ASTM's Role in Performance-Based Fire Codes and Standards

John R. Hall, Jr.
editor

ASTM

STP 1377

STP 1377

ASTM's Role in Performance-Based Fire Codes and Standards

John R. Hall, editor

ASTM Stock Number: STP 1377

ASTM
100 Barr Harbor Drive
West Conshohocken, PA 19428-2959

Printed in the U.S.A.

Library of Congress Cataloging-in-Publication Data

ASTM's role in performance-based fire codes and standards / John R. Hall, editor.
(STP ; 1377)
"ASTM stock number: STP 1377."
Papers presented at a symposium Dec. 8, 1998, Nashville, Tenn.
Includes bibliographical references.
ISBN 0-8031-2620-4
1. American Society for Testing and Materials--Congresses. 2. Fire prevention--Standards--United States--Congresses. I. Hall, John R., 1948- II. ASTM special technical publication ; 1377.

TH9201 .A78 1999
628.9'22'021873--dc21 99-047213
CIP

Peer Review Policy

Each paper published in this volume was evaluated by two peer reviewers and at least one editor. The authors addressed all of the reviewers' comments to the satisfaction of both the technical editor(s) and the ASTM Committee on Publications.

To make technical information available as quickly as possible, the peer-reviewed papers in this publication were prepared "camera-ready" as submitted by the authors.

The quality of the papers in this publication reflects not only the obvious efforts of the authors and the technical editor(s), but also the work of these peer reviewers. In keeping with long standing publication practices, ASTM maintains the anonymity of the peer reviewers. The ASTM Committee on Publications acknowledges with appreciation their dedication and contribution of time and effort on behalf of ASTM.

Printed in Mayfield, PA

November 1999

Foreword

This publication, *ASTM's Role in Performance-Based Fire Codes and Standards,* contains papers presented at the symposium of the same name held in Nashville, Tennessee, on 8 December 1998. The symposium was sponsored by ASTM Committee E5 on Fire Standards. The symposium chairman was John R. Hall, Jr., National Fire Protection Association.

Contents

Overview

The objective of this symposium was to discuss possible roles that ASTM might play in the move toward greater use of performance-based fire codes and standards in the United States and Canada.

This move is a global phenomenon that has been gathering speed and strength for at least a decade. Performance-based fire codes are now established in use from the United Kingdom to Australia and New Zealand, and from Japan to the Nordic countries of Europe. ASTM is a supplier of standards to the world so even if this movement had not reached North America, and it most certainly has, ASTM would have a strong interest in identifying and responding to the challenge and the opportunity presented by performance-based codes and standards.

Performance-Based Codes and Standards

Performance-based codes and standards are documents that state goals and objectives, together with rules and procedures, usually involving testing and modeling, for determining when performance is achieved. Such documents allow designers greater flexibility, which can be used to achieve cost savings, greater safety, or greater quality. Performance-based codes and standards can be written on anything from products, materials and assemblies, to equipment, to whole buildings and complexes, to procedures and programs.

When poorly executed, performance-based codes and standards permit designers too much flexibility, leading to reduced safety, or require bewildering and unmanageable standards of proof, or inadvertently compromise the delicate balance between science and values or between the legitimate interests of different parts of the community. It is not enough to be interested in performance-based codes and standards and intrigued by their potential. They must be approached with care and knowledge.

Do we have enough knowledge? What is a prudent path forward that still offers us the prospect of success in a timely fashion? These were among the sweeping questions addressed in the symposium, but always with a focus on the role ASTM E5 has played and the roles it could (and should) play in the future.

The intent was to give a diverse audience an awareness of relevant concepts and activities, inside and outside ASTM, in order to provide a sound and comprehensive basis for planning by ASTM E5, possibly by Subcommittee E5.91, which has responsibility for planning; possibly by Subcommittee E5.33, whose scope is most nearly aligned with that of performance-based codes and standards; possibly by Subcommittee E5.90, the executive subcommittee; and possibly by all these and others as well.

The symposium featured 12 papers, organized in three groups of four papers each.

Session I—General Concepts and Principles

The first four papers addressed general concepts and principles.

As the symposium chairman and organizer, I spoke first, offering a set of options for ASTM's role and ideas for planning, with associated pros and cons. ASTM E5 was one of the first organizations to offer standards relevant to performance-based activity, but in many ways, the initiative has moved past ASTM E5 in the last few years. This may have occurred because the stage of development of performance-based fire codes and standards now emphasizes elements for which other organizations are more appropriate, or it may have occurred because ASTM E5 is not sure where to go next, having completed the tasks its members defined for themselves when they first entered this arena. The first possibility is acceptable and appropriate, while the second possibility is worrisome and could be threatening to the long-term health of ASTM E5. Determining which is true and what course to follow is the essence of planning.

The second paper was by Vincent Brannigan and Steven Spivak of the University of Maryland, who discussed quality standards for the participants in performance-based regulation. Professors Brannigan and Spivak have degrees in both fire protection engineering and law, which give them a unique perspective on the interaction of these two decision-making systems, both of which have relevance to performance-based codes and standards. One of the recurring concerns in developing performance-based codes and standards is how to assure that the individuals designing to these documents are up to the job. This paper proposed concepts and approaches to this issue, while underscoring that this is not an internal matter for the engineering field.

Ronald Alpert of Factory Mutual Research Corporation, the current chair of Subcommittee E5.33 on Fire Safety Engineering, provided the third paper, which reviewed the history, activities, and plans of this subcommittee. Subcommittee E5.33 and its two predecessors, Subcommittee E5.35 on Fire Risk and Hazard Assessment and Subcommittee E5.39 on Fire Modeling, have been the home for most of ASTM E5's work related to performance-based codes and standards to this point. Subcommittee E5.33 now faces a number of choices. They can maintain their guides. They can take an active role in educating constituents in the use of those guides. They can play a part in applying the guides to the development of fire risk and hazard assessments for particular products or to the review of particular fire models. Or they can defer to relative newcomers like the Society of Fire Protection Engineers, or seek to partner with them.

Completing the session on general concepts and principles was Marcelo Hirschler of GBH International, who provided a highly personal (at the organizer's request) review—but with very general implications—of his efforts to write ASTM E5 fire hazard assessment standards and guides. Probably no one has spent more time and effort attempting to define, in detail, what a performance-based, fire-hazard-analysis-based product standard would look like in the ASTM E5 system. Dr. Hirschler's review of these efforts and of the thinking behind them is an invaluable starting point for anyone else seeking the same objective, no matter how much they may differ on the particulars.

Session II—Specific Methods and Tools

From general concepts and principles, the symposium next moved to four papers on specific methods and tools.

The first of these papers was given by Daniel Gemeny of Rolf Jensen & Associates, who spoke on the preparation of fire test data for use in specifying design fires. This essential step links traditional fire testing and the many associated standards with which ASTM has made its reputation and its contribution over the years with the often-different needs of models and calculation methods for input data on product performance in a wide variety of fire environments. Having conducted a number of performance-based design projects for a company that is among the world's leaders in this area, Mr. Gemeny was able to provide substantial insight into the steps required for this interface and the issues that arise along the way.

The second of these papers is also the only paper not included in this proceedings. Gordon Hartzell of Hartzell Consulting spoke on recent proposals for new approaches to smoke toxicity assessment, currently under consideration in both ASTM E5 and the International Standardization Organization

(ISO), as an example of a new type of ASTM E5 standard, illustrating the incorporation of fire hazard analysis concepts. Because Dr. Hartzell's work in this area is of far-ranging interest, he presented the same paper to the First International Symposium on Human Behavior in Fire, held in Ulster, Northern Ireland, earlier in 1998. ASTM's policies rightly preclude publication of a paper already published, and Dr. Hartzell's paper is available in the proceedings of that conference. Readers of this volume are encouraged to seek this paper out, because it is a rare and important example of the evolution of fire test methods to support more comprehensive fire hazard assessments rather than to produce evaluative data by themselves.

The third of the specific method and tool papers was by Brian Lattimer of Hughes Associates. A project of his required the adaptation of fire test data from the cone calorimeter (ASTM E 1354) for use in a performance-based fire protection analysis. As with the other two papers, the conversion process tends to be anything but straightforward or simple, but it is essential if the calculations supporting performance-based design are to be based on valid data appropriate to the structures and assumptions of the models.

Completing the session on specific methods and tools was Marc Janssens of Southwest Research Institute, who spoke on computer fire model selection and data sources. Dr. Janssens' paper drew on both his own work and the work of ASTM E5.39, for which Dr. Janssens was the last chairman. The four modeling-related guides produced by ASTM E5.39 include some of the first guidance in print on the selection of data for computer fire models.

Session III—Alliances and Activities of Other Groups

The last session of the symposium broadened out from methods and tools to kindred organizations and their activities, with emphasis on opportunities for alliances and partnerships that would advance the cause of performance-based codes and standards and the interests of ASTM.

The first two of these papers addressed initiatives of the Society of Fire Protection Engineers. Morgan J. Hurley of the Society of Fire Protection Engineers spoke on SFPE's task groups to evaluate specific types of fire models, and Eric Rosenbaum of Hughes Associates spoke on SFPE's project to develop a design guide for performance-based design, the latter due to be published late in 1999. Both authors noted the value of ASTM's guides related to fire modeling as starting points for the SFPE exercises.

The last two papers addressed performance-based code initiatives of the National Fire Protection Association and the International Code Council. John Watts of the Fire Safety Institute described NFPA's proposal for a performance-based option within the Life Safety Code, and Beth Tubbs of the International Conference of Building Officials described ICC's proposal for a performance-based version of their building and fire codes. By focusing on codes, as distinct from the standards ASTM publishes, the two authors offered two initiatives that could create demand for supporting standards from ASTM.

Closing Thoughts Amidst the Opening Remarks

After you have read these papers, you may be frustrated that you cannot immediately do a specific job better or identify a new skill you have acquired. The benefit and relevance of these papers is in another form.

If you are an active volunteer within ASTM E5, you should learn a great deal about new ways in which the standards you write will be used. You may even have some new thoughts on whether you are working on the most important issues in the most appropriate way.

If your interest is more in performance-based design, codes, or standards, and only secondarily in ASTM's role, you may discover a resource in ASTM that you had not previously recognized.

You may wish to explore the ability of ASTM E5 standards, existing and prospective, to support your interests.

No matter how you came to this volume, these papers should give you a better sense of context and of possibility, and a lot to think about. But a passive reaction to this material is not what we are looking for.

This volume is meant to motivate even more than educate. It is meant to galvanize even more than inform. We are in the midst of a defining moment for the ways in which we make decisions about the fire safety of everything. If you have any thoughts or any preferences for how this ought to proceed, you owe it to yourself and to your colleagues and progeny to become a part of the debate and contribute a part of the solution.

Whenever you find this volume, it is likely that every author represented here is still working on the subject and would like to hear from you. It is certain that ASTM, especially Committee E5, is still working on this subject and would like to hear from you. So get involved and get in touch.

John R. Hall
National Fire Protection Association
Quincy, MA
Symposium Chairman and Editor

General Concepts and Principles

John R. Hall, Jr.[1]

Options for ASTM's Role — Ideas for Planning

Reference: Hall, J. R., Jr., **"Options for ASTM's Role — Ideas for Planning,"** *ASTM's Role in Performance-Based Fire Codes and Standards, ASTM STP 1377,* J. R. Hall, Jr., Ed., American Society for Testing and Materials, West Conshohocken, PA, 1999.

Abstract: Performance-based codes and standards are a growing reality around the world. With state-of-the-art guides for fire modeling and guides to the writing of fire hazard assessment standards and fire risk assessment standards, ASTM E-5 has played an essential role and has been one of the earliest major players in this activity. But now the landscape has changed. Groups from SFPE to NFPA to ICC, from ISO to IEC to CIB, and others are all active, and each brings a special focus and a special skill to the activity. ASTM E-5 needs to decide what its special role can and should be. This paper will discuss some of the options, based on the traditional scope and areas of traditional strength and emphasis for ASTM.

Keywords: fire risk, fire hazard, fire performance, fire test method, performance-based fire standard, fire scenario, index.

Five years ago, ASTM's E-5 Committee on Fire Standards was arguably the most advanced and the most visible source of materials related to performance-based fire safety design in the U.S.A.

The ASTM Guide for Development of Fire-Hazard-Assessment Standards (E 1546) provided a complete guide to the steps required to write a fire-performance-based product standard using fire hazard analysis as the measure of performance, and a companion guide, the ASTM Guide for Development of Fire-Risk-Assessment Standards (E 1776), based on fire risk analysis was fast nearing final approval. ASTM's Subcommittee E-5.39 had constructed a comprehensive set of complementary guides for fire model users who wished to make sure their model usage met the most demanding criteria for proper and appropriate model usage. These guides addressed validation and verification, uses and limitations, data, and documentation.

That was then, but what about now? At the end of 1998, ASTM's position is virtually unchanged from five years ago. But several other U.S. organizations that

[1]Assistant Vice President -- Fire Analysis and Research, National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101.

arguably had little of substance to offer back then have since moved strongly and effectively to put their stamp on the subject of performance-based fire codes and standards.

Both the National Fire Protection Association (NFPA) and the International Code Commission (ICC) have produced major proposals for performance-based fire codes that are likely to be available by the year 2000. Canada's National Research Council is producing a Canadian counterpart, covering everything from objectives and criteria to what is arguably the world's most comprehensive risk-based fire performance analysis modeling package. The Society of Fire Protection Engineers (SFPE), having already produced two editions of a detailed handbook on engineering methods and tools, has recently sponsored an introductory book on performance-based concepts and will soon produce a design guide for use in performance-based design. [1,2] SFPE has even taken the old ASTM E5.39 guides and begun applying them to the evaluation of particular fire-related models.

All of these organizations have made use of ASTM E-5's materials and have publicly acknowledged the value of these materials. But with every passing year, the approaches used by these organizations are increasingly their own, reflecting the ideas and concepts they added to the ASTM E-5 materials more than they reflect those source materials themselves.

What Next for ASTM E-5?

And what about ASTM E-5? That pioneering body remains committed, in writing in its strategic plan, to the pursuit of fire hazard assessment and fire risk assessment as next-generation approaches to the fire standards that have been a source of value and visibility for ASTM for so many decades. The active membership of ASTM E-5 includes nearly all of the same people who produced those original materials. And yet, there seems to be little consensus on what should come next.

I believe ASTM E-5 is at a crossroads in its history, a defining moment that will dictate what role it will play and what contribution it will make to the shape of performance-based codes and standards that will, I also believe, define fire safety design in the U.S. for the next millennium. There are a number of individuals in ASTM E-5 who have ideas to propose on what that role should be. Many of them are on today's program, and others are in today's audience. So are representatives of the groundbreaking work being done by kindred organizations like NFPA, ICC, and SFPE.

