	157
Henan	Hebei	Hunan	Jiangsu	Hubei	Fujian	Guangxi	Heilongjiang	Sichuan
32	72	106	127	38	47	88	32	75

conducted thereafter on air-conditioning and ventilation systems in various area of China. The reports and papers published since 2002 are collected by the authors with a sample size of 2,027, which is shown in Table 29.11. The concentrations of dust, bacteria and epiphyte are shown in Tables 29.12, 29.13, 29.14 and 29.15.

It can be seen that in the areas with high humidities, such as Shanghai, Liaoning (most surveys in Dalian) and Zhejiang, the pollutions of bacteria and epiphyte are more serious. The concentration of dust in Beijing is large due to the particles from

Table 29.12 The concentrations of dust, bacteria and epiphyte in air-conditioning and ventilation systems for different areas

Area	Sample size	Dust (g/m^2)	Bacteria (10^4 cfu/g)	Epiphyte (10^3 cfu/g)
Beijing	28	60.06	10.00	39.6
Tianjin	32	12.89	1.78	8.0
Shanghai	4	17.40	20.50	240.0
Hebei	72	3.75	2.33	58.7
Shangdong	127	14.22	1.20	9.0
Liaoning (Dalian)	20	21.0	12.0	150.0
Liaoning (Shenyang)	179	17.1	6.01	39.8
Zhejiang	20	9.97	7.60	76.4
Heilongjiang	30	7.7	16	600
Jiangsu	156	15.3	12.5	13.1
Hunan	62	7.18	24.3	87.3
Sichuan	5	3.6	3.38	13.1

Table 29.13 The polluted level for different areas

Area	Light (%)	Middle (%)	Heavy (%)
Beijing	0	23.90	75.10
Tianjin	12.50	65.60	21.90
Shanghai	0	0	100
Hebei	4.20	82.00	13.80
Henan	15.60	62.50	21.90
Liaoning (Dalian)	25.0	40.0	35.0
Liaoning (Shenyang)	1.2	71.5	27.3
Zhejiang	0	80.00	20.00
Heilongjiang	0.00	97.00	3.00
Jiangsu	25.50	14.90	59.60
Hunan	5.00	90.00	5.00

Table 29.14 The definitions of the polluted levels

Item	Light	Middle	Heavy
Dust (g/m^2)	<2	2~20	>20
Bacteria (cfu/g)	1×10^4	$(1–3)\times10^4$	$>3\times10^4$
Epiphyte (cfu/g)	$<3{,}000$	3,000~5,000	$>5{,}000$

Table 29.15 Comparison of the concentrations of the pollutants between hotels and shopping centers

	Sample size	Dust (g/m^2)	Bacteria (10^4 cfu/g)	Epiphyte (10^3 cfu/g)
Hotels	142	21.34	3.30×10^4	3.08×10^4
Shopping centers	147	16.67	2.97×10^4	1.97×10^4

outdoor air. The pollutions in air-conditioning and ventilation systems in public places in China are very serious. A further comparison shows that the concentrations of the pollutants are higher in hotels than in shopping centers (Table 29.15).

29.5 Conclusions

The work on indoor environmental quality and SBS in China are reviewed in terms of the surveys and studies on the health effects of indoor environments, the standards and norms, and the status surveys in national scale. The status of indoor environmental quality and SBS problems in China is serious. The supervisions and executions of the current standards and norms are needed to be strengthened and what is more important is that the studies on health effects of indoor environments are needed to be carried on in systematic ways, which is believed to be helpful for the understanding of the mechanisms of the health effects, the determination of the important environmental factors and their acceptable ranges and the development of the effective technologies for control of indoor pollutions.

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Chapter 30
Sick Building Syndrome Identification and Risk Control Measures

Janis Jansz

30.1 Introduction

Some thoughts on issues associated with "Sick Building Syndrome" (SBS) follow:

If the mechanical services designers follow the Building Code of Australia (BCA) and the related Australian Standards pertaining to fresh air provisions and of course good industry practice then the potential for ventilation nightmares is much reduced. However problems often come about because someone takes short cuts in the installation, commissioning or the running of such systems.

In recent years energy consumption has been a prime consideration where costs have had to be reduced. Where the Building Code of Australia or for other good reasons the percentage of fresh air required is reduced in the misguided effort of attempting to save money, health problems will be a direct result. It is not uncommon for there to be at least 5–10% fresh air (outside air) and more in some cases to be introduced in the supply air side of a refrigerated air-conditioning system. Closing off or reducing the design or statutory fresh air values to save money will lead to false economies.

It is important to ensure the systems that control the introduction of fresh air are maintained. These systems, as with most things that move, will need to be maintained to a manufacturers recommended maintenance schedule. Actuators that move control vanes can fail through wear or inattention; filters need regular replacement or cleaning, sensing systems can fail or wear out and so on. When owning or leasing a building, the arrangements that are in place to service and maintain air conditioning systems need to be known and reported on to minimise the risk of sick building syndrome. Humidity control must be considered to ensure that legionella and other related issues are not encouraged within the plant (that includes cooling towers and duct work).

An issue often attributed to poor air-conditioning performance is where dirt is observed to accumulate around air conditioning diffusers clinging to the ceiling. People will erroneously assume the dirt build up has come from the air conditioning system. In reality the dirt is in the air in the room and due to velocity changes that occur as the conditioned air is introduced into the room through the grille, turbulence between the existing room air (dirt

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laden) and the higher velocity (clean air) the dirt is deposited on the surfaces in the low pressure areas. This dirt will be made up from dust, paper particles, skin residue, photocopier and fax toners, carpet fibres and anything else that can be become airborne. It pays to check what the cleaners actually do. Are floors actually vacuumed according to the contract or service obligations? Does toner from the photo copier get spilled onto the floor? Are old dust laden files brought into the work area? All of these things will affect the air conditioned environment.

We in Perth in general terms do not suffer the same level of issues that confront buildings in say Melbourne and Sydney where air-conditioning system designs are prone to complex humidity issues. In your story, the theme for health care buildings should be that fresh air make up should be higher than normal to minimise the very issues you describe. I recall that at the Queen Elizabeth Medical Centre in the geriatric unit, 100% fresh air was introduced in the facility for health and comfort reasons. A special system was in use to recover the energy from the expelled air where the energy was reintroduced to the fresh incoming air as an energy conservation measure (and that was in the early 1980s). Peter.

Peter has identified the importance of having appropriate effective ventilation in buildings to prevent the occurrence of sick building syndrome. Peter considered some of the building airborne contaminants that can cause ill health in humans and the importance of not only having building cleaners, but of also of checking what cleaners actually do to ensure that their work meets the required building cleaning standards. Peter ends his story by describing how a hospital reduced the incidences of infections being transferred to and from patients and staff by having 100% fresh air used in the ventilation system rather than having recycled air that recycles the micro organisms which can cause infections. Peter considered including the appropriate building ventilation system in the design stage of the building. The Property Council of Australia (2009, pp. 104–119) has check lists to use for the design, operation, maintenance and testing of the Heating, Ventilation and Air Conditioning Systems for public and other buildings. This technical information would be useful to provide to the expert who designs and provides ongoing maintenance of the building ventilation system.

According to the Legislative Assembly (2001) preventing the occurrence of sick building syndrome in building occupants starts in the building design stage and every building should be constructed and fitted out with materials that do not pollute the indoor air.

30.2 Building Design

30.2.1 Introduction to Design Considerations

Buildings were first built to provide protection for the occupants from the extremes of the outside environment that included rain, snow, cold and heat. Technology has enabled the design of buildings that can completely separate the people who occupy the building from the outside environment. Particularly in areas where there was high outdoor pollution after the industrial revolution, this was seen as being beneficial. In 1987 Wallace conducted research the findings of which identified that the time that his research participants spent indoors, not their proximity to industrial sites, was most strongly correlated with accumulated chemical exposure for these research participants, who were university students (Murphy 2006). Wallace's research highlighted the occurrence of the effects of indoor air pollution. There have been some successful cases in law courts, particularly in the United States of America, where building occupants have sued the building owner for indoor air pollution that caused the building occupant to have ill health and the occupants have been awarded substantial financial compensation (Air conditioning and indoor air quality 2006). The Legislative Assembly (2001) wrote that research suggests that sick building syndrome complaints occur in 40–60% of office workplaces.

The Legislative Assembly (2001, p iii–iv) states that the conditions inside a public building are affected by the following.

- Poor building design, particularly the complete isolation of occupants from the outside environment and the recourse to artificial lighting and "air."
- Indoor air pollutants (chemical, biological and physical from building and fit out materials and HVAC systems).
- Poor design and operation of Heating, Ventilation and Air Conditioning Systems.

Passarelli (2009) wrote that there are two ways that building owners can eliminate sick building syndrome in a new building. One is using a preventative approach which is the most cost effective approach. The other is using a reactive approach once the building is constructed and occupants complain of having sick building syndrome symptoms. When using the preventative approach it is important to meet legal requirements. In Australia it is a legal requirement that all new buildings must meet the technical regulations in the Building Code of Australia to gain approval for building proposals from the local Council. Volume one of the Building Code of Australia (2010) covers the legal requirements for public buildings while volume two covers legal building requirements for residential housing. The Building Code of Australia is up dated every year to include the latest best practice requirements. This Building Code contains many Australian Standards including the ventilation and lighting standards.

As well as meeting legal requirements there are other specific factors that can be considered in the design stage of a building to prevent or minimise the occurrence of sick building syndrome for building occupants. A very good checklist to use to help ensure that the building includes all necessary factors is the Sick Building Prevention Check list developed by the Property Council of Australia (2009). This check list has been slightly modified to include additional Australian Standards information on lighting, additional information on energy efficiency and has been included as Appendix 1 of this chapter.

The checklist contains important information to consider in the building design and construction stage. It includes natural and artificial lighting requirements, recommended shading devices (curtains and blinds), acoustic (noise reducing) factors, ventilation, temperature, humidity, air movement, outdoor air source and filtration requirements. The first part of this check list also considers work space ratios required, the distribution of workers in the building, work station designs, cleaning, sanitation and waste management, equipment, furniture and fittings (that do not pollute the indoor environment), interior design and decor. The second part of the checklist documents construction issues to be considered that includes building service design, inspection and maintenance for the central air conditioning plant, air handling equipment, cooling towers, water heaters, location of external air intake and exhaust vents, having surfaces that are easily cleaned, preventing pollution and noise, water proofing the building, energy efficiency and ensuring that the building is easy to clean.

Although this is a useful check list when using this check list think critically about every item and consider if it is required in your building. For example, under the heading of Temperature there is a question that asks "Have you prevented system imbalance by removing tenant access to temperature controls?" (Property Council of Australia 2009, p. 93). In the story provided by Andrew in Chap. 2 of this book (Jansz) there was a major problem with sharing the same air conditioner for more than one room in the building because some tenants found their room too hot, while other tenants found their room too cold. Allowing tenants to adjust the temperature for their work space would increase thermal comfort and productivity. Loftness et al. (2006) agreed with this and stated that allowing individuals to have thermal control reduced the incidences of building occupants experiencing headaches and other symptoms of sick building syndrome. At a hospital in Western Australia patients in each hospital room can use a control panel to adjust the temperature in their room to suit their comfort. Having a comfortable temperature, no matter what the patient's medical condition is, was seen as aiding each patient's recovery from their illness or surgery.

Following 5 years of intense research conducted by research students and staff at the Center for Building Performance and Diagnostics at Carnegie Mellon by Loftness et al. (2006), Fig. 30.1 was produced as research study results which linked the design of a building with the health effects that identified factors could cause to building occupants. This research group analysed 23 international building case studies and conducted laboratory and simulation studies (results recorded at the web address http://cbpd.arc.cmu.edu/ebids) to identify the effects that factors in building design and building fittings, when not present, had on the health of building occupants.

In this Figure it is noticeable that the researchers look at the total person, not just the factors that can cause sick building syndrome as ergonomic factors and the health effects of not including good ergonomic design are also considered. Loftness et al. (2006, p. 5) when writing about their research studies results state that their findings have demonstrated that "Humans need access to the abundance in nature – daylight, natural ventilation, thermal diversity, physical access and views; at the same time, humans need protection from natural stresses – overheating, excessive cold, rain." These researchers described other research studies by Walch et al. (2005), Benedetti et al. (2001) and by Choi (2005) that have demonstrated that the sunlight reduces the stay in hospital of patients who are recovering from surgery, from physical and from mental illnesses. Ultra violet light influences the

Building Massing & Enclosure	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Design for day light / view / passive solar			**X**					**X**	**X**
Design for natural ventilation	**X**								**X**
Engineer thermal load balancing							**X**		
Design enclosure integrity	**X**			**X**			**X**		
Lighting & HVAC system									
Separate ambient & task lighting			**X**						
Specify high performance lighting & controls			**X**						
Separate ventilation & thermal conditioning	**X**						**X**		**X**
Increase outside air and ventilation effectiveness	**X**								
Engineer moisture / humidity management	**X**				**X**				
Engineer individual control of temperature							**X**		
Interior systems									
Specify ergonomic furniture						**X**	**X**		
Design special layout for health / safety						**X**			
Specify acoustic quality				**X**					
Specify materials vs. out gassing / degradation	**X**							**X**	
Specify materials vs. irritation / re-infection	**X**	**X**			**X**				
Specify materials vs. mould	**X**								
Operations									
Continuously commission systems	**X**								
Eliminate standing water, dampness & mould	**X**								
Design for non-toxic pest / plant management	**X**	**X**						**X**	
Design for environmentally benign clean	**X**				**X**			**X**	
Reduce waste / manage waste vs. pests	**X**								**X**

Fig. 30.1 Linking design, decision making and health. For health effects 1 = Respiratory system. 2 = Digestive system. 3 = Eyes, vision, irritation, circadian system. 4 = Ears, hearing damage, concentration. 5 = Skin. 6 = Muscular-skeletal. 7 = Circulatory system. 8 = Nervous system. 9 = Mental health, stress

production of melatonin in the human body. Melatonin controls the human body circadian rhythms which influence the body's sleep cycle. Loftness et al. (2006) cited research by Ulrich (1984), Mendell (1991), and by Kellert (2005) that found that having a view of nature through building windows reduced the incidence of the occurrence of sick building syndrome in building occupants.