If this symposium is successful, it will initiate a substantive dialogue on alternative philosophies and principles by which ASTM E-5 can define its role. Those on today's program who are active in the performance-based fire code and standard activities of kindred organizations may have additional ideas on roles ASTM could play. They will at least provide a clear picture of how the future will be defined if ASTM is not involved, because it will be these other organizations that then will invent the future for America.

I can imagine a number of different roles ASTM could play and — given ASTM's historic strengths and proven capabilities — could play well and effectively. I will try to describe the principal alternatives I see in this paper. Some alternatives I find exciting, while others seem more risky and require more luck for success.

I can even imagine ASTM E-5 making a prudent decision to play no larger or continuing role, based on an explicit and widely shared calculation that ASTM's interests do not require its active involvement and that the needs of performance-based fire codes and standards in the U.S. are being met by other organizations better equipped than ASTM to address each aspect. I would be surprised by such a judgment, but I could imagine a spirited and well-thought-out planning discussion ending in such a determination.

The only outcome I could not respect — and that no one in this room should respect — would be a sideline role for ASTM E-5 resulting solely from ASTM's inability or unwillingness to decide what role to pursue. Irrelevance based on indecision or the inertia of the status quo is not a reasoned or respectable choice. And yet, one could look at the landscape at ASTM E-5 today and listen to the discussions surrounding this topic, and one could well conclude that this one unacceptable outcome is today the most likely outcome of all.

That is why I regard this as a defining moment for ASTM E-5. Performance-based fire codes and standards are on the move worldwide, and the pace in the U.S. is accelerating at an often dizzying speed. Having played a critical role in starting the car forward, ASTM E-5 has yielded the driver's seat to other groups — largely without an explicit choice — and is in danger of losing all influence and communication with those groups entirely. If ASTM E-5 does not care where the car it started ends up — or when and whether it reaches its goal — then this shift is of no importance. But if this is not the case, then now, today, is the time to begin redefining and reasserting ASTM E-5's ideas about this future we will all share.

Having, I hope, made the case that the stakes for today's symposium are very high, I would now like to change to the topic stated in the title of my paper, namely defining some of the alternative roles ASTM E-5 might play.

What Are Performance-Based Fire Codes and Standards?

Performance-based fire codes and standards are the means by which a society controls design decisions so as to achieve acceptable safety while also providing greater flexibility on how that safety is achieved.

It is no secret that fire safety — or safety in general — is not the principal consideration in the design and inventive redesign of products. Instead, products are designed for certain functional, aesthetic, or affordability objectives, with safety regarded as a constraint.

With more explicit statements of how much safety in what form the public demands, combined with agreed procedures for measuring and assessing how much safety a product delivers, a designer or manufacturer is in a better position to innovate. Perhaps as important, barriers to international trade may be lowered as manufacturers are able to provide the levels and types of safety demanded by other countries — and prove that performance in the form demanded by those countries — without being needlessly constrained by local accidents of history regarding how exactly safety is designed into products.

What Does Performance-Based Evaluation Mean for the Kinds of Standards Traditionally Written by ASTM E-5?

How does this intent translate into changes in the form of the kinds of product standards traditionally written by ASTM E-5? Can't we simply say that the results of product tests are measures of product fire performance and let it go at that?

"Performance-based" means rules based on an explicit set of goals and objectives, combined with a defined method of measuring whether the goals and objectives have been met. You can have performance-based evaluation of a product, material, or assembly; a structure, vehicle, or space; a process, program, or activity; an individual or group; or any other subject for which goals and objectives are meaningful. Performance-based fire codes and standards are those for which the goals and objectives relate to fire risk, fire loss, or some other measure of fire safety. If you cannot draw an explicit connection between the measurement of the product's behavior relative to fire and a set of specific goals and objectives that describe a desired level of fire safety, then you do not have performance-based evaluation of that product. You may have measurement relevant to performance, but you do not have performance-based evaluation.

But safety and risk are not inherent characteristics of products. Rather, safety and risk are experienced by people who use products in environments. The characteristics of those people and those environments must be understood and quantified before it is possible to characterize the safety and risk consequences of using particular products.

Mattresses pose little risk of fire loss in normal use. But mattresses in hotels are used by people with significant risk of drinking and smoking, leading to unintentional cigarette exposure. Mattresses in homes have the added risk of exposure to unsupervised children playing with matches or lighters. And mattresses in correctional facilities are used by populations in which vandalism of the product is not just possible but likely. It is unfair, in a philosophical sense, to blame the poor mattress for the fires that result when unsafe behavior or misuse occurs in its vicinity, but as a practical matter, the safety and risk experience of real people with mattresses will be largely defined by the ability of the products to perform well in the face of misbehavior or misuse.

This means we cannot assess the fire performance of a product without making some judgments, not only about what level of performance is considered unacceptably dangerous but also about what level of insult — that is, what types and magnitudes of fire-starting events — must be considered and what other environmental factors may reduce or increase the risk consequences of a mattress fire.

If most homes have smoke alams, then perhaps we can tolerate more severity in mattress fires, given an increased ability of occupants to react quickly and escape. If most correctional facilities restrict occupant movement — as they do by definition —

then we cannot permit mattress fire severity on the basis of some assumed occupant ability to escape, because no such ability exists.

If you look at ASTM Standards E 1546 and E 1776, on fire hazard and fire risk assessment, you will see that they contain a number of steps to follow to define these occupant characteristics, fire scenarios, and environmental factors. Because they are so important to the resulting risk and safety, these factors must be defined by the affected public, through codes, and not solely by designers and manufacturers. But the net result is that ASTM's two guides to product fire performance standards require the user to describe the whole building on the way to assessing the product.

That is a lot of work to do in order to evaluate some products. In my discussions with ASTM E-5 members, I know that many believe such a process is needlessly and unacceptably cumbersome. But this is a defining issue. If you establish the whole-building context, then you can legitimately claim to be evaluating products on the basis of the real effect their performance will have on the fire experience of real people. If you attempt to evaluate the products only on the basis of small-scale tests and associated criteria, you simply cannot know how those artificial laboratory measures of product fire performance will translate into real fire experience for real people. Test results are measures *related* to product fire performance, but they are not measures *of* product fire performance.

But if you accept this argument and evaluate products only in the context of their application and environment, then the structure of the analysis inevitably makes it awkward to treat the product as the subject of the analysis. You are not really evaluating the product but rather the building and its occupants including the product. It is the design of the building that is more naturally the focus of the assessment. Does that mean that performance-based evaluation does not make sense at the product level?

ASTM is traditionally a powerhouse source of product standards, but it leaves the specification of codes for whole buildings to other organizations. Committee E-5 is traditionally a step further back within ASTM, defining the measurement tools by which a product may be evaluated but leaving it to others to define the acceptable level of performance.

The focus on products rather than buildings is a major factor complicating ASTM's ability to play a lead role in performance-based fire codes and standards. It is at least hard and possibly impossible to do performance-based evaluation validly and still maintain a focus on products rather than buildings.

The focus on measurement tools rather than complete assessment requirements is a further complication for Committee E-5 within ASTM. It is no small leap for a group that understands fire tests to expand its interests and transform its way of doing business to embrace calculation and the other elements required by more comprehensive evaluation methods.

Option 1: Provide Standard Test Methods That Yield Data Suitable for Performance-Based Evaluation

One possible role for ASTM E-5 is to continue to concentrate on test methods as measurement tools. The existing test methods were designed to be used for direct control of products. They require only an acceptability threshold for this purpose. Therefore, Option 1 may require some work, i.e. developing new standard fire tests that provide quantitative measurements of product fire performance in a form compatible with and valid for use in more comprehensive product and building risk and hazard assessments that would be defined by others. Such a role would make maximum use of ASTM's proven strengths in its universally recognized area of greatest relative expertise.

However, such a role would also be severely constraining. The authors of the larger product and building assessment frameworks would be in the position to dictate their needs for tests in ever greater detail. The small handful of ASTM E-5 customers who will emerge as primary sources and overseers of fire safety engineering methods, including fire hazard and risk assessment packages, would assume disproportionate importance in deciding whether ASTM E-5 standards are used. Their needs might be so detailed and so unavoidable that ASTM E-5 would lose much of its current independence and prominence, becoming instead a specialized consulting group to code writing organizations and engineering societies.

Another problem with this option involves technical expertise. Valid fire safety engineering calculations require scenario-specific data, and it is increasingly recognized that such data may not emerge from a small-scale test with no calculation applied to its output. Full-scale tests are very expensive, but scaling effects are increasingly recognized as important. Most fire loss in the U.S. occurs in severe fires, such as post-flashover fires, that cannot be reproduced in less than full-scale tests and are difficult to measure in reproducible fashion even in full-scale tests. Add to this the recognition that different fire scenarios pose different kinds of challenges to products and different kinds of threats to occupants, so it is increasingly indefensible to select a single scenario as a basis for test specification or assessment. That means multiple tests — even multiple test methods — or another reason to use calculation.

The bottom line is that writing the tests for a new world of performance-based fire safety design would be a natural role for ASTM E-5, but it still might require us to reinvent the way we think of fire tests. If taken seriously, Option 1 is not a recommitment to the status quo; it involves significant change and expertise going beyond traditional areas of strength for ASTM E-5.

Option 2: Provide All the Standard Methods Required for Performance-Based Evaluation

A second role for ASTM E-5 would be to provide guidance on all the tools employed in designing to performance-based fire codes and standards, not just test methods.

For fire tests, ASTM E-5 would define exactly how they should be done. For other tools, like fire models or product fire performance assessment frameworks, ASTM E-5 could provide standards or could limit its role to guides, which would identify questions to be asked and ways in which good vs. bad tools can be recognized. This path would be a continuation of the work done by E-5.39 in its development of guides for modeling. As noted, the quality of these guides is universally recognized, and they have been adopted as a starting point by every other national organization operating in this field in the U.S.

Having said this, it must also be acknowledged that this role is increasingly being claimed by the Society of Fire Protection Engineers as the domain of engineers defining good practice for each other. In the last five years, SFPE has seen enormous success with its handbook on fire protection engineering, published by NFPA, and is nearing completion of a U.S. design guide, patterned after the design guides in use in other countries where performance-based fire codes and standards are far more established than they are here. SFPE committees are nearing completion on their first two evaluations of modeling techniques for specific problems, which they hope will form a template for a comprehensive series of such evaluations, providing model users with the information they need for appropriate use with proper cautions and caveats.

When ASTM E-5.39 created its original guides, it occupied turf that no one else claimed, and it did a magnificent job. But from here on out, ASTM E-5 will face an increasingly uphill battle in asserting the appropriateness of its role in this arena. It will need a rationale based on the distinctive strengths or interests of ASTM E-5 that will explain to other groups why it makes sense for ASTM E-5 to play a role and to be deferred to in that role. Such a rationale has yet to be clearly or publicly enunciated.

Option 3: Provide Performance-Based Product Assessment Standards

A third role ASTM could play is to create real product fire performance assessment standards based on its established guides. These would be model product requirements, more like codes than standards, and they would be both product- and occupancy-specific. Steps in this direction have been attempted by some of today's speakers, most notably Marcelo Hirschler, although so far, the proposed documents have been put forward as examples or as guides, not as binding requirements. Even so, they have encountered significant resistance, and no such document has yet been adopted.

Before going down this path, ASTM needs to be clear on what kind of organization it is and what kinds of documents it seeks to prepare. ASTM committees are balanced, but they are balanced primarily between subgroups of industry. Only a tiny minority of members are drawn from the enforcer community or even from the collection of communities not associated directly or indirectly with companies that make or purchase products. ASTM management describes its mission as providing industry with the standards it needs. This is a clear and historically true mission, which ASTM committees are well-designed to pursue.

However, model requirements for products would be built around goals defining acceptable levels of safety and risk. They would be built around fire scenarios defining which fire challenges were too severe to be used to evaluate a product and which were so likely that they must be considered. Such requirements would need to address occupant characteristics, which can be an implicit way of saying who needs to be protected and who need not be protected. All of these elements are the legitimate domain of the whole society.

Affected people — and that means everyone in this country — have a right to be represented in decisions about how safe is safe enough. ASTM is not organized to provide that representation at present and could not quickly or easily become so. ASTM should not put itself in the position of claiming society consensus for views that are only known to reflect an industry consensus, no matter how public-spirited, responsible, and conscientious the members of ASTM may be.

Option 4: Provide Standards That Permit Users to Construct Indexes or Other Summary Measures of Performance from Available Product Test Data

A fourth role ASTM could play would be to develop "quick and dirty" product assessment guides, using the available product tests and their resulting data as fixed, then providing guidance on how to summarize and evaluate overall product fire performance from that wealth of data. We have a variety of product fire performance tests already established, and they indicate better vs. worse performance on a number of scales, such as flame spread, intensity of burning, smoke generation, toxic potency overall and by species, ignitability by various smoldering or flaming or radiant heat sources, and so forth. Many products are subject to testing and evaluation on multiple scales or under multiple test specifications, but users are on their own when it comes to synthesizing all the individual results and comparisons into appropriate summary conclusions about which products are safe enough and which are not.

ASTM E-5 could develop analytical frameworks by which users could characterize overall product fire performance based on a profile of data from existing or proposed tests. This would lay the groundwork for well-reasoned trade-offs of one product fire characteristic versus another.

If this option were to be pursued based on fundamentals, it would first mean developing or adopting a fire hazard or risk analysis modeling package, such as the HAZARD fire hazard analysis model developed by the National Institute of Standards and Technology (NIST) or FIRECAM, the fire risk analysis and cost evaluation model developed at the National Research Council of Canada. [3,4] Second, it would require the development of standards for users to follow in converting test-based data into parameters and variables for use by the fire hazard or risk analysis model.

Those large modeling suites emphasized the component models and sought to fit the available data to the data requirements of those models. ASTM could provide a unique contribution by emphasizing the test data and fitting the models to the data, where possible.

The other extreme in pursuing Option 4 would be to list relevant tests and existing thresholds for them, leaving all other details of assessment, evaluation and interpretation up to the user. Somewhere in between, but closer to this profile approach, is the work of ASTM Committee E-6.66 that was scheduled for this symposium but has since been withdrawn.

Option 4 involves ASTM E-5 providing part or all of the standardization of rules — possibly rules of thumb, possibly fundamentally grounded principles — for pulling together the available data, particularly data from ASTM E-5 tests, and evaluating products in some overall fire performance sense. By starting with ASTM E-5 test data, this option would build on what ASTM has already done.

The standard methods developed by ASTM E-5 under this option should allow the user to define any levels of acceptable safety or risk, any specific fire scenarios, and any other assumptions, leaving the ASTM package to provide detailed guidance only on how to calculate the consequences for particular products. But this would require a remarkably flexible calculation method. Producing such a method and making it provably valid might be beyond our technical capabilities. And ultimately, the more guidance this package provides, the more Option 4 resembles Option 2, in which ASTM E-5 provides the standard methods needed for performance-based evaluation. Building on ASTM E-5 tests and accepting heuristic calculation methods may not be enough to make this a simple job.

Option 5: Contribute Experts, Not Standards, to the Performance-Based Standardization Work of Other Organizations

A fifth role for ASTM could be to serve as a resource for organizing people to participate in the work of other organizations, ranging from engineering societies to code-writing bodies like NFPA and ICC to multi-national venues such as the International Standardization Organization (ISO) and the International Electrotechnical Commission (IEC). ASTM, and specifically Committee E-5, already play this kind of role in ISO and IEC committees, so this option might not involve any additional work.

If product standards are the most important part of performance-based codes and standards for international trade — and I believe they are — then ASTM E-5 might use its recognized expertise in product standards to shape, state, and assert a U.S. position on the shape of performance-based product fire standards in the deliberations of groups like ISO and IEC.

But how would this really work in practice? No matter how large a role ASTM E-5 played in sponsoring a U.S. position at ISO or IEC, the positions articulated would not necessarily be ASTM E-5 positions and the resulting standards issued by other groups could not be said to be ASTM E-5 standards. ASTM E-5 staff are not themselves technical experts.

In order for this option to be more than a check-writing exercise, the ASTM E-5 process would have to produce a U.S. position. Traditional ASTM E-5 procedures for reaching consensus take far too much time to be used in this manner, and a useful position cannot be a fixed position. It must be a basis for meaningful negotiation with other countries.

Even if this largely unprecedented process could be successfully implemented, it might make little difference to the final standard. While not every ISO and IEC committee is a closed shop run by the nations of Europe as they see fit, the committees involved in fire safety certainly appear to be. There is no guarantee — and little reason for optimism — that ASTM could make a significant difference in this arena, even if its ideas were technically flawless and devoid of serious competition.

These are not reasons for ASTM E-5 to withdraw from ISO, IEC, or any other third-party group in which ASTM's interests are served by working with or through others. But these are reasons for not treating Option 5 as a complete, or even primary, answer to the question of what ASTM's role ought to be regarding performance-based fire codes and standards.

Option 6: Set No Strategy, but Only React Appropriately to Requests from Others

And so we come to the sixth and final role that I have been able to identify. That role is to react to the requests of others and do nothing more in the absence of such requests.

Organizations that write model national codes for fire safety — such as the National Fire Protection Association and the International Code Council — and U.S. government agencies that write requirements for product fire performance — such as the U.S. Consumer Product Safety Commission and the various transportation agencies — all are interested in shifting to a more performance-based foundation for their work, and all have found benefit in relying on ASTM E-5 for help in the past.

If ASTM E-5 management were to conclude that any appropriate role in performance-based fire codes and standards must be built around deference to other groups — groups that set levels of acceptable risk and safety, groups that define best engineering practices — then perhaps ASTM would be best served to wait for people to ask for help and then give them the help they request.

Temperamentally, I would be uncomfortable with such a role, but the logic may be irresistable. More importantly, this is the default choice. If no other role is explicitly selected and vigorously pursued by ASTM and Committee E-5 — more vigorously than it can now be said to be pursuing any particular role — then reaction and drift — or, more positively, service and husbanding of resources — will be the role ASTM plays.

Conclusion

This is the point at which an author normally discusses the options, the arguments for and against each one, and the conclusions and recommendations he or she has to offer on the choices facing the audience.

I am not going to do that here, partly because that discussion is what this symposium is for, partly because those conclusions are what my closing remarks at the end of the symposium will address, and particularly because right now I don't have a recommendation.

The options seem to me to divide between over-reaching and irrelevance, between a reckless boldness and a timid conservatism, between occupying a shrinking turf defined by others or engaging in competition with groups that ASTM has no wish to confront and that may be better suited to handle the tasks in question.

Yet for all that, I believe — as I think everyone here believes — that ASTM E-5 has a strong base of past accomplishments in the march toward performance-based fire codes and standards and a unique combination of strengths and resources to apply to the considerable work still to be done. Finding the job that most needs doing and best fits those strengths may not be easy, but we owe it to ourselves to find that job.

By the end of this symposium, we may have started a process that will make that best choice clearer — to me, to all of you, and to the constituents of ASTM and of Committee E-5.

References

[1] *SFPE Handbook of Fire Protection Engineering*, P. J. DiNenno et al., Eds., Society of Fire Protection Engineers and National Fire Protection Association, Quincy, MA, 1995.

[2] Custer, R. L. P. and Meacham, B. J., *Introduction to Performance-Based Fire Safety*, Society of Fire Protection Engineers and National Fire Protection Association, Quincy, MA, 1997.

[3] Peacock, R., Jones, W. W., Bukowski, R., and Forney, G. L., *Technical Reference Guide for the HAZARD I Fire Hazard Assessment Method, Version 1.1*, Handbook 146, National Institute of Standards and Technology, Gaithersburg, MD, 1991.

[4] Yung, D., Hadjisophocleous, G. V., and Proulx, G., "Modelling Concepts for the Risk-cost Assessment Model FIRECAM and its Application to a Canadian Government Office Building," *Proceedings of the Fifth International Symposium on Fire Safety Science*, International Association for Fire Safety Science, Melbourne, Australia, 1997, pp. 619-630.

Vincent M. Brannigan[1] and Steven M. Spivak[1]

ISO Quality Standards For Participants In Performance-Based Regulation

---

Reference: Brannigan, V. M., Spivak S. M., "**ISO Quality Standards For Participants In Performance-Based Regulation,**"*ASTM's Role in Performance-Based Fire Codes and Standards, ASTM STP 1377,* J. R. Hall, Jr., Ed., American Society for Testing and Materials, West Conshohocken, PA, 1999

Abstract

Performance-based codes impose novel burdens on regulators. Instead of one-time approval based on statutory criteria, performance-based analyses attempt to describe and control hazards on a building specific basis. As a result it will be necessary to control many aspects of building operations for the lifetime of the building. One approach to the issues of complexity and "cradle to grave" regulation could be third party certification of compliance with an appropriate safety management plan. ISO 9000 and 14000 provide possible models for such a third party certification of compliance. These programs are recognized around the world for quality control and environmental management systems. Under appropriate controls they may even be used for original performance-based approvals.

Keywords

performance-based regulation, code enforcement, ISO 9000, ISO 14000, safety management, third party regulation, registrars, voluntary standards organizations

Introduction

The development of performance-based regulation will require a major overhaul of the code enforcement structures in jurisdictions enforcing such codes. Local Authorities Having Jurisdiction (AHJ) will be asked to evaluate complex proposals on the frontier of fire engineering, often with substantial uncertainties and debatable assumptions. In many cases the needed expertise will go far beyond that found in traditional fire safety regulators. The problem is not merely a question of acquiring the needed expertise, the probabilistic nature of fire hazards may mean a long feedback loop before regulators can acquire the needed understanding, while technological change continues to create new hazards. In addition, performance-based codes require a level of

---

[1] Professor and Professor & Chair, respectively,
Department of Fire Protection Engineering, University of Maryland, College Park, MD, 20742-3031 vb15@umail.umd.edu, ss60@eng.umd.edu

"cradle to grave" regulation with much more sophisticated monitoring of fire hazards than has previously been required. One approach to this problem may be reliance on third party evaluators of proposed engineering solutions, and management operations.

National and international experience with standards for quality management and process control give ASTM and the consensus standards community a plausible approach to these problems. We propose evaluating "quality standards" for organizations proposing, reviewing, managing and enforcing performance-based engineering solutions. An analogy can be drawn from the successful experience of certain voluntary international standards promulgated by the International Organization for Standardization (ISO), and concordant national standards based thereon. In particular the model of ISO 9000 quality management system standards and the even more pertinent the ISO 14000 environmental management system standards could be utilized. Such standards provide for outside evaluation and certification using independent or "third party" registrars (or certifying bodies) employing independent auditors. The entire system operates under nationally recognized authorizing bodies who accredit these registrars.

Standards for the performance-based engineering techniques themselves can be integrated into the larger concept of management control system standards. This paper presents some of the more obvious issues in the development of quality standards and some analogous standards which may be useful in resolving such problems. A proposed role for ASTM in this new system is offered.

Performance-Based Codes: Cradle To Grave Regulation

Performance-based analyses often rely on complex assumptions about the condition of the building or its systems. Engineering tools such as mathematical models cannot predict many of the key variables needed for safety regulation. For example, consider the problem of tables and chairs removed from a multipurpose hotel ballroom. The fire problem represented by those tables and chairs changes dramatically depending on how and where they are stacked and placed. No engineering technique supports any prediction of their location. But regulatory and management system can be used to keep them where they are supposed to be. Performance-based codes will require a continuous monitoring of the hazard to make sure it is kept within the parameters of the performance-based analysis.

We have used the term "cradle to grave" regulation to describe the needed permanent monitoring of compliance:

> Any risk model which purports to describe the reaction of a technical system in a future environment that includes unpredictable human action must be accompanied by a regulatory system capable of keeping the environment within the *conditions* of the model or simulation.[1]

A technical system supporting "cradle to grave" supervision cannot be simply "grafted" onto a regulatory system designed for one time approvals. It requires development of a safety management system.

Safety Management Systems

In particular effective performance-based regulation will require:

1) a regulatory agency or independent authority with the capability of evaluating and approving complex designs which represent the state of the art of fire safety engineering, and

2) an ongoing management system with the technical ability to make sure that the building design and execution stay within the conditions and estimates of the approved performance-based analysis, and

3) a regulatory system that can supervise the management system

Third Party Regulation In A Standardized Environment

The new demands on the regulatory function may require a whole new approach to regulation. We believe that third party regulation has a potential for solving many of the complex problems in performance-based codes. However, to preserve both public confidence and assure proper technical analysis of such third party regulations, it is necessary to have a system in place for ensuring that both the regulated party and the third party regulator are performance correctly. Some models for such systems are currently being accepted on a worldwide basis.

Many areas of safety and public concerns have used third party regulators for years. Professionals such as physicians, lawyers and engineers are controlled by state sanctioned or organized third party regulators. Universities in the United States are accredited by third party regulators and the privacy of computer systems in Europe is widely managed by a system of third party regulators. The role of third party product approving agencies such as Underwriters Laboratories is well known and accepted.

ISO 14000 Standards For Environmental Management Systems

One of the most useful models for examining the use of third party regulation in a related area is the developing international experience with the ISO 14000 environmental management system (EMS) standards. These standards are built on the very successful experience with ISO 9000 quality management system (QMS) standards. In both cases the party attempting to comply with the standards has to institutionalize a control system, which is monitored by an outside registrar or certifier. Of the two standards, it is clear that the ISO 14000 Environmental Management Standards may be the best single analogy to the performance-based code environment.

ISO 14000 EMS standards represent a credible model for the management of compliance with performance-based codes. ISO 14000 is built on the successful ISO 9000 series of quality standards related to manufactured products, systems or services. What makes ISO 14000 different and relevant to the fire safety field is that it is a standard for *management* of an activity and that activity involves compliance with *safety regulations*. ISO 14000 is therefore as "voluntary" method of assuring compliance with "mandatory" standards. Compliance is monitored, not directly by regulatory agencies, but by "registrars" who audit the performance of the regulated entity. A rough comparison might be the CPAs in auditing public companies under rules developed by the (accounting standards body).

This paper assumes in the first instance that the AHJ has the needed technical capability to analyze the performance-based code proposal. Procedures for AHJs that do have this capability are discussed later.

Fire Safety As A Management Problem

Fire risk and environmental degradation share some common characteristics. They are normally byproducts of otherwise successful operations and normally require social and management controls ensure proper attention in the operational process.

The whole approach of ISO 14000 is different from the traditional approach to fire prevention enforcement. Traditional code enforcement is essentially "in rem". (i.e the building, not the building management system is the object of the code enforcement process). There are few if any requirements for qualification of building operators, and many code enforcement efforts impeded by the simple problem that the "owners" of a building may be a foreign limited partnership beyond local law.

Code compliance is often treated of as a "one time" event. For example when dealing with overcrowding, the inspector might determine that the facility is overcrowded and shut it down. But there is normally no systematic method of requiring the management to have a plan for avoiding overcrowding or monitoring the success of the plan.

Traditional codes do not deal with components of the performance-based analysis such as fire load. There is no easy method of measuring or defining fire load, and no system exists for regulating such load. Yet controlling fire load or other hazard variables may be critical for the acceptance of performance-based regulatory environments.

ISO 14000

ISO 14000 offers a possible way "around" some of these problems. It is an alternative approach to regulation in which the building management is required to produce a meaningful plan for controlling the risk, and then uses approved third party registers to certify compliance with the plan. The center piece of the ISO 14000 approach is a comprehensive auditable self study and management plan developed in accordance with ISO 14001. As stated by Puri[2], the basic premise of ISO 14001 can be summarized as follows:

> Organizations should develop an environmental policy with objectives and targets commensurate with the environmental aspects of their activities..
>
> An environmental management system should be established to ensure conformance with the stated policies and objectives..

> The organization should be able to demonstrate conformance to stated environmental policies and principles...
>
> The Environmental quality system should be effectively maintained...

Replacing the words "Environmental" with fire safety would produce the following:

> Organizations should develop a *fire safety* policy with objectives and targets commensurate with the environmental aspects of their activities..
>
> A *fire safety* management system should be established to ensure conformance with the stated policies and objectives . . .
>
> The organization should be able to demonstrate conformance to stated *fire safety* policies and principles...
>
> The *fire safety* system should be effectively maintained...

Puri suggests a six phase management process is implicit in ISO 14001, to which we add the implicit periodic recertification phase as step 7.

1) AWARENESS at all levels of the organization,
2) DOCUMENTATION of manuals and procedures,
3) IMPLEMENTATION to ensure that procedures are followed,
4) AUDITING continuous internal examination,
5) CERTIFICATION by a qualified external registrar,
6) MAINTENANCE by regular management review, and
7) REAUDIT and RECERTIFICATION by the external examiner.

Applying most of these management concepts to fire safety would be relatively straight forward. The original performance-based analysis includes most of the variables necessary for creation of the management plan. The management plan can be tailored to the precise environment, and audits can be scheduled as needed to ensure compliance with the plan.