30.2.2 Designing Ventilation

When designing the ventilation for a new building natural verses artificial ventilation was considered by these researchers and is described in Table 30.1 (Loftness et al. 2006, p. 6).

Table 30.1 Should building windows open?

No	Yes
Avoid outdoor pollution.	Dilute indoor air pollution from materials and activities.
Avoid outdoor humidity.	Diffuse indoor air humidity build up.
Avoid outdoor noise.	Connect to nature – air, sounds.
Well designed and maintained Heating, Ventilation and Air Conditioning system (HVAC) provides temperature control.	Increases local thermal control when there are not adverse weather conditions.
Avoid rain penetration.	Design windows to shed rain.

The authors' answer to the question (Should building windows open?) was that buildings should be designed with natural ventilation being available without drafts or rain entering the building. The Legislative Assembly Standing Committee on Public Works (2001) recorded that naturally ventilated buildings are called yellow buildings. This Committee's investigation found that yellow buildings were healthier than green buildings that were sealed shut and had artificial heating, cooling and ventilation. Using outside ventilation reduces the incidences of headaches, colds, influenza, asthma, allergies and sick building syndrome (Brundage et al. 1988; Jaakkola and Miettinen 1995; Drinka et al. 1996; Sundell 1996; Bourbeau et al. 1997; Frisk and Rosenfield 1997; Smedje and Norback 2000; Menzies et al. 2000; Tham et al. 2003; Myatt et al. 2004; Loftness et al. 2006; Roy 2010). In areas where there are adverse weather conditions a well designed and maintained HVAC system should also be available for building occupants to use. Peter, in the story at the beginning of this chapter, describes what he sees as a well designed ventilation system that uses 100% outside air and allows individual control so providing the best of natural ventilation and temperature control. The system described is also environmentally friendly as energy is recovered from expelled air and reintroduced into the fresh incoming air.

The Health and Safety Executive (2004) agreed with Loftness et al. (2006) as their guideline for occupational hygiene specialist inspectors, stated that sick building syndrome usually occurred in buildings that had air conditioning, a warm thermal efficient environment, and "air tight rooms, e.g. where there are no openable windows or other openings to the outside" (p. 2) and that the presence of unpleasant odours was an indication of poor ventilation. The Health and Safety Executive suggested that contributing factors to the occurrence of sick building syndrome are inadequate ventilation, low humidity, thermal discomfort and/or air borne pollution, including biological hazards.

Loftness et al. (2006) recommend that if a ventilation system is to be used in the building then the building ventilation system should be separate to the building temperature control system so that both can be adjusted separately by the building occupants to meet their comfort needs. These authors also state that the ventilation system should be able to be controlled by individuals so that local pollution can be controlled at its source.

The Property Council of Australia (2009) recorded that when designing the ventilation system it should be designed to maintain the building air humidity between 40 and 60%. If the humidity is lower than this level then the air is too dry and can cause respiratory, eye and dermal drying and the symptoms of sick building syndrome that are related to these body parts. Having air humidity below 20% can cause a build up of static electricity, off gassing and an increase in air borne dust and fibres, all of which can affect the health of the building occupants (Health and Safety Executive 2004). If the humidity of the air is above 70% then condensate forms on surfaces in the building allowing mould and other micro organisms to grow and thrive in this environment. Micro organisms can emit spores, fragments, cells and volatile organic compounds into the building atmosphere. These can cause adverse health effects in the building occupants. Chap. 11 in this book by Pinzari and Montanari describes the sick building symptoms that can be caused by mould and other micro organisms. High humidity can cause biological and/or chemical degradation of materials in the building which in turn generate indoor air pollution. "Dampness has therefore been suggested to be the strongest and most consistent indicator of risk for asthma and respiratory symptoms" related to the occurrence of these sick building syndrome symptoms (World Health Organisation 2006, p. 6).

Roy (2010) found that symptoms of sick building syndrome increase when the building occupants perceive that the air quality is poor. As well as having a ventilation rate of at least 15 litres per second per person for each person in the area Roy states that the placement of the ventilation ducts in the building is very important as if the intake and outlet vent are too close then indoor air pollution is not dispersed. If the intake vent takes in polluted air then this will affect the health of building occupants so air intake vents need to be located away from car parking areas and other sources of outdoor air pollution.

The United States of America Environmental Protection Agency (US. EPA 2010) has recorded that until the 1973 oil embargo building ventilation standards required 15 cubic feet per minute (cfm) of outside fresh air for each building occupant to disperse the carbon dioxide produced by the breathing of the building occupants and disperse the body odours of people in the building. As a result of this oil embargo national US energy conservation measures were implemented which reduced the amount of fresh air per person to 5 cfm per person. The US. EPA (2010) reports that this caused many building occupants to report experiencing sick building syndrome. In Chap. 28 in this book, Nedved describes the currently required ventilation rates in the United States of America. In office buildings this is now 20 cfm per person. In commercial environments with tobacco smoke, the required ventilation rate is now 125 cfm per person. This chapter by Nedved (2011) provides a comprehensive description of what must be considered and included in the building ventilation system in the design stage of the building and includes information on the required location of ventilation air intake and air exhaust vents.

Australian and other Ventilation Standards are a useful guide, but these guidelines need to be supplemented by considering individual differences and asking the building occupants if they are comfortable. If the air flow is perceived as being too high then the building occupants will complain about air drafts. If the air flow is considered too low then occupants will complain about the air in the building feeling stuffy. Furniture in the building needs to be positioned so that it does not obstruct the air intake or air outlet vents or obstruct the air flow through the room.

The Health and Safety Executive (2004) states that sick building syndrome could be a stress response to unsatisfactory workplace conditions, particularly the thermal environment. They state that "personal thermal comfort depends on air temperature, radiant heat, humidity, air velocity, clothing, activity rates and personal preferences" (p. 4). The Health and Safety Executive (2004) recommends that all of these should be measured, considered and that the usual comfortable temperature in a building for occupants in winter is between 20°C and 24°C and between 23°C and 26°C in summer. This should be considered in the planning stage when setting the building temperature.

30.2.3 Planning

It is important when planning a building to consider all of the factors identified in Fig. 30.1 in this chapter as well as the people who will use the building and the activities that will be performed in this building to minimise the occurrence of ill health occurring in building occupants due to building design, building materials used, furniture and building fittings.

The following are practical principles to use for building design, particularly if the building is going to be used as a workplace.

- Plan the ideal, then the practical.
- Plan the whole, then the detail.
- Plan the work process and equipment around the system requirements.
- Plan the workplace layout around the work process and equipment.
- Plan the final enclosure around the workplace layout.
- Use mocks and models to evaluate alternative solutions and to check the final design.

When planning, if possible, involve the people who will use the building in deciding each of the above. In Chap. 13 in this book, Clements-Croome identified that this is important as people need to feel that they matter. The people who will use the building will be able to advise how they intend to use the building, particularly if it is a workplace. They will also know what work processes will occur in the building and the equipment they will be purchasing to use in the building.

In the planning stage of a building the Health and Safety Executive (2000) records that to minimise the risk of sick building syndrome occurring where ever possible in the building design stage include natural light for the building as this minimises the incidences of mould, decreases lighting costs, connects the outdoor with the indoor and promotes a healthier outlook. To minimise glare from the morning or afternoon sun blinds should be included for all windows. Adequate lighting should be included for all work tasks. The Australian Lighting Standards AS/NZS 1680.2.2:2008 and AS/NZS 1680:2006 Interior lighting both provide guidelines for the lighting requirements for specific work processes. As with temperature, ventilation and other environmental factors the people who will use the building need to be able to control the lighting that they use. This must be considered in the building planning stage.

In Mandurah in Western Australia a sustainable home has been built. The key design principles recommended, considered and used for this home include the following.

- Use of passive solar principles. This includes locating the building with a northern orientation (in the Southern Hemisphere), having eaves around the building (to admit winter sun to warn the building and exclude summer sun) and having shading features to keep the summer sun out and allow the winter sun in. This assists with keeping the building at an even temperature throughout the year.
- Use high insulation levels, especially to thermal mass.
- Maximise north facing walls and glazing, especially in living areas with passive solar access.
- Minimise all east and west glazing. Use adjustable shading.
- Use heavy drapes with sealed pelmets to insulate windows to keep the building cool in summer and warm in winter.
- Use cross ventilation through the location of doors and windows to produce passive air flow cooling in summer. Cross ventilation increases effective air circulation within the building.
- Encourage convective ventilation in heating circulation.
- Site new buildings for solar access, exposure to cooling breezes and protection from cold winds.
- Draught seal the building thoroughly and use entry air locks.
- Use reflective insulation to keep out summer heat.
- Use bulk insulation to keep heat in during winter. Bulk insulate walls, ceilings and exposed floors (The Sustainable Mandurah Home 2010, p. 1).

An advantage of following this advice is that artificial cooling and heating, with its resultant difficulties, should not be required for the building in most climate conditions. Using these building recommendations should produce enough natural light during the day time to not require artificial light. Access of sun light to areas of the house, particularly wet areas such as the bathroom, should reduce the occurrence of mould growing in the building. In bathrooms and other wet areas the floors and walls should be made of non porous materials to reduce any opportunities for mould to grow on building materials.

The City of Palo Alto California (2010) records that sustainable green buildings that take in to account the above recommendations are better long term investments as they have much lower operational and maintenance costs. "Green building design typically increases productivity, because it improves factors that enhance life within the building such as good indoor air quality and natural lighting" (City of Palo Alto California 2010, p. 1).

In the building planning stage consider the furniture and fittings. Urea-formaldehyde resins are used when manufacturing plywood, particle boards, wood products surface coatings, flame retardants, textiles, in wood glues, thermal insulation, office copy paper and soft furnishings. All of these omit volatile organic compounds that can cause sick building syndrome symptoms and should be avoided where ever possible. In the case study of the United States of America Environmental Protection Authority, described by Jansz, it was identified that 68 different chemicals were emitted from the new carpet. In combination with other factors this resulted in employees experiencing the symptoms of sick building syndrome. There is a similar story that is told by Malcolm (Jansz 2011b) where employees experienced the symptoms of sick building syndrome after new furniture and floor coverings were installed in their building. In both cases when occupational hygiene monitoring was conducted there were not identified high levels of any particular chemical. There were just low levels of a variety of chemicals. Brinke et al. (1998) reported that a combination of chemicals can have synergistic effects and become an irritant.

Research conducted by Hodgson et al. (2002) identified that if laminate was placed over wood products as a surface coating that it reduced the emission of formaldehyde and odorous aldehydes which have been identified as causes of sick building syndrome. This should be considered in the planning stage. As volatile organic compounds are produced from paints and coatings containing petroleum based solvents and fungicides the City of Palo Alto California (2010) recommends that latex or water based paints should be used when paining the surfaces in buildings as these paints can be manufactured with no volatile organic compounds included. For all products considered in the construction and for use in the building in the planning stage the material safety data sheet should be checked and reviewed for any hazardous ingredients which can have a potential impact on indoor air quality (Massachusetts Division of Occupational Safety Occupational Hygiene Program 1997). Products that are not hazardous to human health should be purchased and used in buildings where ever possible.

In the planning stage floor coverings must be considered. If carpet is selected as a floor covering for some areas the carpet selected should be made of natural materials such as wool. Wool is naturally resistant to mildew and static electricity. It does not contain odorous chemicals (such as 4-phenyl-cyclohexene) which are used in the manufacture of synthetic carpets or vinyl chloride monomer which is a known carcinogen that is included in some synthetic floor coverings, such as vinyl, and which can affect the indoor air quality. Other floor surfaces which may meet the needs of building occupants can be stone, cork or rubber all of which are natural products and do not produce atmospheric contaminants.

Keep records of all suppliers and products, particularly those that have the potential to produce an effect on indoor air quality. This would be important for building owners or tenants who have purchased the products as product manufacturers and suppliers have a legal responsibility for providing safe goods that do not adversely affect human health.

Work equipment chosen should have low noise emission. If the noise level of the equipment would disturb the building occupants then the machinery should be isolated or eliminated to minimise the building occupants having adverse health effects due to building equipment noise. In the planning stage it is important to identify who will be responsible for equipments and for building maintenance and who will supervise this work as regular maintenance is required to keep the equipment and building in good condition to minimise the risk of sick building syndrome occurring. Meeting the required standard of building construction also needs to be considered to prevent sick building syndrome from occurring.

30.2.4 Building Construction

When reporting for a government inquiry into housing construction in Victoria the Royal Australian Institute of Architects and Archicentre Victoria (2005) identified that there has been a decline in the number of skilled building workers in Australia and that building inspections conducted by architects have identified that lack of skilled workers has resulted in problems with unsatisfactory building brick wall construction (in 14.6% of buildings inspected), incomplete building work (18.9%), poor building workmanship (43.6%), dampness in newly constructed buildings (6.9%), poor drainage (4.2%), gaps in window sills (2.7%) and deficits in the ceiling lining (1.6% of buildings inspected). To help prevent the occurrence of sick building syndrome this organisation recommended that building construction workers should be closely supervised to ensure that they produce work of a high standard. They reported that airborne toxins that can cause sick building syndrome symptoms are at their highest level while a building is being constructed and immediately after construction.

The Royal Australian Institute of Architects and Archicentre Victoria (2005, p. 12), recorded that sick building syndrome costs Australians $12 billion a year. According to World Health Organisation (2006), a third of new buildings constructed since the 1960's are sick. Solvents, adhesives, laminates, carpets and certain wood products "off gas" after installation; over time they dissipate to imperceptible levels but always remain present. A fully sealed five star energy rated home has many benefits both in energy and cost savings; however, it also tends to create micro climates that can cause serious illness.

Preventing problems from occurring should commence in the building planning stage however if these problems do occur then their risk of causing harm to building occupants needs to be identified.

30.3 Sick Building Risk Identification

30.3.1 Introduction

A hygienist was contacted by a telecommunications company to investigate complaints from a recently constructed retirement village that a bank of batteries, used to provide emergency backup power for telecommunications equipment, was generating acid fumes. This

> was an unusual complaint, as these batteries are not known to generate fumes and a report from an electro-technical consultant indicated that the batteries were in good condition. The hygienist visited the site to conduct a walk-through survey, prior to conducting a more detailed assessment.
>
> The room where the batteries were located was closed off and sign posted warning people not to enter. Upon entering the room the fumes were so overpowering that they hygienist and the accompanying telecommunications workers were affected. The fumes were highly irritating to their eyes causing tearing and affected the upper respiratory tract; there was a pungent odour. The room, which had recently been painted and carpeted, was used to store new tables, chairs and trestles all of which were made from chipboard. It was noticeable that the room was completely sealed with no ventilation.
>
> The answer was obvious – to an experienced eye (not to mention nose)! The batteries were not the source of the acid fumes. The problem was the room itself. The irritant gas was recognised as formaldehyde, which was being off-gassed by the new paintwork, carpet and furnishings. The problem was compounded by lack of ventilation in the room. This situation is not uncommon in new buildings and time should be allowed for the fittings and furnishings to cure, before the building is occupied. This is sometimes referred to as 'Sick Building Syndrome'. In this case the hygienist had very quickly (and cheaply) solved what could have been a potentially serious problem for the telecommunications company" (Jennings 2010, pp. 216–217).

This story, which describes a situation that occurred in a newly refurbished Nursing Home, highlights the need to keep an open mind when investigating building related problems. It shows how an experienced investigator can identify the cause of sick building syndrome and how valuable identifying this cause can be so that appropriate action can be undertaken to eliminate the cause of the telecommunication workers experiencing ill health.

Gallego et al. in Chap. 16 in this book that is titled "Assessment of chemical hazards in sick building syndrome situations: Determination of concentrations and origin of VOCs in indoor air environments by dynamic sampling and TD-GC/MS analysis" provides information that occupational hygienist can use when investigating and determining if volatile organic compounds are present in the building environment. The Property Council of Australia (2009) Appendix E. "Air Quality Testing Specifications" provides useful information on tests and methods to be used by Occupational Hygienist to investigate and determine causes of sick building syndrome. Appendix F (Property Council of Australia 2009) provides comprehensive information on indoor air gaseous pollutants sources and known health effects, particulate pollutants sources and known health effects, biological pollutants sources and known health effects and other factors that can affect the indoor air quality. These include pesticides, static electricity charges, odours, low levels of negative ions and electromagnetic radiation. All of this information is very useful to have when investigation the causes of sick building syndrome.

30.3.2 Building Inspections

Although SBS can occur in any occupied building, research conducted by the Health and Safety Executive (2000) identified that Sick Building Syndrome most commonly occurred in open plan offices with more than 10 work stations, if there were large areas of open shelving and soft furnishings in the room, or if there was new furniture, carpets and newly painted surfaces. Other building related factors that caused Sick Building Syndrome included the building having air conditioning, particularly if the air conditioner was poorly maintained, if a room had poor lighting, predominantly if there was high glare, insufficient light for work tasks to be performed well or if there were flickering lights, if the building occupants were unable to control the building ventilation, temperature or lighting, if there was very high or low indoor air humidity, if the building was in a poor state and needed maintenance, if the building was poorly cleaned or had dust particles or fibres or chemical pollutants in the atmosphere. The Health and Safety Executive (2000) also recorded that the people who were most affected by Sick Building Syndrome were the people who had the least amount of control over their working environment and people who used display screen equipment.

The US EPA (2010, p. 3) reports that when investigation causes of sick building syndrome the four most important factors to consider are building:

- Occupants,
- Heating, ventilation, air conditioning (HVAC) system,
- Possible pollutant pathways,
- Possible contamination sources.

The Health and Safety Executive (2004, pp. 4–5), Joshi (2008) and the US EPA (2010) state that if sick building symptoms are reported by building occupants then the owner of the building, or the employer, should undertake an investigation into the cause(s) of these symptoms using the following steps.

1. Identify key people who can provide building access and information.
2. Notify building occupants about the investigation.
3. Record any easy to obtain information about the history of the building.
4. Carry out a workplace employee survey to determine if the prevalence of symptoms is higher than expected or if the symptoms are caused by a common virus, etc. The survey can help to identify common causes of sick building syndrome which can easily be remedied such as changing the workplace temperature or humidity. This survey needs to include questions that ask the employees what they think that the causes of their symptoms might be and any pattern of occurrence of these symptoms.
5. Analyse employee sickness and absenteeism records to look for a common trend to pin point where the building problems might exist.
6. Look for the obvious causes of the symptoms that the people in the building have.
7. Check that the building has satisfactory sanitation.
8. Check general building cleanliness, including checking that vacuum cleaners are effective, regularly emptied and that filters are clean.
9. Check proprietary cleaning materials are non toxic and are being correctly used.

10. Check general operation of heating, ventilation and air-conditioning systems, including correct setting of dampers, particularly in the fresh air supply system.
11. Check ventilation air inlets and outlets for effective location and functioning.
12. Check condition and cleanliness of air filters, humidifiers, de-humidifiers and cooling towers.
13. Check heating, ventilation and air-conditioning maintenance schedules and compliance with these schedules.
14. On completion of these steps and after any required remedial actions have been taken, if symptoms persist, carry out a more detailed investigation of the workplace environment. This may require the services of a building service engineer, an occupational hygienist or another competent consultants.

Redlich et al. (1997) record that the best way to identify the causes of sick building syndrome is to use a team approach that includes the person's treating medical practitioner, an industrial hygienist and a building ventilation engineer to conduct the investigation. Korpi et al. in Chap. 24 in this book called "Solving indoor environmental problems: What can be found out through individual measurements?", has tables in this chapter that include important factors to be considered when conducting a building inspection to identify the causes of sick building syndrome symptoms.

30.3.3 Epidemiologic Investigation

If a simple building inspection and a though investigation by an occupational hygienist has not identified the cause of building occupants experiencing sick building syndrome then an epidemiologic investigation may be conducted. Niven et al. (2000) conducted an epidemiologic study with 1,000 research participants from 5 buildings. These participants completed a questionnaire to identify if they had any symptoms of sick building syndrome, if they did how often they had these symptoms and the timing of these symptoms. Demographic data was collected as was the research participants' subjective assessment of their work environment and their attitude to their work. Six areas in which building occupants experienced a high prevalence of symptoms, and 6 areas in which building occupants experienced a low prevalence of symptoms, were identified for a detailed environmental assessment to be conducted on. Air movement, temperature, humidity, velocity, respirable particles, lighting and sound levels were all measured using the appropriate equipment.

Univariate analysis was used to compare the presence of sick building symptoms for the occupants of each building. Questionnaire answers were also analysed using Multiple Logistic Regression with people who experienced symptoms of sick building syndrome as the dependent variable and environmental exposure indices as the independent variable. The results of this research identified that the presence of air borne particulates and the presence of low sound frequency noise were strongly correlated with building occupants experiencing the symptoms of sick building syndrome. Schneider (1999) recommended that questionnaires should be used in conjunction with building indoor air monitoring to identify any correlation between symptoms and the presence of air contaminants. This is what was done in this epidemiologic investigation.

Having identified where the problems were occurring enabled appropriate risk control measures to be implemented in the relevant parts of the buildings. Elci et al. in Chap. 22 in this book titled "Epidemiologic investigation methods for sick building syndrome", provide comprehensive information in relation to conducting an epidemiology investigation. If people become sick it is important to investigate the cause of their illness as Lee did in the story in Chap. 2 (Jansz 2011b) and request the sick person to see their Medical Practitioner for correct diagnosis and treatment. The Medical Practitioner will then make a diagnosis of sick building syndrome or not based on the person's clinical presentation, the absence of any other likely diagnosis and the presence of building related factors that could cause sick building syndrome symptoms (Redlich et al. 1997).

It can be noted that an epidemiologic investigation includes a survey questionnaire being administered to building occupants to assist with identifying evidence of, and causes of, sick building syndrome.

30.3.4 Survey Investigation

To help to identify the symptoms of sick building syndrome and its causes, building occupants can keep a diary for a month. This will provide a record of their experiences, but may not be taken seriously by the building's owner or by the employer if the building is a workplace. In order for building owners or managers to take employees or building occupants' building related ill health complaints seriously, TSSA (2010) recommends that a questionnaire survey should be given to the building occupants, the results of the survey collated, analysed and given to the decision maker for action. Survey results provide relevant information to support building occupant's claims that working or living in the building is harming their health and should mean that the building owner or employer takes action to correct the identified causes of the people's ill health. After the remedial action has been taken by the building owner or employer TSSA recommends that the building occupants be resurveyed to identify if occupants' health has improved and if they are now satisfied with building environmental factors.

Appendix 2 of this chapter contains a Building Occupants' Health Survey that can easily be used to identify the presence of sick building syndrome symptoms and possible causes of these symptoms. All of the questions included in this questionnaire were taken from 3 previously used questionnaires. The National Institute of Occupational Safety and Health (NIOSH) indoor air quality survey questionnaire, the American Industrial Hygiene Association (AIHA) occupational health and comfort questionnaire and the Danish Building Research Institute building diagnostic human resource questionnaire all of which were published by Godish (1995). These three questionnaires have already been used for extensive research studies, had their questions validated and checked for reliability. Combining the most relevant questions from each questionnaire has enabled a useful generic survey tool to be developed that can be used for most buildings and by most occupations. As well as having set questions for ease of data analysis this questionnaire includes open ended questions to also obtain qualitative information from respondents for analysis to identify any factors related to the symptoms and causes of sick building syndrome that were not included in the set questions.

For people who cannot read this survey may be administered orally as an interview with the interviewer recording the answers on the questionnaire. As well as being used reactively when building occupants complain of experiencing the symptoms of sick building syndrome this survey tool may be used proactively with occupants of a new building to determine if the building is healthy. Another proactive use can be for conducting an annual survey, particularly if building occupants have previously experienced the symptoms of sick building syndrome in the building, to determine if the building environment has any problems which may be affecting the health of its occupants.

This book includes another questionnaire that has been used by Abdul-Wahab and Salem and is reported in Chap. 12 titled "Is your library building sick? A case study from the main library of Sultan Qaboos University at Sultanate of Oman". The questionnaire in Chap. 12 has been developed specifically to identify incidences of, and causes of, sick building syndrome in libraries. Information provided in this chapter demonstrates the effectiveness of using a survey questionnaire as it documents a comprehensive identification of building occupants' symptoms in relation to sick building syndrome, potential environmental causes and well written recommendations for risk control measures to make the library buildings healthier places to work in and for customers to visit. A building consultant may be used to investigate the cause of building occupants experiencing sick building syndrome and to make recommendations.

30.3.5 Building Investigation

The following story highlights the advantage of using a qualified consultant to conduct an investigation when people in the workplace do not know the cause of the occupants experiencing sick building syndrome.

Roy (2010) provided a description of how he, as the consulting occupational hygienist, conducted an investigation of a Rural Water Corporation Office building in New Zealand in which many staff experienced symptoms of sick building syndrome. Roy was called in to conduct an investigation into the cause of employees experiencing sick building syndrome after one staff member developed severe pulmonary effects, was unable to continue working in the building and the remaining employees walked out the building and refused to re-enter the building to work there. The building investigated was a new 5 star rated Green Building. The workmanship used when constructing this building was poor. Cold drafts of air were common inside the building due to gaps in the building walls. There was excessive internal negative pressure in this building. Wall cavities contained chip board, saw dust and volatile organic compounds.

When conducting an investigation into the reason for occupants experiencing the symptoms of sick building syndrome Roy (2010) began by undertaking building observations, a walk around survey and talking to relevant people. He took a camera with him to take photos of any factors that may require further investigation. Roy (2010) then conducted a thorough HVAC system inspection. He also under took monitoring for the quality of indoor air including for the following.

- Carbon dioxide level.
- Carbon monoxide level.
- Humidity.
- Temperature.
- Volatile organic compound samples (which were sent for more detailed GC/MS analysis).
- Particulate samples (which were sent for SEM/EDX analysis).
- Ventilation system effectiveness measurements.
- Air and surface monitoring for bacteria, for fungi and for other micro organisms.
- Monitoring for fungal and for bacterial toxins.
- Formaldehyde levels.

Scientific odour panels were used to detect odours. Roy (2010) consulted with experienced toxicologist, mycologist, occupational physicians who had been treating the sick building syndrome symptoms of the employees working in the building and he consulted with the mechanical engineers who serviced the building's air conditioning.

The results of this comprehensive investigation identified that airborne mould spores were being released from localised mould growth at several sites in the building where there were repeated water leakages. One area in this building had to have major renovations because of the extensive wall cavity mould growth. There was diffuse wide spread mould growth because the relative humidity level in this building was consistently above 70%. This occurred because the HVAC system had design problems and was shut down for extended periods of time. Also some areas of the building did not have an air return pathway.

The building owner was unaware that repairs that were paid to be undertaken to the HVAC system were not done as requested. Corroded areas of the air handling unit were bogged and painted over instead of being repaired by the contractor who was employed to make the repairs. Broken door hinges and worn gaskets were not replaced as requested by the building owner. The roof air handling units were found by Roy (2010) to be in a poor state with unsatisfactory air filtration due to the wrong type of filter being used. The air filter used did not meet international ASHRAE

Standard recommendations, did not fit the air handling unit and produced ineffective filtration of the incoming air. The air handling unit lacked mechanical pre-chilling for fresh air dehumidification. There was no air inlet filter. Roy (2010) found that the original fan belt guard in the air handling unit was corroded and had not been replaced. The electric heating elements were exposed. The accumulated dust, dirt, insect parts, plant material, etc on the exposed heating elements released foul odours in the building when they burnt if the building heating system was turned on. This odour made the building occupants feel nauseated.