The major advantage of the whole ISO 14000 process is that governments can be reasonably assured that all key items are being managed over the lifetime of the building, rather than having to rely on vague promises by developers, or their own limited enforcement capabilities. The regulatory costs also clearly fall on those who benefit from the use of performance-based codes, rather than creating an externality where local taxpayers are expected to foot the bill for the more complex regulation needed for these supposedly more efficient structures. The cost of regulation is a true cost which should be borne by the party who benefits. The building management gets flexibility with accountability. There are no legal preconditions on design or operations, but all phases of the operation must meet professional standards for fire safety on a continuous basis.

Accreditors and Registrars

Obviously such a system depends on the development of a useable system of third party enforcers. There is considerable experience with third party enforcers under ISO 9000. Most nations of the world not only have operating ISO 9000 QMS systems in place but are moving to implement ISO 14000 EMS systems as well. Under the ISO 9000 or 14000 system the external audit function is performed by an approved registrar, generally accredited by a national body established solely for that purpose. However terminology is not yet uniform.

In the North American ISO environment the organizations doing inspections are called ***registrars***. Registrars are accredited by national certifying bodies. The USA and Canada chose to use the term "registrar" or "registration" to distinguish the management system (QMS or EMS) approval process from "certification," which is used to describe products that comply with specified standards. In Europe and elsewhere the inspecting agencies are often called ***certifiers*** or certification bodies. But in all cases there are established national bodies that serve as the accrediting authority for the registrars or ***certifiers*** operating under their domain. In this way the registration organizations are scrutinized for expertise and capabilities and, when approved, the national body puts its imprimatur on that third party registrar.

ISO's role is to publish the voluntary international standards, which are then elaborated regionally or nationally as identical or equivalent national standards. For example in the USA the respective standards are ANSI/ASQ 9000. In the United Kingdom ISO 9000 and 14000 are identical to British standards *BS 5750 & 7750* respectively. In Europe the standards are European norms **EN 29000** and **45000** respectively. The process is duplicated in over 100 countries of the world.

In the United States there is a national Accreditation Program (NAP) which is the accreditation body for registrars. It is a joint effort of the American National Standards Institute (ANSI) and the Registrar Accreditation Board (RAB); the latter is an independent organization whose members are drawn primarily from the American Society for Quality (ASQ, formerly ASQC). Other registrars may also be operating in the US, either currently unaccredited or accredited by an equivalent body in another country. In Canada their national accreditation program is administered by Standards Council of Canada (SCC).

In a regulated area such as public safety unaccredited regulators and regulators accredited by other nations may not be satisfactory to AHJs At the very least national authorities would have to be satisfied as to the capabilities of the registrars.

The ANSI:RAB accreditation system currently has thirty or more recognized or accredited registrars. Some have expertise in ISO 9000 QMS, others ISO 14000 EMS, some cover QS 9000 quality management systems of the "big three" automobile makers in North America, and several registrars claim expertise and do business in all three aspects of quality and management system standards. Each registrar employs or contracts with trained, experienced ***auditors*** who actually undertake the independent review of a particular plant site, business entity or operation, or a building or construction project in the case of performance-based codes. It is the auditors who review, inspect and make recommendations to the registrar as to whether or not the plant, business, service (or building, stadium, hotel, etc. in performance-based terms) should be "registered."

Conflict of Interest

To avoid any conflict of interest, the system as developed in the USA and Canada requires that entities operating as registrars do not provide consulting service or internal management audits to entities seeking registration. Similarly the independent experts or consultants do not generally offer registration services.

Summary

The four tiered system consists of :

(a) nationally recognized **accreditors** or authorizing bodies, under whose 'umbrella' come
(b) "third party" **registrars** or registration bodies employing
(c) expert **auditors** providing the detailed review, inspection and recommendation for approval or disapproval, over
(d) the business, sites, operations or buildings, plants, facilities that desire to be **registered** or listed as such.

Third Party Approvals In Lieu Of AHJ approval

Up to this point the discussion has focussed on approvals by AHJs who have the needed capabilities to analyze the performance-based proposal; but expecting local governments to have the capability to do such analyses may be problematical at best. Original approval is a much more sensitive task than monitoring compliance. The distinction between the building approval function and the operational monitoring function is that inevitably public policy decisions have to be made in the course of the approval of any project, and it is critical that any registrar be exquisitely sensitive to the perspective of the AHJ who has jurisdiction over the project.

Despite this problem it is possible that an ISO 14001 system could accommodate the original regulatory approval of performance-based analyses. The key to this approach would be to have registrars acceptable to the AHJ who could examine and accept the original performance-based analyses. Such registrars could be public entities, who would specialize in this type of analysis for other AHJs, or could conceivably be private parties of unquestioned autonomy and capability.

Effect On Insurance

One possible additional benefit from this type of third party regulation is that it might be sufficient to win the support of the insurance industry for buildings using performance-based analyses. Most casualty insurers are very familiar with the idea of private regulation and approval in areas such as maritime operations, and confidence in the approach may reduce insurance obstacles to performance-based proposals.

Caveats

There are a few obvious caveats in adopting the ISO 14000 approach. The first is that traditional ISO based QMS or EMS audits are confidential. Clearly in the area of performance-based codes the original approval and the external auditor's report cannot be treated any more confidentially than any public record is today.

As noted above conflict of interest can also be a major problem if private registrars are also performing design work for other clients. There is also a more subtle form of conflict of interest if approvals are based on the registrar's preference for one or another conflicting views of a technical problem. Approvals should be based on broadly accepted technical consensus.

No government can be expected to give up its fundamental right to change safety standards over time, and to set higher standards for its own environment than desired by other locations. Any management system must be committed to enforcing publicly set levels of safety.

Finally the ISO 14000 approach does not draw the distinction between life safety and property damage that is suggested by some authors in the fire safety field, i.e. saving lives versus property loss control. However, there is a sufficient public interest in property protection that limitation of performance-based design to life safety only may be a major stumbling block for its introduction.

Role For ASTM and Other Parties

Many questions can be raised concerning the role of ASTM in such a process. Should new types of performance-based management system standards be written by ASTM, NFPA or others? Should ASTM have a role in recognizing registrars and accreditation authority? Probably the most difficult task is to identify a qualified group of registrars, i.e. the "third party" or quasi-regulatory authorities. Some organizations are already doing this in registering entities to ISO 9000 and ISO 14000, such as Underwriters Laboratories (UL). Factory Mutual Research Corp. (FMRC), Canadian Standards Organization (CSA), National Fire Protection Assn. (NFPA) and others might operate in this fashion.

Decisions have to be made on who might serve as the accreditation body. Should it be authorized by ANSI or in under ANSI accreditation of private sector bodies? Could there be a joint effort between ANSI and the International Codes Congress (ICC), or ASTM, ICC and NFPA together accredited by ANSI?

Conclusion

Realizing the benefits of performance-based codes will take both an accurate understanding of just what is possible in such analyses and an effective system for independent review and control by some regulatory body. It remains to be seen what role ASTM and ANSI- as well as the other related codes and standards developers-have to play, should our analogy to international management system standards prove viable as a performance-based approach to fire safety design.

References

1. Brannigan V, Smidts C. **Performance-based Fire Safety Regulation under Intentional Uncertainty** *Proc. 1st Int Symp Hum. Behav. & Fire* 1998 p 411-420

2. Puri, ***Stepping Up to ISO 14000: Integrating Environmental Quality with ISO 9000 and TQM*****, Productivity Press, Portland, OR, 1996**

Ronald L. Alpert[1]

The Role of ASTM Subcommittee E5.33, 'Fire Safety Engineering,' in Performance-Based Fire Codes

---

Reference: Alpert, R. L., **"The Role of ASTM Subcommittee E5.33, 'Fire Safety Engineering,' in Performance-Based Fire Codes,"** *ASTM's Role in Performance-Based Fire Codes and Standards, ASTM STP 1377*, J. R. Hall, Jr., Ed., American Society for Testing and Materials, West Conshohocken, PA, 1999.

Abstract: ASTM Subcommittee E05.33 is the result of a recent merger between E05.35 on fire risk and hazard assessment and E5.39 on fire modeling. As such, E05.33 sees its scope as including not only standard guides for the calculation methods and logic used in performance-based codes and standards but also the infrastructure that will allow regulatory officials to evaluate performance-based designs or product risk analyses more easily in the future. Any group in ASTM with an interest in performance-based codes or standards related to fire safety should be able to develop their code or standard, with the help of E05.33. This paper reviews the plans for activities within E05.33, which, it is hoped, will make this promise a reality.

Keywords: ASTM Fire Safety Engineering, performance-based

Background

The strategic plan of the ASTM Fire Standards Committee, E05, contains the following goals related to fire safety engineering (FSE):

- Develop new fire standards which can provide data for fire safety engineering
  - Building design and modeling calculations
  - Product fire hazard/risk assessment studies
- Provide FSE methodology that will lead the way toward the development and implementation of performance-based fire codes

This shows that fire safety engineering is a critical component of the E05 strategy for dealing with future performance-based codes. The International Code Council (ICC) has drafted the first such code in the USA. This ICC Draft Building Performance Code [*1*] contains the following structure:

---

[1] Senior Research Specialist and Manager, Flammability Technology Program, Factory Mutual Research Corporation, P.O. Box 9102, Norwood, MA 02062

- Objectives, stating what is expected in terms of societal goals
- Functional Statements, explaining the function needed to meet the objective
- Performance Requirements, detailing the list of requirements implied by the Function
- Acceptable Methods, to verify performance

The key ICC method for verifying performance would consist of the use of authoritative consensus documents by design professionals. Such consensus documents could include:

  - Prescriptive code provisions (existing codes)
  - Professional standards of practice, e.g., from The Society of Fire Protection Engineers (SFPE) Handbook [2] or Design Guide or task group reports and from ASTM standards
  - Testing/measurement standards (e.g., ASTM)
  - National standards that evaluate performance of materials, products and systems (e.g., ASTM)

It is clear that standard practice documents or guides will be needed for implementation of the USA performance-based code. The scope of ASTM subcommittee E05.33 supports the development of such standard FSE practice documents by emphasizing the following areas for the subcommittee's future activities:

- Standards related to fire hazard and fire risk assessment
- Standards related to evaluation and verification of fire safety designs
- Standards related to FSE procedures & tools
- Stimulation of research on FSE methods
- Liaison with professional/regulatory bodies

The Role of E05.33

The preceding discussion shows that, as part of the scope of E05.33 and the strategic plan of committee E05, ASTM can help provide the authoritative, consensus documents required by the draft, ICC Building Performance Code [*1*]. Such documents would include standards on FSE logic, calculation tools and required input data.

The existing standard guides that were produced by the two subcommittees that have merged to become E05.33 already constitute an impressive array of tools and recommended procedures for fire safety engineering design and hazard analysis. These guides, which are available from ASTM, include:

- E1355: Evaluating Predictive Capability of Deterministic Fire Models
- E1472: Documenting Software Fire Models
- E1546: Fire-Hazard Assessment Standards
- E1591: Data for Fire Models
- E1776: Fire-Risk Assessment Standards
- E1895: Uses & Limitations of Fire Models

The two guides on fire hazard and fire risk assessment (E1546 and E1776, respectively) mainly focus on products that are introduced into a building that already exists or has been designed. To evaluate the safety impact of the introduction of products into such existing environments, these two guides contain recommended procedures for the development of future hazard or risk assessment standards, each new standard to be aimed at specific combinations of products and occupancies.

To further clarify the procedures in guide E1546, flow charts and examples of how to develop an actual hazard assessment standard for a specified product/occupancy combination are now being balloted.

Among the recommended hazard assessment procedures in Guide E1546 are the following:

- Define the scope of the assessment
- Identify measure of harm to be assessed
- Identify/describe scenarios of concern
- Identify test methods or calculations that will determine impacts
- Use scenarios to define key input parameters or specifications
- Identify types and sources of data
- Identify evaluation of hazard measures relative to impacts

The remaining four guides developed under the auspices of E05.33 are aimed at the proper implementation of computer fire models. These four guides, which mainly focus on <u>zone models</u> of compartment fire growth, accomplish the following:

- Standard E1472 provides detailed information on how to document software for fire models through:
  - Program identification (authors, capabilities)
  - Technical documentation (scientific and mathematical basis for the model)
  - User's manual on software operation and preparation of input data
  - Maintenance and programming manual to allow for modifications or conversions of software
- Standard E1591, which describes data required as input for models (e.g.: heat release and mass loss rates, combustion efficiency, heats of combustion and gasification, etc.):
  - Contains guidelines on how such data can be obtained, e.g., from ASTM and other test methods
  - Provides guidance on where to find values for typical input variables
- Standard E1355 provides a methodology for evaluating the predictive capabilities of a fire model for a specific use by:
  - Defining the model & scenarios to be evaluated
  - Verifying theoretical basis and assumptions
  - Verifying mathematical/numerical robustness
  - Quantifying uncertainty and accuracy of model
- Standard E1895 provides recommendations for model users and the authority having jurisdiction (AHJ) in establishing the limitations of models in fire risk and hazard assessment and assists in evaluating the appropriate use of fire models in fire safety engineering of products and designs.

The approaching introduction of a performance-based building/fire code by the ICC will require a comprehensive infrastructure to be in place permitting competent and timely evaluation and approval of performance-based designs by code officials. Certainly, the upcoming roll-out of a detailed fire safety engineering design guide by the SFPE and the tools provided by the existing set of E05.33 standards described here will be some of the major components of this required infrastructure, but really, just the first steps. Contributions will be needed from all interested professional and standards organizations in order to have the proper environment in which code officials can operate effectively.

In addition to the excellent, existing set of E05.33 standards, there can be many other contributions to the required infrastructure for performance-based building codes from ASTM subcommittee E05.33. The following options explain these potential contributions:

- Option A: Provide standards that help implement the performance-based FSE evaluations in the SFPE Design Guide
- Option B: Expand existing E05.33 standards for additional applications
- Option C: Provide standards for third-party review of performance-based FSE designs

Examining the first option in further detail, E05.33 can develop standard methods for use of the upcoming SFPE Design Guide in specific situations to meet the critical need of code officials to have confidence in performance-based FSE. Such confidence can be established through the application of the principles presented in the SFPE Design Guide to combinations of generic building products, or building contents, and generic building occupancies or building processes. Here, "process" refers to the generic activity taking place at a given location, independent of the specific type of business or residence occupancy.