Roy's building investigation (2010) identified that air borne fibreglass dust particles (synthetic mineral fibres) which came from damaged and exposed ceiling tiles and the ceiling insulation through the ventilation system were causing building occupants to experience skin itchiness, skin rashes, eye, nose and throat irritations. In the ceiling space Roy found that there were uncapped open air supply fittings that were dumping air into the ceiling spaces instead of supplying air to the rooms below. These air leaks pressurised the ceiling spaces and drove contaminants from the ceiling into the occupied rooms below. The ceiling was filled with damaged, dirty, mouldy fibreglass batts piled loosely in the ceiling.

The building air had high levels of volatile organic compounds (VOCs) in it from new furniture, new carpets and newly painted walls. As the ventilation system did not work properly there was insufficient fresh air flow rate to disperse these chemicals from the air that the building occupants were breathing. Other issues that contributed to the occupants' ill health were found to be poor control over the air temperature, drafts of cold air that building occupants said caused them to shiver and develop respiratory infections, stuffiness due to the poor quality of air, musty odours caused by the presence of mould and poor ventilation, poor lighting that made conducting work tasks difficult and equipment noise and vibration that caused headaches to occur amongst the building occupants. As the building ventilation system circulated insufficient fresh air this resulted in the building air having elevated levels of carbon dioxide in it.

Prior to Roy (2010) investigating the causes of the sick building symptoms the building occupants had developed anxiety, stress (which can decrease the person's immune function), anger, and distrust of the building owner because of the long standing and "mysterious" nature of the workplace environmental issues that were causing them to experience the symptoms of sick building syndrome and because of the management's well meaning, but failed, attempts at risk communication. Due to the above issues the building occupants had walked out of the building and refused to re-enter this building to work until the cause of their ill health was identified and rectified. Their employer had to transfer all staff to temporary rented offices for almost a year while the building related causes of employees' ill health were identified and the necessary renovations were under taken to make the building safe for occupants to work in it without their health being adversely affected.

30.4 Sick Building Syndrome Risk Control Measures

30.4.1 Building Investigation Risk Control Measures

Once the cause of the building occupants' ill health was determined, Roy (2010) recommended risk control measures to eliminate the causes of sick building syndrome. Remediation measures used to make the Rural Water Corporation Office Building in New Zealand habitable following Roy's investigation included the following:

- New roof mounted air handling units were installed that had mechanical pre-chill and dehumidification capacity.
- Ceiling spaces were cleaned.
- Direct ducted air supply was provided to the rooms.
- The correct filters were installed for all air handling units.
- All deficiencies in air distribution and air return pathways were corrected.
- All damaged ceiling tiles were replaced.
- New plaster tiles with polyester fibre pads instead of fibreglass batts were used as ceiling insulation.
- Adequate lighting was installed for all work processes.
- Noise and vibration producing equipment was located outside of the office areas and isolated.
- Water leaks were repaired.
- Mould damage was remediated.
- Gaps in the building walls were filled.

Major problems had occurred when this building was built and when repairs were made to the building air conditioners as the contractors doing the work were not supervised effectively and the necessary checks at the completion of the contractors' work were not undertaken. The poor initial quality of the building contractors' workmanship resulted in the necessity for expensive re-work to provide a healthy environment for employees to be able to work in the building. While the above repairs were being conducted, and at the completion of the work, Roy conducted site inspections to verify that all remediation steps were undertaken and that the work was completed by the contractors to a satisfactory standard.

Regular project briefings and reports were provided to all office staff. Roy also held weekly meetings with the Property Owner/Manager, Employee Representatives, Government Agency Officials and Consultants to keep everyone updated on the progress of the investigation and then on the progress of the remedial measures being implemented. At the conclusion of the remediation measures being completed employee representatives were taken on a final building tour. There was a final close-out meeting with the project team when consensus was reached by all of the stakeholders that all issues were resolved. Roy (2010) worked with the Project team to ensure that an ongoing building maintenance plan was put in place.

This building was then fully re-occupied and has remained occupied with no further incidences of sick building syndrome being reported.

As a summary for risk control measures for sick building syndrome the US EPA (2010) documented that education and communication in both preventative and remedial indoor air quality management and information on causes and consequences of having poor indoor air quality for building owners, employers and relevant employees is important. Also important, according to the US EPA, are the following:

- Immediate repair of any building water leaks from plumbing, roof, HVAC system, or other sources must be undertaken. Any water stained ceiling, carpet and or other water stained fixtures must be removed and replaced to prevent the growth of mould or other micro organisms on them.
- Any emissions that have the potential to harm the building occupants' health should be ventilated out of the building from the source of the pollutant. This may require local exhaust ventilation.
- Paints, solvents, adhesives and pesticides should be stored in a well ventilated area outside of the main building and should only be used when the building is not occupied. If these substances are used then the building must be well aired before re-occupancy.
- HVAC ventilation rates must meet local building codes and standards.
- Periodic cleaning and replacement of the HVAC system filters and routine maintenance of the HVAC system must be undertaken.

30.4.2 Maintenance

In Western Australia accommodation supplied by mining companies must meet the requirements of the Occupational Safety and Health Act 1984. For this reason it is a legal requirement in Western Australia that employees who work in the Western Australian mining industry, and who live in company supplied accommodation, have safe and healthy accommodation. The following is a story supplied by a mining industry employee who lived in company supplied accommodation in Western Australia. This story highlights the importance of the air conditioning unit, of preventing the growth of mould in the house and of having good HVAC and building maintenance.

> We first moved into a 3 bedroom brick and tile house in Craig Street on 10th Dec 2007 at which time the APAC ducted air con system had been turned off for approximately 2 week immediately prior to us moving in. On arrival we turned on the ducted air con and smelt a strong mould smell. We proceeded to air the house out and disinfect everything including the air con filter and ducting outlets. After couple days to a week later the whole family came down with severe sinusitis. We normally did not suffer from sinus problems prior to this. We could not shake the flu even with antibiotic for about 6 weeks. Once over the sinusitis we regularly suffered from chest infections and sinusitis for the next 12 months until we finally got moved to another house.

> On 20th Dec 2008 we moved into a 3 bedroom fibro house in Robinson Street with APAC ducted air con. Once in the house we noticed after a couple of week we all started to feel a lot healthier. Over the next 9 months we had minimal sinus problems until, under the advice of the Housing Department, we turned off the re-fridge compressor and just ran the air con unit fan to reduce power cost for the winter period. About 1 month after turning off the compressor we started to notice a small amount of mould starting to grow around the ducting and insulation, so we disinfected and immediately started the compressor again and have not turned it off since. Over the last couple of month we have noticed an increase in mould growth despite our regular attempts to disinfect the filter and duct outlets. Our health has started to deteriorate again and we regular wake up of a morning with congestion in the sinus and even breathing difficulties.
>
> Note we have two young children 3 ½ and 1 ½ who regularly play with other children who could also be a source of infection. None of us are smokers. We spend most of our day outside other than during the heat of the day and from dinner time until we wake in the morning and go to work. Michael.

It is evident from this story that in both of these houses there was not good building and HVAC maintenance. The Property Council of Australia (2009) in Appendix B has a useful HVAC maintenance and operational checklist that contains 22 considerations for HVAC maintenance. Some of the important factors included in this checklist include the need to meet the Australian Standard requirements, what to check and how to check for vermin (mice, rats, birds) access and system contaminants, what and how to check to ensure that there is correct air distribution in the building and that the outdoor air cycles are effective, the mechanical operation of the system and filter inspection, maintenance and when to replace the filters.

If a building is well designed then the Health and Safety Executive (2000) has recorded that having good and regular maintenance procedures is one of the best ways to prevent the occurrence of sick building syndrome symptoms from occurring. There should be a schedule for regular (for example, monthly) cleaning and maintenance of the building air conditioner (which supplies building heating, cooling and ventilation), and lighting. Lights should be kept clean and any defective lights replaced promptly. As part of building maintenance regular inspections by the maintenance personnel should be undertaken of the physical condition of all relevant equipment and of the system components. Items with fixed life spans, such as air conditioner filters, should be replaced as recommended by the equipment manufacturer. There needs to be a documented, known and used system for reporting any building maintenance problems. Building occupants need to be encouraged use this system to report any problems so that repairs can be attended to promptly by the building maintenance department or by the contractors employed by the building owner. For example, if there is building damage or leaks identified following a storm then this needs to be reported and action taken immediately to repair any damage.

Part of the maintenance schedule should be to consider seasonal variations. For example the building temperature, ventilation and lighting may need adjustment to take into account the differences that occur between winter, spring, autumn and summer in the outdoor environment. Records must be kept of building inspections, testing, maintenance activities performed and the building cleaning that occurs.

There should be documented procedures for the people who perform this work to let the building owner and other relevant people know any abnormalities that occur so that these can be actioned promptly. As well as having effective building maintenance procedures to prevent the occurrence of sick building syndrome it is important to ensure that the building is well cleaned to maintain a high standard of cleanliness.

30.4.3 Cleaning

Poor sanitation or poor cleaning practices can contribute to the occurrence of building occupants experiencing sick building syndrome as micro-organisms thrive in unclean environments. It must be identified who is responsible for building cleaning, who will do the cleaning, who will supervise this work and how often each area will be cleaned. For example, in a workplace, after work has finished each day, a contract cleaning company may clean all floors, furniture, internal surfaces and empty all rubbish bins daily, clean all windows and scrub walls monthly and deep clean all carpets and soft furnishings 3 monthly. Cleaning at the end of the day is a better time than cleaning before work commences as this allows dust to settle and provides a better quality of air at the commencement of the next day's work time.

Cleaning materials that give off strong odours should be avoided. Methods of cleaning that produce a lot of dust and air borne fibers should not be used. Vacuum cleaners with high efficiency filters can help to achieve effective cleaning without raising dust and fibres into the air. When used for cleaning vacuum cleaners must be regularly emptied before they become too full of dust, fibres, etc as an over full vacuum cleaner can spread dust rather than picking it up (Environmental Illness Resource 2010). Cleaning equipment must have regular maintenance to ensure that it functions effectively. There must be enough cleaning supplies and people with enough time to perform the cleaning work safely and efficiently. Having a high standard of building cleanliness should be included in the building risk control action plan.

30.4.4 Risk Control Action Plan

A risk control action plan is essential to have to ensure that a building keeps a healthy environment for the building occupants. In Appendix 3 there is a risk control action plan for the following hazards of:

- Inadequate or poor ventilation,
- Uncomfortable temperature,
- Too drafty or insufficient air movement,
- Air humidity too high or too low,
- Presence of airborne particles or fibers,
- Unsatisfactory lighting,

- Too much noise,
- Presence of toxic vapours or gasses in the air,
- Biological hazards including micro organisms,
- Poor sanitation,
- Unclean building,
- Unpleasant odours, and
- Psychosocial issues.

This list of hazards is not exhaustive and can be added to depending on the identified causes of sick building syndrome and the types of risks that exist in the building due to individual building construction, work processes performed in the building and the use that occupants make of the building. The risk control action plan in Appendix 3 just provides a starting point, and a format to use, for risk control measures. The risk control action plan provides a format for likelihood of each of the hazards present in the workplace to be assessed. In this action plan, for a generic building, the likelihood is assesses as either certain to occur, could possibly occur or would rarely occur. The next column is for the assessment of the consequences of this hazard being present in the building. Consequences are assessed as high (would cause catastrophic health effects or financial loss), moderate, or low (would cause minimal health effects or financial loss).

In this action plan combining the likelihood of the hazard being present in the building with the consequences of this hazard provides a risk rating. If the risk rating is E (extreme risk) then immediate action is required. If the risk rating is high risk then senior management attention is required. If the risk rating is moderate then the appropriate manager is responsible for organising for this risk to be controlled. If the risk rating is low then the risk of the identified hazard causing harm can be managed by routine maintenance. The next column in this risk control action plan includes the proposed actions to be taken by the appropriate people to minimise the risks of the identified hazards causing harm to the building occupants. The 6th column has a space for the name of the responsible person to be included to carry out the required risk control actions. Recording the name of the person responsible for this action provides a person with the responsibility to carry out the required actions. The last column is to record the date that this action is completed. This provides a record of the actual date that risk control measures were implemented.

What is not included in this action plan, and which needs to be done, is to evaluate the effectiveness of the risk control measures implemented. The evaluation can be conducted by occupational safety and health representative in a workplace, by an occupational safety and health professional or by building occupants in private residences. The questionnaire included in Appendix 2 of this chapter is a useful tool to use to check the effectiveness of risk control measures with the building occupants. Building owners, or employers, may not always want to make the recommended improvements unless they can see that it is cost effective to do this. To be able to demonstrate to building owners and employers that it is in their best interests, and financially worthwhile, to include sick building syndrome prevention measures in the design stage of the building, or to implement recommended risk control measures, it may be advisable to perform a cost effective analysis.

30.5 Cost Effectiveness Analysis

A cost effectiveness analysis identifies (1) if the cost of undertaking a particular action, or buying a particular product, saves more money than it costs and (2) if the benefits of purchasing this product, or undertaking this action, outweigh the cost. Mendelson et al. (2000) identify, in the story reported in Jansz (2011b), that Hospital 3 in their research study had over 200 employees on sick leave due to experiencing the symptoms of sick building syndrome. This is a good case study to use when examining the cost of preventing the cause of sick building syndrome in this hospital and the cost of not including these measures (which is the cost of undertaking the remedial actions).

In Hospital 3, in this case study, there had been problems with the air quality in the hospital building in that sulphuric acid, hydrochloric acid and sodium hydroxide had entered the building through the air intake ducts causing adverse health effects in employees. Cleaning fluids used in this hospital contained phenol and formaldehyde. Exposure to these substances adversely affected employees' health.

The cost to manage the risks and prevent sick building syndrome symptoms from occurring to building occupants could be as follows:

- Instead of the present location locate the air intake ducts in a different location of the building wall in the design stage of the building. This would have been at no additional cost.
- Purchasing and installing air inlet filters to prevent sulphuric acid, hydrochloric acid and sodium hydroxide or other fumes from entering the hospital air handling units could have cost $100.
- There is no difference in cost between purchasing cleaning products that contain phenol and formaldehyde and cleaning products that do not contain chemicals that are toxic to humans.

In this example the total additional cost to prevent the occurrence of sick building symptoms in the 200 employees in Hospital 3 would have been $100.

Employees at this hospital are paid an average of $50 an hour for their work. They work an average of 40 h a week. Employees were each absent from work on sick leave due to the symptoms of sick building syndrome for an average of 2 weeks. The cost of not taking the above actions could be as follows.

- Cost of replacement employees' wages to cover the work of employees absence on sick leave = 200 × 50 × 40 × 2 = $800,000.
- Additional cost (to the $800,000 in wages) of obtaining replacement employees from an Agency to cover the employees' sick leave = $10,000.

- Payment to a consultant to investigate the cause of sick building syndrome, to write a report on the causes and suggested hazard control measures = $5,000.
- The cost to relocate the air intake ducts = $50,000.
- Cost to purchase and install air inlet filters for the hospital air handling units = $100.

Potential additional costs, that have not been included, but which could occur, are as follows:

- If any of the employees consider that their illness is work related then there will be medical treatment and other workers' compensation costs.
- If the occupational health and safety legislative enforcement agency perceives that the workplace is not safe and healthy for employees the employer or building owner may be fined for not complying with the Occupational Health and Safety Act.
- Legal advice, representation and court costs if the legislative enforcement authority or an employee or another person commences legal action against the company due to the company not meeting its legally required occupational safety and health responsibilities.
- If employees return to work from sick leave and are not fully recovered then they may be less efficient and effective in their work duties than they were before experiencing adverse health effects due to sick building syndrome.
- If psychosocial issues develop with employees due to work related environmental problems or other causes related to sick building syndrome then there could be the cost of dealing with lower employee morale and with industrial relations issues.
- Patients in Hospital 3, and visitors to this hospital, could be affected by the symptoms of sick building syndrome as well as the staff being affected. The affected patients and visitors may sue the hospital for damaging their health.
- There could be unfavourable media publicity in relation to the occurrence of sick building syndrome which managers would be required to spend time dealing with.
- Due to replacement Agency Staff (who are covering employees' sick leave), being unfamiliar with the workplace layout, where equipment is kept, how to use this equipment and what the hospital policy and procedures are, the replacement staff may take longer performing their work and not be as efficient as the employees who are on sick leave. This would require additional staff to be able to complete the same volume of work. Alternatively existing staff may have to work overtime and this attracts a higher rate of payment for the extra hours worked.
- If employees leave work due to ongoing ill health, or due to dissatisfaction work the work environment, there is the cost of loosing these employees' skill and experience, advertising for new employees, interviewing and selecting new employees and of educating new employees concerning company policies, procedures and other aspects of their work for the company.

The total of these potential costs could be over a million dollars if they all occur.

The cost of preventing the incidences of sick building syndrome for employees at Hospital 3, in the worked example, is $100. Without considering the potential costs, the cost of not preventing the occurrence of the sick building symptoms for Hospital 3 = $800,000 + $10,000 + $5,000 + $50,000 + $100 = $865,100. This is a *difference in cost of $865,000*. In this example the cost effectiveness analysis clearly demonstrates to the building owner and employer that it saves more than it costs to prevent the occurrence of sick building syndrome and that the benefits outweigh the costs. Every dollar spent, in this example, in preventing the occurrence of sick building syndrome symptoms occurring in building occupants, saved at least $8,650.

Other financial analysis that can be undertaken by employers or building owners include a cost benefit analysis. A cost benefit analysis relates to allocated efficiency in financial terms and considers if the actions proposed to be undertaken are worthwhile so that a judgment can be made on whether it is advisable to undertake the proposed action or not. Opportunity costs can be considered. Opportunity costs are comparing the cost of spending money on something, such as an air conditioner filter, and comparing this with the opportunities lost to spend the money on something else to determine if it is worthwhile spending the money on the proposed action or equipment. A cost utility analysis includes assessing the quality of life provided by making an investment in purchasing equipment or performing an action. Efficiency cost may be considered to identify if the proposed purchase is being made at the lowest possible cost in terms of material and human resource costs. Other costs that may be considered include direct and indirect costs, economic and non-economic costs, fixed and variable costs, external and internal costs.

Further information on cost effectiveness analysis can be obtained from Edejer et al. (2003) in the 318 page publication called "WHO Guide to Cost-effectiveness Analysis". This publication includes extensive information on how to conduct cost effectiveness analysis. Clements-Croome in Chap. 13 in this book describes the cost of not having a healthy building environment, a variety of methods of cost analysis and how to perform these analysis.

30.6 Conclusions

This chapter has provided information on important factors related to building design that should be considered in the planning stage to prevent sick building syndrome from occurring. There is information on sick building syndrome risk identification, recommended risk control measures and how to conduct a cost effectiveness analysis in relation to preventing or elimination the incidences of sick building syndrome occurring in a building. This chapter has also includes references to the information included in other chapters in this book that contain research studies conducted in relation to sick building syndrome, practical knowledge and experience in conducting risk assessment and management of sick building syndrome and an extensive review of published information related to sick building syndrome causes and risk control measures. As these authors live in many different countries in the world (including Australia, Brazil, China, Finland, India, Kuwait, Italy, Japan, Pakistan, Portugal, Spain, Sultanate of Oman, Sweden, The Caribbean, Turkey, United Kingdom) an international perspective on sick building syndrome has been provided. This chapter has 3 Appendix. Appendix 1 is a checklist to use in the building planning and construction stage to minimise the opportunities for sick building syndrome to occur in building occupants. Appendix 2 is a building occupants' health survey. Appendix 3 is a risk control action plan. Each of these Appendix are practical tools to use in relation to sick building syndrome either for prevention, assessment of the current situation or for risk control. In relation to sick building syndrome it must be remembered that most people don't complain about ill health, they just find another company to work for, or another place to live or to visit.

Acknowledgements Anitha Arasu is thanked for identifying published literature on sick building syndrome for review.

Paul Jansz is acknowledged for the assistance given in typing the Building Occupants Health Survey included in this chapter as Appendix 2.

Appendix 1: Checklist for Building Planning A construction to Minimise Opportunities for Building Occupants to Experience Sick Building Syndrome

Reference: Property Council of Australia (2009) Managing indoor environmental quality. Sydney, NSW: Property Council of Australia 91–103.

1: Tentant Facilities

The following tenant facilities are considered in this section:

- Lighting;
- Acoustics;
- Ventilation;
- Plants;
- Work spaces;
- Recreational facilities;
- Cleaning, sanitation and waste management;
- Equipment, furniture and furnishings; and
- Interior design and décor

Lighting

Natural Lighting/Windows

☐ Is occupied space close enough (within eight metres) to the external window line or a sufficiently lit atrium/light well?

☐ Does the design take advantage of available natural light to lower lighting energy consumption?
☐ Is the office space designed to allow maximum daylight penetration? Are you using glazed partitions parallel to windows for perimeter offices to allow penetration of light to interior space? Are you suing borrowed light where direct access to external windows is not possible?
☐ Are there any fully enclosed solid walled, internal offices?
☐ Do window configurations and shading devices ensure adequate control of solar heat gain?
☐ Have you considered high performance glazing to minimise unwanted heat gain? (i.e. double/low-E with low U-values and solar heat gain coefficient)
☐ Is sufficient glare control provided to occupied spaces?
☐ Are the workstations designed to reduce the reflection of daylight on computer screens?

Artifical Lighting

☐ Are there any areas with extreme lighting levels causing tenant discomfort and eyestrain?
☐ Are lighting levels adequate? Illuminance levels should be selected to match occupant tasks, and both the age and visual characteristics of likely occupants.
☐ Are there any habitable areas with very low lighting levels that may adversely impact upon the occupant's wellbeing?
☐ Do you need task lighting?
☐ Is general lighting intensity appropriate and are fittings well laid out? Is there uniformity of light on task surfaces?
☐ Do you, or can you, provide some individual lighting control?
☐ Are light switching zones less than 100 m^2
☐ Are you using the correct low brightness, non-glare standard light fittings in commercial office spaces?
☐ Is glare caused by artificial lighting minimised by appropriate lighting design? Do light fittings have diffusers to reduce glare?
☐ Is there any lighting control system provided, e.g. PE cells, dimmers, time switches or motion detectors?
☐ Are you using electronic ballasts and not magnetic ballasts (for existing fit-outs)?
☐ Is flickering of lamps avoided (e.g. by using high frequency ballasts)?
☐ Are you using efficient lamps?
☐ Is the colour temperature of lamps and colour rendition index suitable for activities and supporting people's wellbeing (greater than 80)?
☐ Have you avoided lights causing irritating glare on computer screens? Are glossy surfaces avoided where reflection of artificial lighting might be an issue?

For more important information refer to Australian Standards AS1680.1 series:

- AS/NSZ 1680.1:2006 Interior and workplace lighting – General principles and recommendations.
- AS/NZS 1680.0:2009 Interior lighting – Safe movement.
- AS/NZS 1680.2.1:2008 Interior and workplace lighting – Specific applications – Circulation spaces and other general areas.
- AS/NZS 1680.2.2:2008 Interior and workplace lighting – Specific applications – Office and screen-based tasks.
- AS/NZS 1680.2.3:2008 Interior and workplace lighting – Specific applications – Education and training facilities.
- AS/NZS 1680.2.4:1997 Interior lighting – Industrial tasks and processes.
- AS/NZS 1680.2.5:1997 Interior lighting – Hospital and medical tasks.
- AS 1680.3-1991 Interior lighting – Measurement, calculation and presentation of photometric data.
- AS/NZS 1680.4:2001 Interior lighting – Maintenance of electric lighting systems.

Shading Devices Curtains and Blinds

☐ Are your curtains and blinds providing effective shading?
☐ Have you considered internal as well as external shading devices?
☐ Do your shading devices effectively control solar heat radiation and glare?
☐ Do your shading devices allow beneficial sun penetration in the cold seasons?
☐ Does the curtain fabric/shading screen effectively reduce glare? (e.g. density, colour)
☐ Do your shading devices allow solar access to areas further from the windows? Do your shading devices allow sufficient daylight levels?
☐ Are you using low volatile organic compound (VOC) blind and curtain materials?

Acoustics

☐ Avoid ambient sound that is distracting or unpleasant.
☐ Does the office area provide a comfortable background noise and good speech privacy?
☐ Are shared noise generating resources (e.g. meeting rooms, discussion area, lunch rooms, printer/photocopiers) located away from occupants who need quiet to concentrate on tasks on tasks, or are they effectively soundproofed?
☐ Do you have an office etiquette policy to control noise?
☐ Do you have sound absorbing ceiling panels? Light fittings can also reflect sound between workstations.
☐ Does partition height contribute to acoustic comfort? High, wide partitions can block sound travel.

☐ Have you chosen internal finishes to avoid echo? Did you consider eliminating echo at the design of spaces?

Refer also to "Airborne Noise" below

Ventilation

Temperature

☐ Do system designs accommodate realistic population and equipment loadings?
☐ Does zoning provide efficient operation and close control of conditions?
☐ Are swings in space temperature acceptable and are you maximising energy savings?
☐ Have you minimised variations in temperature between supply air and room air to avoid thermal shock, which may cause draughts and condensation?
☐ Is supplementary cooling provided for areas with high loadings, such as conference/meeting rooms and communication rooms?
☐ Are temperature thermostats located in a clear area, away from full sun?
☐ Have you prevented system imbalance by removing tenant access to temperature controls?

Humidity

☐ Have you considered all specialised processes or computing areas that require humidity control?
☐ Is your system designed to limit the relative humidity range?
☐ Will your humidity remain stable throughout the cooling process?

Air Movement

☐ Does your system provide an adequate air quantity with even distribution, so as to prevent stagnation of the air within the occupied space? (i.e. air change effectiveness)
☐ Can you specify higher than minimum requirements air flow rates to promote more stable conditions?
☐ Do your supply air outlets provide an even distribution under heating and cooling conditions, taking air stratification into account?
☐ Do your supply air fittings take ventilation system type into account, and in particular, are they consistent with the needs of variable air volume (VAV) systems operating under low load conditions?
☐ Are return air paths clear and unobstructed?
☐ Have ductwork and coils been cleaned in the previous 3 years?

Outdoor Air

☐ Does your system provide sufficient outdoor air to prevent stagnation of the room air, and to ensure that pollutants such as carbon dioxide, body odours and the like, are adequately diluted?
☐ Is your outdoor air source free of pollutants and dust?
☐ Does your building operate under positive pressurisation to minimise infiltration of unconditioned outdoor air?
☐ Does your plant configuration ensure adequate mixing of return and outdoor air and an even distribution of outdoor air throughout the system?

Ventilation

☐ Are ventilation systems sufficiently serving amenity areas such as toilets, showers and change rooms?
☐ Are printers and photocopiers provided with a separate exhaust system to outside the building?
☐ Is CO_2 monitoring and control provided to improve indoor air quality?
☐ Is VOC monitoring provided?
☐ Are economy cycles provided and do dampers operate freely and as designed?

Filtration

☐ Is outdoor and re-circulated air filtered?
☐ Does your filter efficiency match the requirements of the space?
☐ Is there a regular maintenance plan for air filters?