The generic building products that potentially could require FSE evaluation during design or hazard assessment are:

- Interior floor, wall and ceiling linings for buildings
- Exterior siding/roofing (including skylight, window and exit/opening) products
- Structural components that are combustible
- Typical contents (furnishings or equipment)

The following list provides examples of generic processes that might have to be considered in a FSE design (compare to the list of General Property Uses in the NFPA 901 National Fire Codes):

- Residence
- Care Provision
- Mercantile
- Distribution/Storage
- Information processing (schools, offices)
- Basic Industry (materials processing, etc.)
- Manufacturing

The first option for future E05.33 contributions to the performance-based infrastructure could involve the development of application standards, in the form of standard guides or standard practices, for use of the proposed SFPE Design Guide with important combinations of the preceding products and processes. These new E05.33 standards could, for example, contain:

- Recommended Safety factors for FSE design and hazard assessment calculations or extrapolations of test results
- Design scenarios for ignition or initiation of fire involvement of materials or products
- Fire growth and smoke production rate design values for generic combinations of materials/products and processes
- Design values for the sensitivity of materials or products to effects of heat and smoke generated by building fires, e.g., in terms of critical temperatures or damaging gas species/soot concentrations.
- Procedures for documentation of the entire performance-based design process

A second way in which E05.33 could contribute to the performance-based infrastructure is to expand existing E05.33 hazard/risk assessment and computer modeling standards. This expansion could involve, for example, the following:

- Expansion of standards on computer fire models to cover critical issues involved with the use of field models, hybrid zone/field models or other types of computational models.
- Providing additional examples in the Hazard and Risk Assessment guides showing how to develop application standards.

The third option for an E05.33 infrastructure contribution would be to facilitate third-party review of performance-based designs or assessments. Such a contribution could involve, for example, the development of standard guides for third-party review of the final FSE design and the entire performance-based design process, including:

- Required capabilities and experience of the third-party organization
- Structure and content of the review
- Procedures to document the review

Conclusions

A number of specific E05.33 activities related to the establishment of a standards infrastructure have been suggested. The objective of this infrastructure is to increase the confidence of the AHJ in fire safety engineering approaches that satisfy performance-based requirements in codes and standards.

References

[1] Performance Code Draft, International Code Council, unpublished document distributed at the International Forum for Cooperation in Fire Research, Gaithersburg, MD, October 1998.

[2] *SFPE Handbook of Fire Protection Engineering*, 2nd Edition, Society of Fire Protection Engineers, Bethesda, MD 20814, 1995.

Marcelo M. Hirschler[1]

What I Have Learned While Writing Draft Fire Hazard Assessment Standards and Guides for ASTM E5

Reference: Hirschler, M. M., "**What I Have Learned While Writing Draft Fire Hazard Assessment Standards and Guides for ASTM E5,**" *ASTM's Role in Performance-Based Fire Codes and Standards, ASTM STP 1377,* J. R. Hall, Jr., Ed., American Society for Testing and Materials, West Conshohocken, PA, 1999.

Abstract: Since ASTM adopted its guide to the writing of fire hazard assessment standards, there have been several initiatives aimed at producing an actual standard for a specific product class and occupancy. I have been the leader in several of them, from a draft for fire safety in rail cars to a draft on upholstered furniture in health care facilities. So far, none of them has become an ASTM standard. Part of the reason is that this is an entirely new type of document that is technically very challenging. But there are also other reasons that go to fundamental questions about what types of standards and guides people want to use in the built environment. This paper will be an overview of what I have seen and heard while pursuing draft fire hazard assessment standards and guides, and my own opinions and sense of what it all means for the direction of performance-based fire safety documents at ASTM.

Keywords: active fire prevention, fire, fire hazard, fire hazard assessment, fire performance, fire retardance, fire risk, fire safety, passive fire prevention, sprinklers

Introduction

Committee E-5, on Fire Standards, was one of the first committees created by ASTM, back in 1904. Its role was to write standards and get involved in research to address fire risk. Usually, it actually conducted that process by writing fire test methods only. In fact, during the first 85 years of its existence, the committee issued 21 standards, 16 of which are test methods (76.2%) (this includes ASTM E 69, which is now under the

---

[1] GBH International, 2 Friar's Lane, Mill Valley, CA, 94941, USA.

jurisdiction of committee D-7 on wood). Four of the five others were: Terminology E176, Practice E535 (on how to write fire test methods), Guide E603 (on how to run room scale fire tests) and guide E800 (on how to measure combustion products). Only Practice E931, "Standard Practice for Assessment of Fire Risk by Occupancy Classification" addressed directly the issue of fire risk (or fire hazard) (4.8%). This was the first document produced by ASTM E-5 dealing with a potential performance approach to fire standards, as opposed to the prescriptive approach of test methods. The history of the development of Practice E931 (and subsequent withdrawal for being inaccurate) is useful and illustrative of the tendencies within the committee [*1*]. In the 1990s, committee E-5 has issued 17 new standards, of which 12 are test methods (70.6%), and 5 are guides. This improvement appears marginal, until one looks at the content of the guides. Three of the Guides address fire models (E1355, E1472 and E1591), one addresses writing fire hazard assessment standards (E1546) and one addresses writing fire risk assessment standards (E1776), so the issues of fire hazard and fire risk are being addressed in 29.4% of the new documents issued in the 1990s, compared with only 4.8% of the new documents issued before the 1990's. This is progress.

Appendix 1 shows the 1998 versions of the Scope and Goals of Committee E-5. This is included in this work because it shows that the committee believes that fire safety engineering, as represented by the development and revision of fire hazard and fire risk assessment standards, is a critical role of the committee. Such standards should include those suitable for use by regulatory officials, and dealing with buildings, structures, materials, products and assemblies; furnishings and contents; appliances and equipment; and transportation facilities and equipment.

In the 1990s, following the issuance of Guide E1546, it became evident that the instructions in that guide were very broad and required further clarification before they would be able to be used for drafting an actual fire hazard assessment. Therefore, drafting of bridging documents was initiated to develop the needed clarifications. This work will discuss some of the issues that have arisen when attempts were made to produce such bridging documents.

Such standards and guides are technical documents, and rather complex ones. However, technical issues are only one of the elements of the development process. In fact, it is likely that the technical issues may even play a minor role in the entire process.

Understanding what is happening within ASTM to affect the process of fire hazard assessment standards and guides development (which in itself is an essential step in the development of performance codes and guidance documents for them) needs a review of processes by which society arrived at fire safety requirements, or guidelines. The effects of fire safety requirements on the marketplace must be analyzed then, as standards development is clearly a commercial process, even if usually disguised as a technical endeavor. This has been clearly understood in the European Union, where an essential step in the elimination of "barriers to trade" between countries, coordinated by the European Community Directorates General, is the "harmonization of standards."

This work is presented in several parts:

* Background on fire safety requirements.
* Customers of fire safety requirements: who they are and what their needs are.
* Debate over active and passive fire protection.
* Technical issues associated with fire hazard assessment standards and guides.

* Nontechnical issues associated with fire hazard assessment standards and guides.
* Discussion and conclusions.

Fire Safety Requirements - Background

Most common fire safety requirements are based on prescriptive measures. The designer is told to follow certain rules, such as the test methods a material or product must meet to become acceptable, and certain limitations on physical dimensions, instead of declaring that the fire safety objective of designing a site is that its users should be safe from fire. Requirements, either via codes or through specifications, limit choices: for example materials must meet certain fire properties or exitways must meet certain physical characteristics. Furthermore, it is usually not stated that this involves the implicit assumption that the prescribed design is intrinsically fire safe. The prescriptive measures, in turn, imply a level of fire safety deemed acceptable by the authority having jurisdiction, usually unquantified in numerical terms. In fact, many fire safety requirements result from problems with earlier habits. Some large historical fires are examples of the problems resulting from the movement of large numbers of people to cities: the Great Fire of London, UK (in 1666), that of Chicago, IL (in 1871), and that of San Francisco, CA (in 1906), destroyed large parts of great cities where wood construction was prevalent, and societal fire protection was nonexistent. By the time of the Chicago fire, insurance companies were starting to see the potential for minimizing huge losses by prevention measures. Thus, organizations like ASTM, NFPA (National Fire Protection Association) and UL (Underwriters Laboratories started, around the turn of the 20th century, developing standard tests and recommendations for obtaining public fire safety.

The most frequent way to change fire safety requirements is, as always, public demand following journalistic headlines. Thus, if multiple fire fatalities occur in a single large fire, e.g. a hospital, hotel, school, or nursing home, the headline news often triggers some major "improvement" in requirements, that appears to "solve" the specific cause of that particular tragedy. However, such easy "solutions" do not generally take into account either the probability of such a fire occurring or the side effects (is there some other issue which the "solution" adversely affects?). Headline tragedies usually represent small fractions of the overall fire fatalities. Even when the NFPA definition of catastrophic fire (one that kills 5 or more people) is used, such fires almost inevitably add up to less than 10% of the overall fire fatalities (see Table 1, with United States data, as an example). This means over 90% of all fire fatalities occur in fires that rarely merit headlines.

This way of dealing with fire safety is not unique to the United States: in many (or most) countries, the vast majority of fire fatalities occur in areas (often single-family residences) where no authority having jurisdiction handles fire safety requirements. This is coupled with the traditional freedom to do one's own thing in each person's "castle" (home). Moreover, even when requirements exist, they tend to be prescriptive, and may become obsolete when technology advances. The use of performance-based fire safety requirements would be a way to help society so that it does not need to overreact to journalistic headlines and that fire safety remains based on the most recent technology.

Table 1. *Fire Fatalities in the USA and in the Largest Fires*

Year	Fire Deaths	Fire Deaths in Large Fires *	Percentage **
1991	4465	342 (26, 25)	7.7% (7.1)
1992	4730	176 (11)	3.7% (3.5)
1993	4635	316 (47)	6.8% (5.8)
1994	4275	307 (9)	7.2% (7.0)
1995	4585	384 (168)	8.4% (4.7)
1996	4990	322 (110)	6.5% (4.2)
1997	4050	216 (10)	5.3% (5.1%)

* Figures in brackets represent the largest single fire of the year: board and care facility in Pennsylvania in 1997, ValuJet airliner in Florida in 1996, Oklahoma City government building bomb in 1995, residential fire in Maryland in 1994, Texas dormitory in 1993, hotel restaurant fire in Indiana in 1992, Oakland Hills, California, wildland forest fire (26 fatalities) and chicken processing plant in North Carolina (25 fatalities) in 1991.

** Figures in brackets represent the percentage of overall fire fatalities if the most tragic fire is excluded.

Customers (or Users) of Fire Safety Requirements

Fire safety engineering is complex enough that most people deal with some subsets, and are uncomfortable with changing a familiar system by an unfamiliar and/or difficult one. Fire safety techniques have the following nine types of users/stakeholders:

(a) the ultimate user or consumer of the product, service or operation,
(b) the manufacturer of the intermediates (such as materials or components),
(c) the manufacturer of the ultimate product (or operation),
(d) the fire protection professional responsible for the design of the ultimate product or of an intermediate material or product,
(e) the fire protection professional responsible for assessing the suitability of the ultimate product or of an intermediate material,
(f) the fire protection professionals responsible for assessing the suitability of a structure or operation,
(g) the authority having jurisdiction,
(h) the specifiers associated with particular materials, products, buildings, services or operations, and
(i) the attorney searching for the product liability implications of the manufacture and use of either the ultimate product or an intermediate.

An analysis follows, attempting to draw some broad generalizations on how the use of new performance-based techniques can affect each one of these groups, and some of their expected potential reactions.

(a) The least technically sophisticated users are the first ones, consumers. Moreover, such people are generally involved in the debate only to the extent that consumers can choose whether or not to acquire a product or service. Moreover, consumers are those people most vulnerable to the journalistic pressures described above.

(b) Manufacturers of materials or intermediates have a direct stake in today's fire protection requirements. Those requirements may or may not allow them to sell their material into an existing (or new) market. Thus, attitudes depend both on technical sophistication and on the degree of market penetration of their materials. The following are some examples of conflicting attitudes and their rationales.

Large manufacturers, for example, tend to have greater research and development budgets, and are likely to be capable of developing new responses to market changes in a shorter time frame than smaller manufacturers. Therefore, they are more likely to welcome challenges that cause changes in requirements, because it will keep them one step ahead of their smaller competition.

However, even large manufacturers, if, they already control a very significant fraction of a particular market, may oppose change, as it is likely to generate revenue losses for them, at least in the short term. Furthermore, manufacturers of materials have the distinct disadvantage that they must aim for a moving goalpost when fire safety engineering techniques are applied, because the effect of their material cannot be directly quantified with performance requirements, but will depend on the combination of materials and components comprising the ultimate product. Thus, specific prescriptive instructions for every material will allow a material manufacturer to know exactly what to aim for, and to develop adequate business plans; so this manufacturer will tend to support prescriptive techniques.

Another approach is that of material manufacturers who may have developed a new material that is safer, overall, than the material in use today, but falls short on one of the prescribed requirements. In this case, their material is, for all practical purposes, prevented from use and they need alternative ways to penetrate the market; for example fire safety engineering techniques based on performance (defined in ASTM E05 as: response of a material, product, or assembly in a specific fire, other than in a fire test involving controlled conditions).

A different example is a materials manufacturer who has designed a new material that is equally safe than the one in use, but only when using new techniques to evaluate it, because the traditional techniques (whether via testing or overall evaluation) are inappropriate. It is likely that this manufacturer will want to use performance-based fire safety engineering techniques. A different scenario is that the introduction of alternative techniques may well require re-evaluation of materials to ensure compliance with the new approach. Occasionally the introduction of alternative techniques may bring, probably unwarranted, fear of product liability exposure (see also analysis of attitudes by attorneys).

In conclusion, certain material manufacturers are most likely to wish to retain a prescriptive set of requirements for two reasons: inertia and market protection, while some other material manufacturers are most likely to wish to move to a performance approach so as to penetrate a market with innovative materials.

(c) Manufacturers of final consumer products are directly affected by fire safety requirements: they can see the goal line directly and a prescriptive requirement appears to be a simple solution to their needs. Such manufacturers, by making the regulated product, already know the material or component combinations they plan to use. However, market forces in effect here are similar to those discussed for material manufacturers, and need not be repeated.

There is also a unique issue: the replacement of one material in a product may yield both significant cost savings or an improvement in a certain property, both of which would increase profits (either by decreasing manufacturing costs or by increasing sales). Thus, a manufacturer envisioning such a composition change could be interested in considering alternative performance-based techniques, because such techniques could be used to demonstrate that increased profits are not necessarily opposed to maintaining safety.