Airborne Noise

Have you eliminated any noises which emanate from:

☐ the air conditioning plant (generally the fan) via the distribution ductwork;
☐ air outlets, generated by the throttling of the supply or return air;
☐ office equipment located within the occupied space;
☐ external sources such as vehicular traffic, trains, air craft etc;
☐ exhaust vents within staff amenity areas; and
☐ air ducts?
☐ Have you eliminated occupant generated noises conveyed between adjacent spaces such as conference rooms, private offices, male and female toilets and the like, via common ductwork systems?
☐ Have you provide sufficient soundproofing to relevant components of the A/C systems.
☐ Have you sized air ducts adequately to avoid noise generated by high speed airflow?

Plants

Plants are desirable in offices but they must be maintained regularly. Poor maintenance can lead to proliferation of moulds and bacteria on leaves and in the soil. Pot plants are not rubbish bins or kitchen sinks. Flowering plants can aggravate allergies so they may have to be pruned at the flowering stage.

☐ Is there a plant maintenance plan provided?
☐ Is the planting mix and mulch appropriate to prevent the growth of moulds?

Worker Space

Workspace Ratios

Workspace allocations have increased over the past decade due to increased support facilities (e.g. conference and training rooms) and increased equipment requirements in workstations.

☐ Do office space layouts provide enough room for equipment that the average worker uses?
☐ Are fit-outs sufficiently flexible to allow reallocation of space and positions?

Worker Distribution

☐ Are workspaces arranged to provide all or most parties with daylight and an outdoor view?
☐ Are lighting design, switching and operation suited to varied work/occupation patterns?

Workstation Design

☐ Are the workstations designed to respond in a flexible way to service requirements?
☐ Do workstations have adjustable components? Such as shelving, lock up cabinets, adjustment to computer screen positioning and associated keyboards, armrests and task lighting so that maximum physical comfort and ergonomic support will be achieved?
☐ Are acoustic/ergonomic factors considered when designing office and workstation layouts?
☐ Does workstation design eliminate solid paneling, which extends to the floor, hampering cleaning as well as restricting air circulation and flow?
☐ Does the workstation design allow for personalisation of the space? Does it provide sufficient privacy, where required?

☐ Are workstation finishes low contrast?
☐ Have workstations been chosen to include low VOC emitting materials?

Cleaning, Sanitation and Waste Management

☐ Do cleaning staff have a program with guidelines for procedures?
☐ Are cleaning contractors required to avoid cleaning products with phenolic compounds or petroleum solvents?
☐ Are cleaners briefed well on hazardous waste collection, selective waste collection and recycling, as well as on the maintenance of green waste equipments (e.g. compost bins or worm farms).
☐ Is there sufficient lighting level provided for cleaners throughout the office?
☐ Does building management conduct periodic surveys of building cleanliness and contractors work?
☐ Do cleaning contractors have responsible, supervisory staff checking all areas daily?
☐ Are contract cleaning staff treated fairly and compensated appropriately for the work they undertake?
☐ Do vacuum cleaners have the sufficiently high performance to clean carpet on a deep level, and to recycle clean and well filtered air?
☐ Are ample power points provided for cleaner's equipment?

Waste

☐ Are there Construction/Operational Waste Management Plans provided, addressing waste streams and recycling?
☐ Is there sufficient storage place allocated for selective waste collection and recycling?
☐ Is there a tenant guide on waste management?
☐ Is there sufficient access provided for waste streams?

Equipment, Furniture and Furnishings

☐ Have you avoided furnishings and fit-out items that include high – VOC or formaldehyde emitting components?
☐ Is equipment which off-gasses ozone, such as copying machines, laser printers and any high voltage equipment, in areas segregated from general occupied space? Are they well exhausted? Is it ensured that exhaust is not connected to the return air duct?
☐ Is equipment, which emits heat or pollutants, placed in one enclosed area where polluted air can be exhausted?
☐ Is there sufficient storage for equipment and associated facilities?

Interior Design and Décor

☐ Are the colours of the spaces and fit-out items selected with consideration of how they affect people's work efficiency, emotions and abilities?
☐ Is there sufficient contrast of colours to between walls and furnishings? Is there sufficient contrast at sharp edges?
☐ Are ceilings in very light colours to be light reflective and bring daylight to areas further from windows?
☐ Are floor colours of general light neutral tones?
☐ Have you avoided desktops and other fit-out items, which are too reflective, creating excessive glare?"
☐ Are breakout space, lunchroom and staff training room colour schemes different from workplace colour schemes to provide visual relief?

Construction Issues

The following construction issues are discussed in this section:

- Services, design, inspection and maintenance;
- Location of external intake and exhaust vents;
- building materials;
- structural layout;
- building seals and drainage;
- energy efficiency; and
- building cleanability

Service Design, Inspection and Maintenance

Management

☐ Are design and installation drawings with any modifications available on site to facilitate maintenance procedures and the design of any future alterations to the systems?
☐ Is there a tenancy user's guide?
☐ Is there a building user's guide? Does it include a programmed maintenance strategy?
☐ Is there a building management system?

Central Plant

☐ Is central plant arranged to facilitate access, minimise downtime and avoid disruption to tenants?
☐ Can adequate service be provided during maintenance shut-downs- either by programming of maintenance visits, or by provision of standby plant?

Air Handling Equipment

☐ Does the type of plant provide access required for ongoing maintenance?
☐ Does your plant design reduce the amount of equipment within the occupied area, and the ceiling space in particular?
☐ Is ceiling space accessible for adjustment of volume control dampers, valves etc?
☐ Can heat exchange surfaces and drain pans be access for cleaning?

Cooling Towers

☐ Has the cooling tower been designed and installed as per AS/NZS 3666.1:2002 Air-handling and water systems of buildings – Microbial control – Design. Installation and commissioning.
☐ Is there a regular maintenance plan?
☐ Is there a risk management plan?
☐ Are towers located well away from building air intakes, other building openings, and areas of public access?
☐ Is make-up water fed from a clean water source to reduce sediment build up?

Hot Water Heaters

The Victorian "Legionella" Guidelines are a good example of best practice and when followed have been shown to reduce the risk of *Legionella* and other microbial growth.

☐ Is hot water held at 60°C for at least 1 h per day to minimise *Legionella* risk while also minimising energy use?
☐ Is hot water supply to hand basins and showers tempered to no more than 50° C?

General

☐ Have you replaced all natural rubber components within water supply and drainage pipe work with neoprene or suitable synthetic material to prevent microbial growth?
☐ Has redundant pipe work containing stagnant water been removed?
☐ Is water reticulation pipe work configured to connect to a ring main system?

Location of External Intake and Exhaust Vents

☐ Are intakes and discharges (including cooling tower discharges) sufficiently isolated to prevent cross contamination under varying wind conditions?

☐ Locate vents to minimise external pollution.
☐ Have you considered ingress of noise when placing external vents?
☐ Are discharge vents located to minimise condensation or discolouration of building façade?
☐ Do all vent locations comply with the requirements of statutory bodies and local authorities?

Finishes and Surfaces

Easily Cleaned Finishes

☐ Are finishing materials surface sealed and easily washable?
☐ Have you selected hard wearing and easy to clean finishes for surfaces which are frequently handled or soiled?
☐ Are finishing materials long lasting and durable? In the event of damage can that part of the finish be replaced the majority untouched?
☐ Where concrete or cement is the finished surface in areas such as plant rooms or parking areas, have the floor surfaces been sealed or painted?
☐ Have you selected carpeting that is easy to clean and maintain? Has a manual been provided to inform future uses of how to remove the most vulnerable surfaces?

Low Pollutant Materials

☐ Have you avoided building materials, finishes and finishing fabrics with high VOC content?
☐ Have you used E1 or better rated composite timber products to reduce formaldehyde emissions?
☐ Have you ensured appropriate maintenance of carpeting?

Structural Layout

Location of Plant Area

☐ Are plant rooms properly located so as to minimise noise transmission to the occupied areas?
☐ Are doors and walls in plant rooms sound proofed and sealed to prevent transmission of air and noise?

Prevention of Pollution Migration and Noise

☐ Are all building construction openings sealed to prevent migration of polluted air?

☐ Have you provided dedicated exhaust systems or allowed for effective natural ventilation for contaminated service areas such as gas meter rooms, sewage ejectors, kitchens, battery rooms and process areas?
☐ Have you provided exhaust systems or allowed for effective natural ventilation for all parking areas, service vehicle parking space and loading dock areas?
☐ Have you provided vibration isolation devices for all air conditioning plant, diesel stand-by power generation, lifts, fire pumps and hydraulic pumps?
☐ Have you provided acoustic treatment to building fabric to minimise noise from external sources?
☐ Have you provided acoustic isolation or treatment of all service pipe work, including air conditioning pipe work, sanitary lines, storm water piping, roof drains and internal gutters, where appropriate?

Building Seals and Drainage

Prevention of Water and Air Leaks

☐ Is the building fabric effectively weather proofed?
☐ Have you met Building Code benchmarks for air infiltration through facades? Have you minimised such infiltration?
☐ Are doors opening onto roofs and balconies weather proofed?
☐ Is drainage provided for water spray from weather proofed louvers?

Water Proofing Membranes

Have you considered the following to ensure you meet suitable membrane performance requirements?

☐ Moisture vapour transmission rate;
☐ Water absorption;
☐ Acceptance of cyclic movement;
☐ Durability; and
☐ Suitability for use over particleboard?

Refer to AS/NZS 4858:2004 Wet Area Membranes for more information.

Energy Efficiency

Energy

☐ Does the base building have a National Australian Built Environment Rating System (NABERS) Energy Rating Certificate? (This energy rating, which should be displayed in the building, is an Australian national initiative managed by the New South Wales Department of Environment, Climate Change and Water (2010).) Has the tenancy NABERS rating been estimated or measured?

☐ Does the building/tenancy have an energy management plan?
☐ Are there sub-meters for lighting and small power on each floor and/or tenancy?
☐ Have you installed lighting control systems to turn lighting off when space is unoccupied, or when natural lighting levels are sufficiently high? Have you installed a Building Management System?
☐ Have you specified high efficiently light fittings and appliances?
☐ Have you minimised air conditioning energy use by allowing for a wide comfort band within the building?

Renewable Energy

☐ Have you considered providing renewable energy generation for your building?
☐ Have you considered Green Power?
☐ Have you considered using geothermal/solar power for air conditioning and water heating?

Other Alternatives

☐ Do conditioning systems have controls to prevent over-cooling, over-heating and the simultaneous provision of heating and cooling?
☐ Have you provided for full outdoor air economy cycles on air conditioning plant?
☐ Do you take full advantage of available waste heat sources (such as condenser water) to provide heating via heat pumps?

Passive Solar Design

☐ Have you minimised air conditioning energy use by effective passive solar design, provision of thermal mass, and well insulated building fabric?
☐ Have you specified external glazing with high thermal performance?
☐ Is your building design oriented to take full advantage of natural light and solar heating?
☐ Have you investigated the thermal efficiency of glazing vision panels or spandrel panels?
☐ Have you investigated the thermal efficiency of external shading to windows and glazed doors?

Building Cleanability

Design Implications-General

☐ Are materials easy to clean and maintain?
☐ Have you avoided internal materials, which will fret, fray, powder on surface and generally add particles of dirt and dust to the air?
☐ Have you avoided materials which absorb cleaning fluids and emit pollutants?
☐ Have you avoided unnecessary rebates or articulations that will be difficult to access and clean?
☐ Have you avoided unnecessary horizontal ledges and deep recesses which can gather dirt and dust and which are inaccessible for cleaning?
☐ Have you avoided small recesses on vertical surfaces, such as at skirting ducts and plinths which will make it difficult to vacuum?
☐ Are all paint finishes in all public areas washable to allow removal of dirty marks?
☐ Are all concrete floors either sealed or painted?
☐ Are all surfaces used for food handling durable and easy to maintain in a hygienic condition?
☐ Have you avoided rough and absorbent surfaces which are difficult to keep clean?
☐ Is fixed equipment installed in such a manner as to facilitate cleaning of surrounding areas?
☐ Are all door finishes high gloss to help with cleaning and wiping of high wear areas?
☐ Have you provided cleaners' facilities such as sinks and power outlets?

Design Implications For Toilet Areas

☐ Have you avoided floor mounted fixtures and cubicle partitions that will hamper cleaning?
☐ Have you provided coving at the junction of floors and walls, at cubicle partitions and on vanity bench tops?
☐ Are floor, wall, partition and fitting materials impervious to water and are they easily cleanable?
☐ Are floor wastes provided?

Design Implications Services

☐ Is service equipment laid out to provide ease of access for maintenance purposes?
☐ Are intake louvers accessible and cleanable?

☐ Are air intake louvers fitted with bird/insect screens?
☐ Are cooling towers accessible for cleaning and maintenance?
☐ Have you avoided stagnant water sources?
☐ Have you provided access to domestic water tanks for cleaning purposes?
☐ Have you used microbiologically inert paint for painted storage tanks?

Construction Phase

☐ Is the building site regularly cleaned during construction?
☐ Do contract documents refer to progressive site equipment cleaning?
☐ Do contract documents specify protection and cleaning of any air handling equipment?
☐ Do contract documents specify final cleaning expected of the builder?
☐ Do contract documents require the builder to verify that all air handling and supply systems have been cleaned to comply with the specification?
☐ Are ends of ducting plastic sealed to minimise entry of dirt and dust during construction?
☐ Are fan opening sealed until ducting connections are made?
☐ Are all internal ducting insulation completely sealed, especially at ends or take-off points?
☐ Are all filters checked and clear prior to occupation of the building?
☐ Are temporary filters employed during construction?
☐ Have all intake areas of louvers and associated bird and insect screens been cleaned prior to building handover and occupation?
☐ Have all air supply and return systems been cleaned?
☐ Have all dirt or dust producing works carried out after occupation been screened to limit contamination?
☐ Has purge ventilation been employed during and after construction?

Appendix 2: Building Occupants' Health Survey

Demographic Information (Please tick where appropriate)

Which of these age groups are you in :

Under 18 year old [__]
18 – 29 [__]
30 – 39 [__]
40 – 49 [__]
50 – 59 [__]
60 – 69 [__]
70 + years old. [__]

Gender Male [__] Female [__]

Do you smoke tobacco? Yes [__] No [__]

<u>Occupation :</u>

Position (Job title): ____

Department : ____

Industry : ____

How long have you been at your present place of work ? ____________________

Job Description

(1) Employment status:
Permanent F/T [__]
Permanent P/T [__]
Casual F/T [__]
Casual P/T [__]
Temporary [__]
Other ____

(2) I have worked in this area/room since (date) ____________________

(3) I have worked in this building since (date) ____________________

(4) I have worked in the present location since (date) ____________________

(5) Describe briefly your main work duties.

____

____

____

____

Work Environment (Please tick where appropriate)

(1) Listed below are items related to the work environment. Next to each item, enter in the box the number from the following scale that best describes the acceptability of your work area at present.

(1) = Very unacceptable	(4) = Somewhat acceptable
(2) = Unacceptable	(5) = Acceptable
(3) = Somewhat unacceptable	(6) = Very acceptable

If any of the following are unacceptable use the following scale to indicate the time problems occur. Morning [1]; afternoon [2]; all day [3]; no trend [4]; specific days [specify]

	Acceptability	Time
Temperature	[___]	[___]
Humidity	[___]	[___]
Air movement	[___]	[___]
Odour (smell)	[___]	[___]
Amount of dust	[___]	[___]
Loudness of sounds	[___]	[___]
Noisy distractions	[___]	[___]
Pitch / frequency of Sound	[___]	[___]
Brightness of lighting	[___]	[___]
Glare	[___]	[___]
Shadows	[___]	[___]
People in work area	[___]	[___]
Overall environment quality	[___]	[___]

(2) I am in (please tick):

A closed office	[___]
My own cubicle	[___]
An open area shared by others	[___]

Other (specify) ____

Indicate how much work space you have in square feet or meters ________________________

(3) What is the geographic location of your desk within the building?

East side	[____]	Northeast side	[____]
West side	[____]	Northwest corner	[____]
South side	[____]	Southeast corner	[____]
North side	[____]	Southwest corner	[____]

(4) (a) Are you sitting within 3.7 m (12 feet) of a window? Yes [___] No [___]

(b) Can the window be opened?: Yes [___] No [___]

(c) What is the number of windows in your work area? ________________________________

(5) Is your work location within 10 m (33 feet) of a:

Computer?	Yes	[___]	No	[___]
Photocopying machine?	Yes	[___]	No	[___]
Printer?	Yes	[___]	No	[___]
Fax machine?	Yes	[___]	No	[___]

Other machines (Specify) ____

(6) Aspects of your work environment:
(Tick "yes" if following are disturbing and indicate which aspect and to what degree.)

(a) **Noise**: Yes [___] No [___] Tick frequency.

	Often (weekly)	Sometimes	Never
Nearby conversation?	[____]	[____]	[____]
Ventilation system?	[____]	[____]	[____]
Office equipment?	[____]	[____]	[____]

Other (specify)____

(b) **Lighting**: Yes [___] No [___]

	Often (weekly)	Sometimes	Never
Too Bright?	[____]	[____]	[____]
Not bright enough?	[____]	[____]	[____]
Glare, Flicker?	[____]	[____]	[____]
Gives reflections?	[____]	[____]	[____]
Too warming?	[____]	[____]	[____]

Other (specify)____

(c) **Ventilation**: Yes [___] No [___]

	Circle relevant description	Often (weekly)	Sometimes	Never
Temperature?	Too hot / Too cold / varying :	[____]	[____]	[____]
Humidity ?	Too dry / Too moist / varying :	[____]	[____]	[____]
Air movement ?	Too little / Too much / varying :	[____]	[____]	[____]

Other (specify) ____

(d) Static electricity causing shocks Yes [___] No [___]
If yes how frequently? ____

(e) Dust and dirt Yes [___] No [___] (Specify) ___________________________

(f) Any other environmental problems? Yes [___] No [___] If Yes specify below.
____

____

(g) Is there a smell in your area? Yes [___] No [___] If yes, describe it.

(i) The smell resembles (Tick) Glue [___] Vinegar [___] Alcohol [___]
Ammonia [___] Propane [___] Gasoline [___] Perfume [___]

Other (specify) ____

(ii) It smells (Tick) Smoky [___] Dusty [___] Musty [___] Stale [___]

Other (specify) ____

(iii) What location(s) is the smell coming from?________________________

____.

(h) Are any of the following used in your work environment?

(i) A desk lamp? [___]
(ii) A fan? [___]
(iii) A heater? [___]
(iv) A humidifier? [___]
(v) An ion generator? [___]
(vi) An air cleaner? [___]
(vii) Personal care products? Specify: e.g. hand cream, hairspray, etc.

____;
(viii) No such items [___]

(i) Have you any control over the following for your location?

(i) Ventilation ? [___]
(ii) Temperature ? [___]
(iii) Humidity ? [___]
(iv) Lighting ? [___]

Write any other comments or observations about your work environment that may affect your health.
____

If there are indoor air quality problems, in your opinion, what are the causes these problems?

____

____

Work Conditions

	Often	Sometimes	seldom	never
Do you regard your work as interesting?	[__]	[__]	[__]	[___]
Do you find your work stimulating?	[__]	[__]	[__]	[___]
Do you have too much work to do?	[__]	[__]	[__]	[___]
Do you have opportunities to influence your working conditions?	[__]	[__]	[__]	[___]
Do your fellow workers help you with problems you may be having in your work?	[___]	[__]	[__]	[___]

Please comment on any factors you consider important concerning the quality of your work conditions.

____

Health (Please tick where appropriate.)

1. Have you experienced any of the symptoms below while in this building?

Symptoms	Occasional	Frequent	Not related to building	Appear after arrival	Increased after arrival
Bad concentration	[_____]	[_____]	[_____]	[_____]	[_____]
Aching joints	[_____]	[_____]	[_____]	[_____]	[_____]
Muscle twitching	[_____]	[_____]	[_____]	[_____]	[_____]
Back pain	[_____]	[_____]	[_____]	[_____]	[_____]
Hearing problems	[_____]	[_____]	[_____]	[_____]	[_____]
Dizziness	[_____]	[_____]	[_____]	[_____]	[_____]
Dry, flaking skin	[_____]	[_____]	[_____]	[_____]	[_____]
Discoloured skin	[_____]	[_____]	[_____]	[_____]	[_____]
Skin irritation	[_____]	[_____]	[_____]	[_____]	[_____]
Itching	[_____]	[_____]	[_____]	[_____]	[_____]
Heartburn	[_____]	[_____]	[_____]	[_____]	[_____]
Nausea	[_____]	[_____]	[_____]	[_____]	[_____]
Bad odours	[_____]	[_____]	[_____]	[_____]	[_____]
Sinus congestion	[_____]	[_____]	[_____]	[_____]	[_____]
Sneezing	[_____]	[_____]	[_____]	[_____]	[_____]
High stress level	[_____]	[_____]	[_____]	[_____]	[_____]
Chest tightness	[_____]	[_____]	[_____]	[_____]	[_____]
Eye irritations	[_____]	[_____]	[_____]	[_____]	[_____]
Fainting	[_____]	[_____]	[_____]	[_____]	[_____]
Hyperventilation	[_____]	[_____]	[_____]	[_____]	[_____]
Contact lens problems	[_____]	[_____]	[_____]	[_____]	[_____]
Head aches	[_____]	[_____]	[_____]	[_____]	[_____]
Fatigue/drowsiness	[_____]	[_____]	[_____]	[_____]	[_____]
Temperature too hot	[_____]	[_____]	[_____]	[_____]	[_____]
Temperature too cold	[_____]	[_____]	[_____]	[_____]	[_____]
Other (Specify)	[_____]	[_____]	[_____]	[_____]	[_____]

____

No health effecting symptoms experienced in this building. [______]

2. Please circle any of the following symptoms that you may have at this moment:

Headache	Backache	Drowsiness	Hand cramps
Eye irritation	Sore throat	Itchy feet	Stiff arm
Nose irritation	Neck pain	Leg cramps	Dry skin
Rash	Itchy skin	Mental fatigue	
Unexplained memory loss		Dry mucous membranes.	

Record any other current symptoms you experience that may be related to your work environment.

____

3. **Effects of specific symptoms**:

During the previous week while working in your ar ea please answer the following about your health.

LEFT Do symptoms interfere with work?	RIGHT Which are the troublesome symptoms?	
(A) **Nasal symptoms**		
YES [_____]	Nosebleeds	[_____]
NO [_____]	Congestion	[_____]
	Sinus problems	[_____]
	Sneezing	[_____]
	Runny nose	[_____]
	Dry nose	[_____]
	Other (specify) ____________________________	
(B) **Throat symptoms**		
YES [_____]	Sore throat	[_____]
NO [_____]	Dry cough	[_____]
	Other (specify)____________________________	
(C) **Eye symptoms**		
YES [_____]	Redness	[_____]
NO [_____]	Watering	[_____]
	Burning	[_____]
	Puffiness	[_____]
	Dryness	[_____]
	Irritation	[_____]
	Blurred vision	[_____]
	Other (specify)____________________________	
(D) **Contact lens wearer**		
YES [____] NO [____]		
Problems with wearing them	Problems with	
YES [____] NO [____]	Cleaning	[_____]
	Deposits	[_____]
	Discomfort	[_____]
	Pain	[_____]
	Other (specify)____________________________	

(E) **Skin symptoms**

YES [_____]		Dryness	[_____]
NO [_____]		Flaking	[_____]
		Rash	[_____]
		Irritation	[_____]
		Unusual "mole"	[_____]
		Other (specify)___________________________	

(F) **Chest symptoms**

YES [_____]		Wheezing	[_____]
NO [_____]		Coughing	[_____]
		Lung congestion	[_____]
		Other breathing	[_____]
		Chest pains	[_____]
		Breast pains	[_____]
		Breast lumps	[_____]
		Blurred vision	[_____]
		Other (specify)___________________________	

(G) **Aches and pains**

YES [_____]		Headache	[_____]
NO [_____]		Backache	[_____]
		Muscle pain	[_____]
		Tendon pain	[_____]
		Joint pain	[_____]
		Other (specify)___________________________	

(H) **General complaints**

YES [_____]		Drowsiness	[_____]
NO [_____]		Dizziness	[_____]
		Faintness	[_____]
		Concentration difficulty	[_____]
		Other (specify)___________________________	

(I) **Other symptoms**

YES [_____]		Digestive	[_____]
NO [_____]		Menstrual	[_____]
		Other (specify)___________________________	

(J) Were you ever absent from work because of any health problems that may have been caused or aggravated by working in your present area? YES [_____] NO [_____]

If YES, state the health problems. ____

____

____

(K) Did you seek medical attention or treatment because of any health problem(s) caused by working at your present location? YES [_____] NO [_____]

(L) Do you have allergies? YES [_____] NO [_____]

If YES, state the nature of your Allergy ____

____

(M) Are you taking any prescribed medication for any of the symptoms you mentioned?

YES [_____] NO [_____]

What medications and dose? ____

____

____

(N) Are there any further comments which you would like to make?

____

____

4. **Symptoms frequency**

(A) During the last 3 months, have you had any of the following symptoms ?

	Yes, often (weekly)	Yes, sometimes	No, never	If Yes: Do you Believe that it is Due to your work Environment ? YES	NO
(a) Fatigue	[_____]	[_____]	[_____]	[___]	[___]
(b) “Heavy headed”	[_____]	[_____]	[_____]	[___]	[___]
(c) Headache	[_____]	[_____]	[_____]	[___]	[___]
(d) Nausea	[_____]	[_____]	[_____]	[___]	[___]
(e) Dizziness	[_____]	[_____]	[_____]	[___]	[___]
(f) Hard to concentrate	[_____]	[_____]	[_____]	[___]	[___]
(g) Eye irritation: eg. Itching or burning	[_____]	[_____]	[_____]	[___]	[___]
(h) Nose irritation: eg. Stuffy or runny	[_____]	[_____]	[_____]	[___]	[___]
(i) Throat irritation: eg. Hoarse or dry	[_____]	[_____]	[_____]	[___]	[___]
(j) Cough	[_____]	[_____]	[_____]	[___]	[___]
(k) Skin irritation eg. Dry, flushed, itchy, red.	[_____]	[_____]	[_____]	[___]	[___]
(l) Scalp/ ear irritation eg. Scaling or Itching	[_____]	[_____]	[_____]	[___]	[___]
(m) Other (please specify)	[_____]	[_____]	[_____]	[___]	[___]

(B) When do these symptoms occur (please tick or circle)?

(i) Morning [____] Afternoon [____] Evening [_____]

(ii) Days of the week : Sun M Tu W Th F Sat

(iii) Months: Jan Feb March April May June July Aug Sept Oct Nov Dec

(iv) Seasons: Summer Autumn Winter Spring.

(C) Do symptoms disappear? YES [___] NO [___]

When ? ____

(D) If these symptoms have ceased when did they cease? ________________________________

5. Past/present medical history

	YES	NO
Have you ever had asthmatic problems ?	[_____]	[_____]
Have you ever suffered from hay fever ?	[_____]	[_____]
Have you ever suffered from eczema ?	[_____]	[_____]
Does anybody else in your family suffer from allergies or have any of the above?	[_____]	[_____]

The questions included in this Building Occupant Health Survey have been taken from 3 questionnaires. The National Institute of Occupational Safety and Health (NIOSH) indoor air quality survey questionnaire, the American Industrial Hygiene Association (AIHA) occupational health and comfort questionnaire and the Danish Building Research Institute building diagnostic human resource questionnaire.