(d) Fire protection professionals responsible for product design, whether of the final product or of an intermediate material or product, have the greatest technical knowledge of fire safety engineering techniques, both as prescriptive requirements and as performance specifications. Such people have professional interest in using more sophisticated techniques, which will create greater needs for their services.

(e) Fire protection professionals responsible for assessing suitability of materials, components, or products are typically involved in testing, and are more likely to have a vested interest in retaining the use of current prescriptive techniques. New techniques will require this individual to invest in them, causing added short term expenses. Again, the more technically sophisticated professionals are more likely to be receptive to new techniques, at least partially as it will allow them to outflank competitors and be among the first to offer new services to customers.

(f) Fire protection professionals responsible for assessing or designing the fire safety of a structure (for example a high-rise building, a group of buildings, a shopping mall or a bridge) or operation (a manufacturing plant or a power plant) are almost invariably users of some type of fire safety engineering technique. The most common, and rapidly growing, approach used by these professionals is the assumption that all materials or products can be classified as either "combustible" or "noncombustible" and that the former should be rendered "safe" by using active fire protection techniques, with which they are familiar. This issue, which is quite critical, will be addressed at greater length later in this work.

(g) Authorities having jurisdiction have the power, and the responsibility, to make the decisions. It is not uncommon for such decision makers to prefer to maintain a status quo, which ensures minimum risk to them and is "safe." Responsibly making changes in requirements, means investment of time and/or money to ensure that the new set of requirements is as acceptable as those being replaced. Moreover, techniques for performance based alternatives tend to be more complex, and this group of people tend to have nontechnical responsibilities that prevent them from studying the new techniques as exhaustively as can actual practitioners.

Therefore, many authorities having jurisdiction require bridging tools to explain the novel techniques, and the critical assumptions involved, to get familiarity with these methods. In the absence of such bridging tools, authorities having jurisdiction are likely to have some reluctance to use fire performance based requirements. Thus, it is incumbent upon the fire protection community to help devise the tools needed to convert authorities having jurisdiction into advocates of alternative techniques. Interestingly, the fact that such bridging documents don't exist, influence this group not to favor performance-based techniques, if not actually oppose them. As other groups, authorities having jurisdiction must also contend with market forces; thus they are likely to be swayed, at least to some extent by opportunities to lower public expenditures and increase public safety.

In fact, too, authorities having jurisdiction are often confronted with manufacturer requests to be granted a code variance, via "equivalency," usually involving performance-based fire safety engineering, as it almost invariably involves a material or product failing to meet a prescriptive requirement. The relatively low frequency in which code variances are granted is probably indicative of the hesitancy of the code officials or other authority having jurisdiction.

(h) Specifiers are similar to authorities having jurisdiction in that (a) they have the power to make decisions affecting the products of others and (b) they normally prefer the "safe" status quo, because they don't have the time to study new techniques. They differ in that their major drivers are market forces. The other peculiarity is that they must be somewhat knowledgeable about how product liability can affect their company.

(i) Attorneys representing both plaintiffs and defendants in civil litigation associated with fire incidents have long been in the forefront in using alternative techniques, particularly those based on fire modeling and fire hazard assessment. This derives from the forces at battle in civil litigation. Such litigation often involves a manufacturer and a major consumer, following an incident where something went seriously wrong. Both parties are probably law abiding citizens who complied with existing regulations, but, at least one of them (and perhaps both) committed some serious mistake that caused the fire to become a severe loss. At this stage, compliance with regulations and specifications is no longer considered an issue: failure to comply involves almost automatic "guilt," but compliance does not bring automatic "acquittal." The issue that will be considered by legal counsel (on each side) will be whether "due diligence" was used by the defendant, and whether state-of-the-art concepts were employed when the product that was involved in the fire was manufactured. The history of decision making by the manufacturer will be brought into the open, and the methods relied upon to make recommendations and reach conclusions will be analyzed. A manufacturer who can show that the materials (or products) made cannot be faulted because nothing better is available to meet the usage guidelines put forward by the final customer (and not necessarily the specifications), using the most modern experimental techniques and mathematical models, is most likely to defend charges successfully. This is, of course, a very stiff requirement, rarely, if ever, met. Therefore, the maneuvering that goes on both before and during trial tends to involve the use of fire safety engineering techniques to investigate whether the material or product supplied (and used) was adequate for its stated purpose. This, of course, cannot be achieved with traditional testing techniques, which cannot address alternatives.

Passive or Active Fire Protection - Materials and Products

An element of the struggle between prescriptive and performance requirements is the difference between using active or passive fire protection. Active fire protection involves devices such as automatic sprinklers and alarm systems; passive fire protection involves using difficult to burn materials that give off low heat and smoke if they burn.

Traditional prescriptive requirements were based exclusively on passive fire protection. On one extreme were specifications that detailed (occasionally using trade marks) the materials to be used. A more common approach described the fire tests to be met for every property; this approach often cannot keep up with technology (as shown later on). The opposite extreme, based entirely on active fire protection, would be a simple code stating: "A facility containing combustible materials shall be properly sprinklered to ensure no fire fatalities will occur". There is a tendency, by certain organizations, to design fire safety purely based on active fire protection measures (mostly sprinklers) and to (conservatively) assume that, all combustible materials must be actively protected. Both approaches are inadequate. Neither approach actually gives the type of flexibility that is the inherent advantage of fire hazard and fire risk assessments.

Most prescriptive testing techniques in use for fire safety requirements have been developed many years ago; many suffer from deficiencies (and some may actually be unsuitable) when applied to new materials. Techniques designed for traditional materials, e.g., often involve vertical or ceiling mounting, both of which can generate misleading results when assessing melting materials. Traditional techniques may also be incapable of generating data for fire safety engineering applications (such as fire models) and thus represent an end point and not a source for additional information on fire safety.

If the wrong assessment technique is used for a material or product, 3 outcomes are possible: the technique still gives the right answer (this is the most unlikely outcome, in view of the premise the analysis started with, but is of course the most desirable one); the technique assesses the material or product as better than it really is or it assesses the material or product as worse than it really is. If the technique is too lenient for the material, an unsafe material can be approved for use, so that valid safety concerns are the potential outcome. If the technique is too severe on the material, manufacturers of novel materials would be unfairly excluded from a market to which a safe alternative could have been offered. If the technique is too severe on the material, but still classifies it as suitable, there is no fire safety problem, but the consumer is charged an excess cost to meet the fire safety requirement.

If a technique adequately assesses the material or product, but is unable to generate results in adequate fire safety engineering units, the assessment is incomplete as it can only be used for a simple comparison of competitive materials for the same application. It may be a suitable qualitative, or semi-quantitative, assessment technique, but will need to be supplemented by other techniques to ensure safety of the material under study.

Almost all traditional fire property assessment techniques are of this kind: suitable for limited use but unable to provide fire safety engineering information.

The following is an example of problems that can be encountered by an advanced material which needs to meet inappropriate requirements. The hypothetical material is combustible, but has an extremely high critical ignition flux (such as over 70 kW/m^2), and very low heat release. A comparison of the fire hazard of a fire associated with using that material to one using a noncombustible material, in an application where ignition sources are mostly absent: differences would be negligible. On the other hand, the combustible material may have some idiosyncracy making it unsuitable for test in the specified test for the application. As a result, a material that would have been extremely safe would be excluded from the application in the prescriptive code and would be classified in the same category as a highly flammable material, like dynamite, in the active-fire-protection-only performance-based code, leading to its likely exclusion on cost grounds.

Sprinklers are not fail safe. A recent study of nonresidential fires in London, England, showed a failure rate of > 17% for automatic sprinklers [*2*]. Such a failure rate is probably unusually high and partially due to the low numbers of fires involved. However, it is still troubling. In a similar note, recent NFPA Fire Investigations Reports have addressed fires at 4 fully sprinklered retail stores (in one case even having additional draft curtains and heat vents) where severe fire damage was caused (in 2 cases the entire building was destroyed) [*3*]. There is no statistical validity to extrapolating any conclusion from this information, except to infer that full protection by an active system is insufficient to ensure safety.

The argument of whether passive or active fire protection measures should be used is futile: both have a role to play. For example, it is extremely unlikely that high-rise buildings can be fully protected without active devices. However, an active device must become activated, and can fail, while passive fire protection is an inherent property of the materials or products used.

Technical Issues Associated with Fire Hazard Assessment

As explained above, technical issues are only one elements involved in the process of standard and guide development. In the special case of fire hazard assessment, the technical issues can often be resolved easily, by reaching consensus between all interested knowledgeable parties. The technical issues involved are laid out briefly as follows.

The traditional approach to codes and standards is the specification of individual fire-test-response requirements for each material, component or product that is placed in a certain environment and is deemed important to ensure fire safety. This practice has been in place for so long that it gives a significant level of comfort: a manufacturer knows what is required to comply with the specifications and a specifier simply applies the requirements. The implicit assumptions are not stated, but they are that the use of the prescribed requirements would ensure an adequate level of safety. There is no need to impose any change on those manufacturers who supply safe systems meeting existing prescriptive requirements. However, as new materials and products are developed, manufacturers, designers, and specifiers often wish they had the flexibility to choose the way in which the overall safety requirements are to be met. Thus, it is the responsibility of the developer of an alternative approach to state explicitly the assumptions being made to produce the output. The way to generate explicit and valid assumptions is to provide a performance-based approach, based on test methods providing data in engineering units, suitable for use in fire safety engineering calculations. Fire hazard assessment is an estimation of the potential severity of the fires that can develop with certain products in defined scenarios, once the incidents have occurred. Hazard assessment does not address the likelihood of a fire occurring, but is based on the premise that there an ignition has occurred. A fire hazard assessment focuses on a particular product in a certain fire scenario. It requires developing all the fire scenarios to be considered and the effect of all contents and design considerations within the occupancy which are potentially able to affect the resulting fire hazard and to obtain an adequate level of resulting fire safety.

The hazard assessment process and its potential outcomes are:

1. A fire hazard assessment must specify all steps required to determine fire hazard measures for which safety thresholds or pass/fail criteria can be meaningfully set.
2. A fire hazard assessment must develop fire safety objectives and apply them to specific scenarios, under certain assumptions, and using well defined assessment techniques (or test methods) as input into calculation methods.
3. A fire hazard assessment must assess a new product being considered for use in a certain occupancy, and reach one of the following five conclusions.
    - i. The new product is safer, in terms of fire performance, than the one in established use (on any arbitrary scale). Then, the new product is desirable, from the point of view of fire safety.
    - ii. There is no difference between the fire safety of the new product and the one in established use. Then, there is neither advantage nor disadvantage in using the new product, from the point of view of fire safety.
    - iii. The new product is less safe, in terms of fire performance, than the one in established use. Then, the new product is undesirable, from the point of view of fire safety, and should not be used unless other changes are made.
    - iv. A new product that is less safe, in terms of fire performance, can nevertheless be made acceptable if it is part of a complete design for the scenario, that includes other features, such as use of an alternative layout or increased use of automatic fire protection systems, that demonstrably produce the same or better safety for the complete design. Then, a more in-depth fire hazard assessment would have to be conducted to ensure that the entire design achieves the safety goals, and the new product would be acceptable only as part of the larger, approved design.
    - v. The new product could offer some safety advantages and some safety disadvantages over the product in established use. An example of this outcome could be increased smoke obscuration with decreased heat release. Then, a more in depth fire hazard assessment would have to be conducted to ensure that the advantages outweigh the disadvantages, before the new product could be accepted.
4. If the scenario does not contain the product being assessed, then the fire hazard assessment implications of the introduction of the new product must be analyzed

in the same way as above. The fire safety should then be compared with that achieved in the scenario in established use (without the new product). The same analysis would also apply if an additional product of the same type as one already present is being considered for introduction: the fire hazard assessment should compare the fire safety implications of the addition.

5. Following the analysis described above, the fire hazard assessment must be able to reach a conclusion regarding the desirability of the product being studied.

The technical issues to be resolved include the occupancy scenarios to be studied (including the ignition sources to be considered), the assumptions to be made, the fire properties to be measured, the fire models to be used for obtaining results and the end points to be used. If a Guide is to be drafted, as a bridging tool, consensus is required only on how to decide each one of those technical issues, since the actual fire hazard assessment will get into the details.

NonTechnical Issues Associated with Fire Hazard Assessment

The other (commercial) issues are much more complicated to resolve, as there are conflicting interests between the various stakeholding parties, and there is "fear of the unknown." Issues can be categorized, in the author's opinion, into several groupings. The relative number of groupings shown in support and in opposition to fire hazard assessment reflects the potential reasons for people to act in a certain way and not actual rationales given for negative votes nor relative support for fire hazard assessment.

Opposition:

* Some organizations offer materials or products with fire performance exceeding requirements of actual fire hazard, but which now represent a very large (or even overwhelming) fraction of a particular niche market. They are likely to oppose a fire hazard assessment because flexibility and alternatives could open the market to competing materials or products which cannot meet present requirements.
* Some organizations offer materials or products which meet present requirements but which may exhibit fire performance inadequate for the actual fire hazard requirements, but which now represent a very large (or even overwhelming) fraction of a particular niche market. They are likely to oppose any fire hazard assessment because, by requiring a fire hazard assessment, it would close the market to their materials or products or force them to redesign the materials or products to meet the enhanced requirements.
* Some organizations offer materials or products with fire performance which may or may not be adequate for actual fire hazard requirements based on interpretations given by regulators or specifiers, but which now represent a substantial fraction of a particular niche market. They are likely to oppose any fire hazard assessment because, a change in interpretation of the fire hazard might close the market to their materials or products or force them to redesign the materials or products to meet the potentially enhanced requirements.

* Some organizations offer materials, but not products, for certain markets, and can meet the prescriptive requirements for their materials, as specified by the final material manufacturers. They are concerned that such specifications could change, following fire hazard assessment, so that they would be facing the uncertainty of either more severe or less severe requirements, which could change their competitiveness. They are likely to oppose any fire hazard assessment because the uncertainty of amended requirements could close the market to their materials, or force them to redesign the materials (if requirements become more severe), or open the market to competitive materials (if requirements become less severe).
* Some organizations have been involved in product liability litigation and are concerned that the flexibility inherent in fire hazard assessment would require them to offer a warranty of satisfactory fire performance for their material or product. They are likely to oppose any fire hazard assessment because they feel the uncertainty of potentially being exposed to liability.
* Some organizations mistrust the technical competency of regulators and are concerned about the inherent flexibility of fire hazard assessment which would allow regulators to make decisions, perhaps based on inadequate information. They are likely to oppose any fire hazard assessment because they feel it may increase the power of regulators.
* Some organizations want to preserve the status quo in the markets in which they work. They are often concerned that any market change can spill over to the area they work in. They are likely to oppose any fire hazard assessment because they feel it may cause a change in requirements, which may not be to their advantage.
* Some organizations fear their technical competence is insufficient to fully understand the intricacies of fire hazard assessment. Thus, they may oppose fire hazard assessment as they don't fully understand the technical issues involved.
* Some organizations want to maximize fire safety requirements. In some cases they may oppose fire hazard assessment as they believe that the inherent flexibility of fire hazard assessment may not ensure equally severe fire safety requirements.
* Some organizations want to prevent excessive fire safety requirements. In some cases they may oppose fire hazard assessment because they believe that fire hazard assessment may bring about more severe fire safety requirements.
* Some individuals want ASTM E-5 to generate test methods or specifications, and not guides or practices, which can be open to misinterpretation or misuse.