Reference: Godish T (1995) Sick Buildings. Definition, diagnosis and mitigation. Boca Raton, Florida: Lewis Publishers. 254–268

Appendix 3: Risk Control Action Plan

Legend

L = Likelihood.	**C = Consequences**
C = Certain.	H = High.
P = Possible.	M= Moderate.
R = Rare.	L = Low.

RR = Risk Rating:
E extreme risk; immediate action required
H high risk; senior management attention required
M moderate risk; management responsibility must be specified
L low risk; manage by routine procedures.

P = Person responsible. In this column record the person's name, for example, Jessica Allen.

D = Date that action is completed.

OHSP = Occupational Safety and Health Professional.

Hazard	L	C	RR	Action. To be conducted by the OHSP annually or when ever complaints are recorded.	P	D
Ventilation inadequate or poor.	P	M	M	Monitor air quality using an Air Velocity Meter. If ventilation inadequate arrange for installation of adequate ventilation points & conduct further monitoring to ensure that ventilation is adequate. Ensure 3 monthly ventilation maintenance occurs and check adequacy of this maintenance.		
Temperature too hot or too cold.	P	M	M	Use a Heat Stress Monitor to measure temperature and humidity. The heat stress monitor measures wet bulb, dry bulb and radiant heat in degrees Centigrade, wind speed in m/second and Barometric pressure in KPa. Adjust temperature levels then conduct further monitoring of employees' comfort until employees state that temperature is satisfactory.		

(continued)

Air movement. Insufficient or too drafty.	P	M	M	Monitor employee work comfort levels. Conduct air speed measuring using a Kata thermometer, which allows air velocity to be measured by determining the cooling power of the air. Make recommendations for air flow improvements and ensure implementation of improvements.
Humidity of air too high. Excess sweating in building occupants. Humidity too low. Drying of mucus membranes of eyes & nose experienced.	P	M	M	Moisture content should be measured with a hygrometer and the relative humidity measured by use of a whirling hygrometer (sling psychrometer), which consists of both wet and dry bulb thermometers & psychrometric charts. If moisture level is too high or low arrange for ventilation maintenance to set air conditioning moisture at correct level.
Airborne Particles. Large particles may lodge in the nose & throat while smaller particles can be deposited lower in the lungs. Asbestos is often present in old buildings. Synthetic fibres may be shed from deteriorating insulation material or ceiling tiles.	P	M	H	Conduct Filtration sampling by drawing a known volume of air through a pre-weighed filtering device by means of an air pump. The device is then weighed to determine the mass of dust, fibreglass, asbestos, etc. collected during the sampling period, which may be the working day. The pore size of the filter will determine the size of particles that are collected. A Dust Track and a p-track can be used for dust monitoring. Personal exposure monitoring can also be conducted. If airborne particles are present determine the cause and eliminate this cause if practicable.
Lighting. Sources of illumination can deteriorate with time due to windows and light fittings accumulating dirt. Surfaces may become dirty so reducing the amount of light reflected from them. Correct level of illumination does not necessarily mean that the workplace is properly lit. Measurement of illumination takes no account of glare from unshielded lights or windows or of the position of the worker in relation to the light source.	P	M	M	Use a Lux Meter or Photometer to conduct lighting surveys to measure luminance levels. Also conduct a visual assessment of lighting adequacy, suitability to the work being done for lighting level, shadows, reflections, glare, colours, cleanliness, flicker and light distribution. Talk to people occupying the room about what they feel about the lighting levels. Make the necessary adjustments and retain maintenance records. Ensure adequate cleaning for maximum light source effectiveness. Monitor employees' satisfaction with work related lighting.

(continued)

Noise.	P	M	M	Sound level meters, or personal noise dose monitors, should be used to measure the intensity of sound in units called decibels (dB). A reading in dB(A) cuts out those sound frequencies that the human ear is not sensitive to and boosts the sensitive frequencies. Interview people in the workplace to determine if there is nuisance noise that interferes with their work concentration. If problems identified make recommendations for noise minimisation & ensure implementation.
Carbon Dioxide (CO_2).	P	M	M	Monitor to ensure that CO_2 remains below 800 ppm in building air. If above this level assess cause (such as too many people in the room or inadequate ventilation), make recommendations for reducing the level of CO_2 & ensure implementation.
Carbon Monoxide. Nitrogen Oxides. Nitrogen Dioxide. Sulphur Dioxide. Polycyclic Aromatic Hydrocarbons. Airborne contaminants.	P	M	H	Monitor indoor air quality to determine if there are any pollutants including carbon monoxide (CO), nitrogen oxides (NO), nitrogen dioxide (NO_2), sulphur dioxide (SO_2) or polycyclic aromatic hydrocarbons (PAHs). If present identify cause, make recommendations for eliminating the air borne contaminant(s) in the indoor air & ensure implementation of risk control measures.
Vapours from new furniture, fittings and/ or floor coverings.	P	M	M	Ideally furniture, fittings and floor coverings should be selected that do not omit volatile organic compounds (VOCs). If air monitoring determines that VOCs are present in the atmosphere provide advice to area on managing staff sensitivities/symptoms. Assess cause and manage resolution. Make recommendations for hazard control and ensure implementation.

(continued)

Ozone.	P	M	H	Monitor for electrical discharges & presence of ozone from photocopiers, laser printers, air filters, electric motor brushes, air ionisers & other electrical equipment. As ozone is toxic even at low levels if present consider replacing the machine producing the electrical discharge that generates ozone with a machine that does not do this. If this is not possible isolate the machine in a well ventilated area of the workplace that is only used by building occupants for very short periods of time.
Mould.	P	M	H	Cleaners should be instructed to check for evidence of mould in all areas of the building that they clean each day, particularly in wet areas such as toilets and bathrooms and also after storms if any structural damage has occurred. If mould is reported the OSHP should identify the cause, make recommendations for elimination of the mould, prevention of further occurrences due to the same or similar causes and ensure implementation of risk control measures.
Dust mites, bacteria, viruses or other micro organisms.	P	M	H	Cleaners' supervisor must check adequacy of building cleaning at least weekly. If inadequate cleaning that leaves dust in the workplace the OSHP, or cleaners' supervisor, is to check why this occurs (may be due to inadequate time allowed for cleaning, inadequate equipment or products for cleaning, poor work procedures, lack of training, etc) and to rectify the cause so that the building cleaning is adequate. Annual cleaning report to be written by the OHSP in conjunction with the cleaners' supervisor with praise for what has been well done and any opportunities for improvements documented.

(continued)

Vermin, such as rats, mice, silverfish, spiders, cockroaches.	P	M	M	Cleaners' supervisor to check waste management and adequacy of rubbish removal daily. Supervisor to ensure that food scraps and other waste are not left to attract vermin into the building. If the presence of vermin is identified arrange for a vermin exterminator to rid the building of vermin and implement risk control measures to remove vermin food sources and to minimise vermin access to the building. OSHP to monitor risk control measures for adequacy.
Poor sanitation.	P	M	H	Cleaners to check adequacy of building sanitation each day. If sanitation is inadequate cleaners to report this to their supervisor and the OSHP. OSHP to investigate the cause, make risk control recommendation and ensure implementation of risk control measures.
Unpleasant odour.	P	M	M	Determine cause of the odour. Recommend risk control measures as appropriate to minimise or eliminate the cause of the odour and monitor to ensure that these risk control measures are effective.
Employees complain of symptoms of sick building syndrome.	P	M	M	Administer Building Occupants' Health Survey (Appendix 2 Survey). Analyse results to determine symptoms and factors that have influenced the occurrence of symptoms. Table 1 in Chap. 2 in this book is useful for assisting with determining known causes of particular symptoms. Make risk control recommendation and ensure implementation of risk control measures. Refer building occupants to medical practitioner for treatment of symptoms if this is required. Check that symptoms are relieved when risk control measures are implemented.
Psycho social issues.	P	M	M	Inform employees' manager of the causes of psychosocial issues unless the Manager is the cause of these issues. If the employees' immediate manager is the cause, discuss this with the manager and then report the cause to the next level up of management if appropriate and if the issues are not resolved. Appropriate level of Management to take action for risk control of psychosocial issues. Monitor that the situation has resolved once risk control measures are implemented.

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Chapter 31
The Way Forward

Mahmoud Yousef Abdulraheem

Sick Building Syndrome (SBS) is a phenomenon considered to be caused by poor architecture, exposure to some man-made building materials, air borne biological, chemical, dust and fiber hazards, low frequency noise, inadequate lighting and by inadequate ventilation/air conditioning systems. In arid regions, such as the Arabian Peninsula, where extreme heat and high dust loads are a common feature, communities have adapted their home designs and building materials to provide the maximum insulation and natural ventilation. However, the region leaped into an urbanization boom in the middle of last century, with high rise buildings made from concrete, glass and metal and fitted with artificial lightning and air conditioning all year around. The indoor environmental conditions have radically changed. This change in the micro climate of buildings has attracted little attention by the environment and health authorities and experts. Cases of allergies, migraines, rhinitis and other symptoms are often diagnosed as allergies and attributed mostly to the high dust loads in the air. Accordingly, this book comes in time to fill a gap in our knowledge of the causes, symptoms and mitigation approaches of SBS conditions.

Upon the kind invitation of Professor Sabah Abdul-Wahab, I had the pleasure of looking at the final draft of the book. I commend her on the choice of contributors who are authorities in their specific fields. The chapters are focused, well written and oriented towards the provision of guidance in understanding, assessment and mitigation of SBS. I hope that this book will not only capture the eyes of planners in our region but also becomes a base for developing guidelines for planning, design and assessment of building designs throughout the world to reduce the potential for developing SBS.

After reading the chapters in this book I suggested that the Sultan Qaboos University would take the initiate to call for a regional conference on SBS during which this book can be launched and the authors are invited to conduct a workshop for planners, architects, environmental and health specialists to be educated on SBS and engage them into initiating the process of developing guidelines for meeting

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health and comfort indicator values in the indoor environment, and thus promote avoidance of SBS. I have been asked by Professor Abdul-Wahab to put forward some ideas to be discussed at the proposed workshop that may help in pointing the way forward in SBS related research. I can see that there are areas of applied research, planning and management that may be pursed in future, building upon the concepts and information elegantly elaborated in the various chapters of this book. These include carrying out epidemiological studies on randomly selected households, development of alternative building designs and development of alternative air conditioning systems. The following are some recommendations that have arisen from the research conducted to write this book.

1. Conduct cohort epidemiological studies. More and more, it is realized that indoor environments can represent a health risk that may equal that associated with outdoor exposure (Harvard School of Public Health 2005; Abdulraheem 2006). Two cohort studies have been conducted in the Gulf Cooperation Council (GCC) region, one in Kuwait by the Harvard School of Public Health (Evans 2006) in which both indoor and outdoor air quality were assessed and related to the health status of the occupants. This study was aimed at determining the impact of war on the Kuwaiti population but it did give an insight on the health-related effects of the indoor environment. The most recent study was carried out by the University of North Carolina in the UAE (MacDonald and Brammer 2009; MacDonald et al. 2010) which was funded by the Abu Dhabi Environment Authority (EAD). The study confirmed that particulate matter in air represents a greater risk to health to the public and that cigarette smoke may pose greater health risks indoors. The study also suggests that smokers may represent as much as 30% of the population. Repeating such studies with a focus on ventilation (rate of air exchange), type of air conditioning and social habits as smoking, incense burning or cooking inside air conditioned homes and the relationship with the health status and SBS may be extremely useful to health officials in the GCC countries. The impacts of total suspended particles (TSP), their composition and health impacts are of extreme importance to such an arid region and thus may be simultaneously monitored and assessed.
2. Development of alternative building designs. Traditionally houses in the GCC countries were built from available materials, e.g. coral rock, mud and palm leaves and were mostly one floor with an open yard located in the middle of the house. The ceiling was high and the roofs were built from wooden logs covered with sheets of bamboo slices that were covered with mud. Air cooling tunnels running on the side wall, locally called Badgeer, provided air circulation. During the 1970s a comparative study of globe temperature was made on a traditional house and a modern concrete villa. The indoor air temperature reached equilibrium with the outdoor temperature by around 10 in the evening, while it barely reached such a level by 3 am in the concrete houses. In the GCC countries air conditioning is a necessity that comes with an extremely high cost. Electricity consumption by building air conditioning represents around 70% of the total house electrical bill. To keep homes cool in the extreme heats of June until

September, air conditioning suppliers tend to reduce the fresh air exchange rate to the minimum to conserve cold air. This means that contaminants would be trapped and re circulated. Cigarette smoke, chemicals from furniture, dust from outside, insect remains and stove emissions are common indoor contaminants, the exposure to which would increase if the air exchange rates are reduced. This is a major dilemma, i.e. while resources are spent on burning fossil fuels to produce electricity which is spent to run air conditioners; we increase the health risk by reducing the air exchange rate at home. The problem becomes more complicated during dust storms which have increased in intensity and frequency over the past decade due to droughts, dams that reduced river flows and agriculture as well as overgrazing and urbanization.

The reason for pushing this condensed information upon the reader is to emphasize the complexity and potential areas of research that are associated with the issues of building design in the GCC region. It is a challenge to the environmental and to health specialists that must be addressed before all buildings become boxes of concrete and glass that are lacking when it comes to human health and comfort.

3. Alternative air conditioning systems. As stated above, air conditioning is responsible for up to 70% of energy consumption at homes, while not necessarily guaranteeing indoor air quality, and may even be responsible for SBS symptoms. Looking at more energy efficiency, with greater potential for mixing indoor and outdoor air seems to be a sound area for research. Systems such as floor cooling, adiabatic cooling and heat exchange between cooled exhaust air and outside air are only few of the potential areas for research.

The social aspects of SBS may also be in need of further assessment. To elaborate, an indoor environment that is healthy and pleasant would be more inductive for family members to spend more time at home and allow for a more relaxing environment to prevail.

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