Support:

* Those individuals who believe in the benefits of flexibility of choice for business.
* Those organizations that promote technological advancement, because they believe it to be the way to inevitable progress, are likely to support fire hazard assessment.
* Those organizations that are best equipped to respond quickly to technological changes, by bringing new materials or products to market, are likely to support fire hazard assessment.
* Those organizations that make materials or products presently marginalized from a particular market are likely to support fire hazard assessment, because it would give them another opportunity to gain market penetration.

How to Draft ASTM Fire Hazard Assessment Documents

The process of drafting ASTM standards involves:

* Development of technical expertise in a subject of interest to the committee and for which there is a societal need.
* The subject chosen should represent the needs of users, while the committee should strive for wide participation, particularly by committee "customers," including building and code officials, the fire service and the fire research community.
* Development of knowledge of the technique of writing ASTM documents.
* Preparation of first draft for discussion by the process participants.
* Considerations of affirmative and negative comments on the document.
* Revisions to ensure optimum technical correctness and full consensus.
* Further revisions and complete consensus of the committee and society.

However, the process of drafting fire hazard assessment standards or guides requires a substantial additional step: negotiation with committee members to develop a consensus, in a way similar to industrial or political diplomacy. This is a novel experience for activities within committee E-5 (and perhaps even within the entire ASTM organization), where normal standards development addresses technical issues.

An example of these differences is the nature of affirmative or negative comments on the document. Many comments are neither technical nor helpful for incorporation into a new draft of the document. That fact does not, of course, make them any less valid or important to consider. They may be philosophical, rhetorical, editorial, or simply confrontational, but they represent the opinions of an important constituency. It is critical to "read between the lines" and try to understand the rationale for the comment, and the required action which would solve the problem the proposed document is presenting to the commenter. It is also critical to avoid fruitless discussions (such as active vs. passive fire protection, or details of proposed techniques) and prejudicial approaches, since the development of consensus is the objective. At the time this work is being completed, in late 1998, there has been no successful completed ballotting of a fire hazard assessment standard or guide by ASTM E-5, indicating that the necessary convergence of minds between (a) the proponents of the issuance of such documents and (b) those with reservations about their desirability, has not yet been achieved.

Final Thoughts

The title of this paper says it will discuss "What I Have Learned While Writing Draft Fire Hazard Assessment Standards and Guides for ASTM E-5." The most important issue learned is: development of consensus documents on some subjects requires more than technical input: it requires negotiating skills. None of the several initiatives aimed at producing an actual standard for a specific product class and occupancy have been successful by late 1998, in spite of several years of activity. The main reason for this lack of success in obtaining consensus is the technical difficulty of the issues involved, but a much more important one is that it is critical to achieve consensus on what type of performance-based fire safety documents should be developed at ASTM.

Fire hazard assessment, like all performance based fire safety engineering is an opportunity for entrepreneurship, innovation and ingenuity, which will help open (or maintain open) markets for new materials and products. In the new millennium it is critical to realize that safety (in fire and elsewhere) is not an absolute state of nature, but a relative issue, and that each one of us, as consumers, "buy" the degree of safety we require, within societal guidelines. However, as educators, we fail if we can not convince our colleagues of the societal advantages of these concepts.

References

1. Hirschler, M.M., "Concepts behind ASTM E931-85: Empirical practice for the classification of occupancies for their relative fire hazard to life," in "*Fire and Flammability of Furnishings and Contents of Buildings, STP 1233*," A.J. Fowell, Ed., American Society for Testing and Materials, 1994, pp. 32-49 (ASTM E-5 Symposium, December 7, 1992, Miami, FL).
2. Sardqvist, S., "*Real Fire Data - Fires in non-residential premises in London 1994-1997*," Report 7003, Dept. Fire Safety Engineering, University of Lund, Sweden, 1998.
3. NFPA Investigations Reports: Bulk Retail Store Fires: Quincy, MA, May 23, 1995, Albany, GA, April 16, 1996, Tempe, AZ, March 19, 1998; Retail Store Fire: Mableton, GA, October 26, 1997, Natl Fire Protection Assoc., Quincy, MA.

Appendix 1
Scope of Committee E-5
(As Approved by ASTM Board of Directors in September 1996)

1. The Committee shall be responsible for:
   a) The development and revision of fire standards intended for analysis and assessment of the fire performance of materials, products and assemblies within their relevant environment;
   b) The development and revision of fire test standards intended to measure and describe the response of materials, products and assemblies to sources of heat and/or flame under controlled conditions; and
   c) The stimulation and, where appropriate, support of fire-related research; and, the administration and evaluation of fire research programs related to E5 activities.
   d) The development and revision of fire hazard and fire risk assessment standards, including those suitable for use by regulatory officials, which deal with, but are not limited to: buildings, structures, materials, products and assemblies; furnishings and contents; mechanical and electrical appliances and equipment; and transportation facilities and equipment.

e) The development and revision of fire test methods for measuring fire responses and properties of materials, products and assemblies when exposed to laboratory sources of heat, or flame, or both. Such methods shall relate to the fire performance of materials, products and assemblies as part of a relevant fire environment, using appropriate information and experience from actual fires and analysis of results of fire research.

f) Identifying means for measuring the hazard or risk associated with fire, or during the fire extinguishment process.

g) Monitoring the public need for fire standards, and proposing new standards as appropriate.

h) Providing guidance to the user of fire standards on the words and methods used to communicate fire aspects of materials, products and assemblies.

i) Providing guidance to laboratories performing fire tests and encouraging good laboratory practice to promote safe use of materials, products, and assemblies.

2. The work of this committee shall be coordinated with other ASTM committees and other organizations having mutual interests.

Goals for ASTM E-5 (Approved in 1998)

1. **Maintain and update existing fire standards, with emphasis on those most widely used.**
   A significant number of the fire test standards issued by ASTM E-5 are widely used, for example as requirements in building codes, regulations or specifications. It is the foremost responsibility of the committee to ensure that these standards are adequately maintained, and periodically updated, so that the newest available technology is used, while ensuring quality, minimizing misuse and maximizing user-friendliness for those organizations employing them.
2. **Develop new fire standards for regulatory, quality control, product development, and screening purposes.**
   Where customer needs have been identified, it is appropriate for ASTM E-5 to develop new test methods or specifications useful for the purposes mentioned, even if the results are not expressed in fire safety engineering units. These tests must have been validated to ensure that they have a sound technical basis and that they adequately represent the fire-test responses of the materials, products or assemblies tested.
3. **Develop new fire standards which can provide data for fire safety engineering calculations.**
   Many existing ASTM E-5 fire test standards cannot be used for input into fire safety engineering calculations for two types of reason: (a) the output of some test methods is non quantitative information (e.g. pass-fail tests) or is not expressed in fire safety engineering units and (b) the fire exposure conditions (input) for other fire test methods are not representative of the range of conditions under which the material, product, or assembly is likely to be used in actual practice. Therefore, it is the responsibility of the committee to develop new fire standards which

provide the data required for fire safety engineering calculations, including fire modeling, fire hazard assessment and fire risk assessment.

4. **Develop fire safety engineering methodology.**
ASTM E-5 must provide leadership in developing and standardizing state-of-the-art methodology for making fire safety engineering calculations. Fire safety engineering will range from research into active fire protection techniques through manufacturing of materials, products or assemblies designed to be fire safe, to the construction, and evaluation of buildings or vehicles which ensure adequate levels of fire safety to its users. In future, fire safety will be assessed through engineering calculations by the use of performance-based fire codes. Therefore, the committee must provide methodology to lead the way for the development and use of such codes.

5. **Coordinate with users and potential users of fire standards to ensure most efficient resolution of their needs.**
ASTM E-5 must remain alert to evolving global technologies and worldwide customer needs. Its standards will be more suited to the needs of users if wide participation and membership is encouraged, including that of building code officials, the fire services and the fire research community. This will only be achieved if the interests of new members are raised by developments which have an impact on their own organization or business. Thus, the committee must communicate with all relevant organizations (including other ASTM technical committees) to identify issues or standards developments that will have major or lasting impact on fire testing, fire performance, or fire safety, and to make ASTM standards the standards of choice throughout the world.

Specific Methods and Tools

Daniel F. Gemeny[1] and Nathan B. Wittasek[2]

Fire Test Data for Design Fires: A Perspective from One Practitioner

Reference: Gemeny, D. F. and Wittasek, N. B., "**Fire Test Data for Design Fires: A Perspective from One Practitioner**," *ASTM'S Role in Performance-Based Fire Codes and Standards, ASTM STP 1377*, J. R. Hall, Jr., Ed., American Society for Testing and Materials, West Conshohocken, PA, 1999.

Abstract: Performance-based codes and standards, like performance-based design and analysis, depend critically on fire scenarios and associated design fire specifications. These need to be as real and relevant as they can possibly be. But they also need to be built from fire test data, and that typically means adapting the fire tests from their traditional purposes. This paper will discuss principles and procedures for applying fire test data to the specification of design fires, drawing in part on what the authors have learned in a number of real-life design projects.

Keywords: design fire scenario, fire hazard, fire model, fire scenario, fire test

Introduction

The performance-based design of smoke control systems for buildings is currently required by those communities adopting the Uniform Building Code, 1994 Edition. Development of future national model building codes, through the International Building Code process, promises an even larger arena for performance-based fire safety design. A fundamental of performance-based fire safety design is the development of design fire scenarios which place a demand on a building in the form of a design fire curve. The design fire curve is a heat release rate history of fuel packages which relate to the unique use of each building. Heat release data is generally obtained from full- or bench-scale fire tests. The published test data is limited and, therefore, new data has to be obtained by conducting fire tests or existing data has to be correlated to meet the design fire scenario. The application of fire test data is presented in examples of recent building design projects, including a convention center, a Buddhist temple, a warehouse, and a concert hall.

[1] Engineering Manager, Rolf Jensen & Associates, Inc., 16975 E. Imperial Hwy., Suite 200, Yorba Linda, CA 92886

[2] Associate Engineer, Rolf Jensen & Associates, Inc., 16975 E. Imperial Hwy., Suite 200, Yorba Linda, CA 92886

Design Requirements

The Uniform Building Code (UBC) requires the design of a smoke control system for covered mall buildings, atria, and high-rise buildings. The smoke control system design must be in accordance with Section 905 which provides performance rather than prescriptive design criteria. It states, "This chapter...is intended to provide a tenable environment for the evacuation or relocation of occupants. These provisions are not intended for the preservation of contents or for assistance of fire suppression or overhaul activities." The methodology requires, in many cases, the development of heat release rate data as input into the analysis. Furthermore, the UBC, as with other model codes, allows alternative methods and materials for which performance-based design methods are used to demonstrate equivalency. Whether it is performance of a fire-resistive column or evaluation of exit designs, fire scenarios and heat release rates are required as part of a fire safety engineering assessment.

The future International Building Code (IBC), the next edition of the Life Safety Code – NFPA 101, and the soon-to-be-published Society of Fire Protection Engineers (SFPE) Performance-Based Design Guide will all require the use of fire scenarios and design fire curves. This will place an even greater demand on specifying and collecting heat release data.

There are many fire test standards which allow the collection of heat release data. They range from large-scale tests such as ASTM Standard Guide for Room Fire Experiments (E603) to bench-scale tests such as ASTM Standard Test Method for Heat and Visible Smoke Release Rates for Materials and Products Using an Oxygen Consumption Calorimeter (E1354). A list of North American and ISO Test Standards, compiled by Dr. Marcelo Hirschler, which can be used to collect heat release data, is found in the Appendix.

Despite the tests that allow collection of heat release data, existing heat release data for most fuel packages do not exist. Several sources of heat release data can be found in texts such as the SFPE Handbook of Fire Protection Engineering and "Heat Release in Fires." Sometimes, the existing data can be correlated to meet a specific design scenario. Other times, it may be necessary to conduct fire tests.

The benefits of conducting full-scale fire tests include the following:

- Precision – Specific data can be collected for each fuel type and configuration. Multiple fuel packages can be evaluated including different ignition scenarios.
- Verification – Generates data for verification of the results of deterministic analyses.

However, there are a number of practical limitations to the use of standard full-scale fire tests for collecting heat release data. They include:

- Cost – The cost of conducting the full-scale tests often exceed the value of an alternate design.
- Schedule – A performance-based approach is typically undertaken in the early schematic phase of a building design with a time frame of one to two months. Scheduling tests and collecting data from large-scale apparatus is difficult on such short notice.
- Nature of item (art, boat, religious significance).

- Flexibility – Materials are unlikely to remain in the configurations and quantities in which they were tested.

The ideal way to overcome many of these limitations is through the use of bench-scale tests such as a cone calorimeter to obtain material data. This data can be useful as input into full-scale correlations. Examples of such correlations include pool fire and furniture models described by Vytenis Babrauskas in the SFPE Handbook for Fire Protection Engineering*[1]*. Bench-scale data can also be useful in CFD model applications such as described by Rich Pehrson of the Minnesota State Fire Marshal Division*[2]*.

Unfortunately, there are still too few recognized methods and correlations which allow easy conversion of bench-scale data to design fire curves. Therefore, in an engineering application, there is often as much art as science involved in the development of design fire curves.

Examples

Five real world examples of the use of fire test heat release data are presented to illustrate principles and procedures adapted to meet design requirements. Each represents a unique engineering approach with inherent limitations.

Anaheim Convention Center

This example is taken from work done in support of the expansion of the Anaheim Convention Center. A performance-based design approach was undertaken to establish exiting design requirements from the new expansion and the design of mechanical smoke control systems for the lobby atrium. The project required a worst-case credible fire scenario for the exhibit hall and the first-floor lobby serving the exhibit hall.

Two different approaches were used to develop the design fire curves. The first was the use of bench-scale data to calculate an approximate peak heat release rate. The second was the application of full-scale calorimeter data which was expanded to represent a single large fuel package.

Exhibit Hall Fire - The design fire for the exhibit hall was based upon a fiberglass boat measuring approximately 13.4 m long, 6.1 m wide, and 7.6 m high. A full-scale fire test was obviously impractical and other pertinent data could not be found. The solution required calculating the potential peak heat release (Q_{max}) based upon complete surface burning of a representative cube.

The prescribed boat dimensions represented a cubic surface area of 230 m^2. Fiberglass, which was considered the most significant fuel representation of the cube consists typically of 50 percent polyester resin. Cone calorimeter data*[3]* for polyester tested at a flux of 50 kW/m^2 indicates a heat release rate of 60 kW/m^2. The resultant peak estimate was 19 200 kW $\approx$ 20 MW. The fire growth was assumed to be exponential with time (t^2) with a fast growth represented by a constant of proportionality, α=0.0469 kW/sec^2. *[4]* Accordingly, the design fire curve was represented as Q= 0.0469 (t^2).

The design fire curve was input into DETACT*[5]* to predict sprinkler activation, at which time the heat release was assumed to be steady (Figure 1). This curve was used to predict smoke filling in the exhibit hall in comparison with evacuation time estimates.

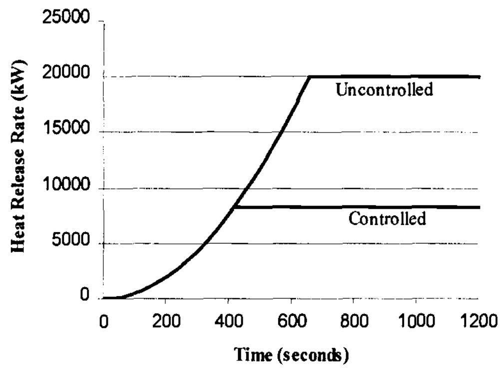


Figure 1 – *Exhibit Hall Fiberglass Boat Fire*

Lobby Fire - The design fire scenario for the lobby was based upon a fire involving the furnishings and contents of a registration area. The design fire scenario for this area consisted of a group of three registration kiosks and three 4-sided workstations. This worst-credible design fire scenario had to be described with a design fire curve.

Full-scale heat release data was obtained for kiosks and four-sided workstations*[6]*. A design fire curve was constructed as a progressive summation of the individual heat release histories. This reflects the fire spread from one fuel package to the others. The total heat release history can be quantified by the sum of the individual histories. The summary curve (Figure 2) became the design fire curve used as input to deterministic models to predict smoke filling and to calculate smoke exhaust requirements for the atrium lobby.

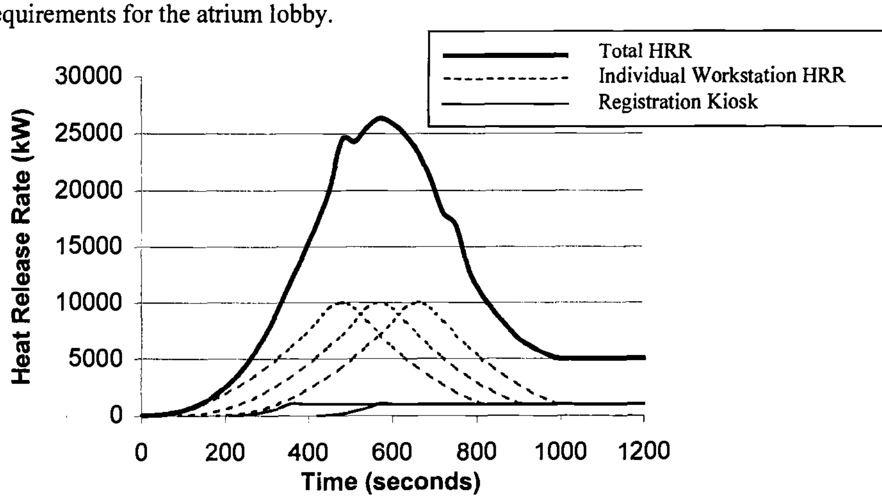


Figure 2 –*Workstations and Registration Kiosks*

Hsi Lai Buddhist Temple

The next example, the Hsi Lai Buddhist Temple, demonstrates the use of a large-scale test method to collect heat release data. The walls of the main temple were lined with polystyrene and polyolefin plastic Buddhas to a height of 10.7 m. The plastic wall surfaces represented a significant fire life safety concern for the occupants of the large single room assembly space. Smoke filling and timed egress analysis was conducted to determine safe evacuation times and fire protection mitigation for the temple.

The initial development of a design fire curve was attempted using empirical methods to calculate vertical flame spread. However, this effort was abandoned due to the complex geometry of the Buddhas (Figure 3) and the inability to verify the results. This required a better solution.

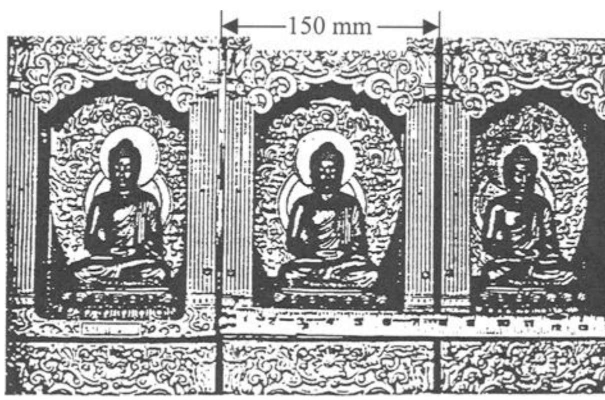


Figure 3 – *Plastic Buddhas*

Heat release data was collected in accordance with a large-scale room corner test method, UBC Standard Test Method for Evaluating Room Fire Growth of Textile Wall Covering (UBC 8-2). Two walls were lined with the plastic Buddhas and were ignited with a 40 kW sand burner ignition source. The room went to flashover after approximately four minutes.

The heat release data collected prior to flashover was considered conservative because of the increased radiation effects of the relatively small dimensions of the test enclosure (2.4 m x 3.7 m x 2.4 m) versus the dimensions of the Temple (16.5 m x 30.5 m x 10.7 m). Nonetheless, the pre-flashover data was extrapolated to represent the design fire curve. This was done by identifying the maximum fire growth rate and extending the data along a representative slope. The design fire curve was used as input into deterministic models in order to predict smoke detection, sprinkler actuation, and smoke filling. The maximum heat release rate of 2,400 kW, at which time sprinklers were predicted to activate, was used to represent a steady-state fire for the smoke filling analysis.

Warehouse Design

This example represents the use of full-scale test data as a verification tool. Empirical methods were applied to develop a representative design fire curve. The results compared favorably with published full-scale test data from Factory Mutual Research Center (FMRC).

The design of a 69 675 m^2 warehouse results in exit distances in excess of the prescribed 61.0 m. The fire hazard assessment for smoke filling and timed evacuation was undertaken to evaluate the hazard of the actual travel distance to exits. A worst-credible design fire scenario was needed to estimate smoke filling and the onset of hazard within the warehouse.

The two design fires depicted in Figure 4 represent the upper and lower bounds of reasonable but severe fire scenarios that would be expected based upon the arrangement and nature of fuels present. For both design fires, controlled and uncontrolled scenarios were considered in order to estimate the time at the onset to hazardous conditions.

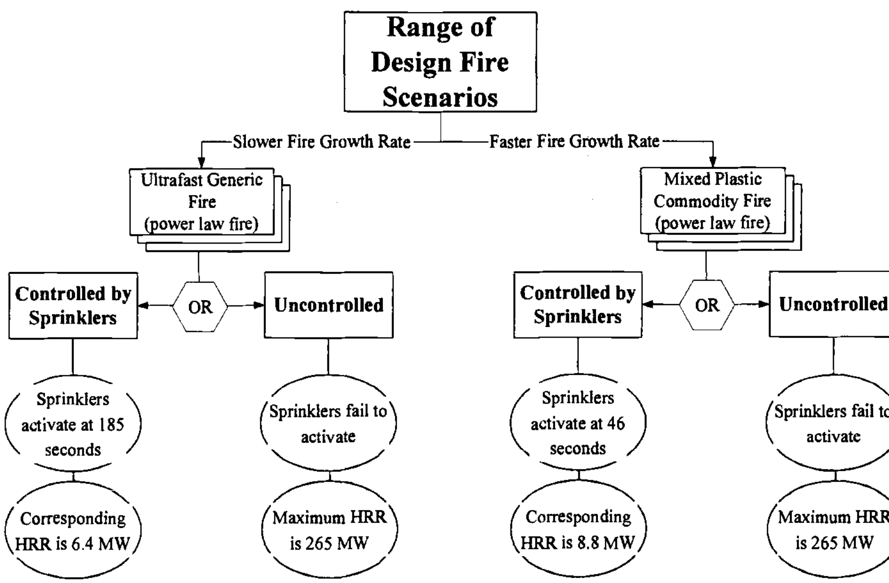


Figure 4 – *Design Fire Flowchart*

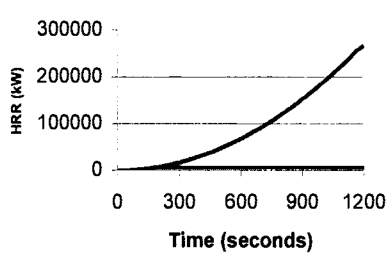
Ultra Fast Design Fire Background - The ultra fast design fire was developed based on information presented in the Second Edition of the SFPE Handbook of Fire Protection Engineering*[7]*. The fire growth rate was characterized by a power law equation where the heat release rate, Q, is a function of some constant of proportionality, α, and the time, t. Equation 1 summarizes the relationship used in the analysis. The constant of proportionality was assigned a value of 0.1876 kW/sec^2.

$$Q = \alpha t^2 \tag{1}$$

Mixed Plastic Commodity Design Fire Background - Based upon information by You*[8]*, the first 26 seconds of the mixed plastic commodity fire were treated as a t^3 fire where the constant of proportionality was directly proportional to the number of racks. Data obtained using a fire products collector indicates that, after the initial 26-second growth period, the remaining growth period for up to approximately three minutes could be treated as a t^2 growth curve. The initial t^3 and t^2 growth corresponds with flame spread in the vertical direction. After this time, the heat release rate varies linearly, approaching a maximum value determined as a function of the nature of the fuel and the quantity of fuel present.

Key results from fire products collector free-burn tests completed by Lee and Spaulding, as cited by Robert Zalosh*[9]*, support the use of fire growth rate coefficients having values of 0.90, 0.57 and 0.45 kW/sec^2 for two-tier rack storage of polystyrene, polyethylene, and PET products respectively. Maximum heat release rates were 22.5 MW, 17.8 MW, and 13.3 MW, for the polystyrene, polyethylene, and PET arrays. Assuming a 33/33/33 mix of these Group A plastics, the average growth rate coefficient was found to be 0.64 kW/sec^2 and the maximum HRR estimated at 17.9 MW for a two-tier, 2 x 2 array, respectively. The values for the two-tier array were then tripled to give conservative fire growth rate coefficients and maximum heat release rates for the six-tier array. The growth rate coefficient, α, was determined to be 1.92 kW/sec^2 and the maximum total heat release rate was 53 MW for the six-tier fire.

Figure 5 depicts the design fire HRR curves for ultra fast generic fire and mixed plastic commodity fire under controlled (via sprinkler) and uncontrolled conditions.

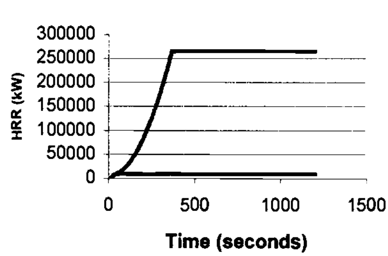


ULTRA FAST GENERIC

Principal Fuels: cellulose, some plastics

Storage Configuration: portable pallets, or transitory in the loading dock

Source: SFPE Handbook, Second Edition



MIXED PLASTIC COMMODITY

Principal Fuels: mixed plastic including PET, polystyrene, polyethylene

Storage Configuration: rack storage

Source: You, Lee, and Spaulding

Figure 5 – *Design Fire Scenario*

Comparison - Mixed Plastics Commodity Design Fire - In order to benchmark the design fire heat release rate curve, Fire Products Collector Data published by FMRC, and presented in a thesis*[10]* by John Sleights was directly compared with a composite t^3 and t^2 relationship for the first 90 seconds. Figure 6 indicates that the relationship chosen for the composite t^3 and t^2 fire results in heat release rates for a six-tier array of more than twice the magnitude of those obtained from the test data of the four-tier plastic commodities tested at FMRC. The composite curve, therefore, seemed to represent a conservative and reasonable approach.

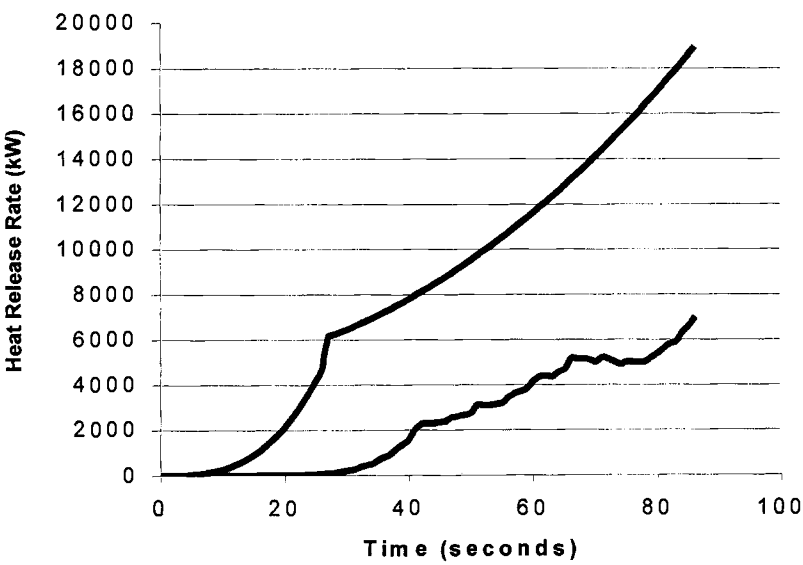


Figure 6 – *Comparison of Test Data with Mathematical Model*

Theater Smoke Control Design

This last example demonstrates the use of a method*[1]* by Babrauskas, which is based upon a correlation of data from multiple fire tests. The empirical results are then extended with a rationale for horizontal fire spread.

A large concert hall project requires a smoke exhaust system to allow safe evacuation from the upper reaches of the seating area. The fire involving upholstered seats was considered one of the design fire scenarios. The method of calculating the maximum heat release rate was based upon a progression of fire spread along rows of seats (see Figure 7).

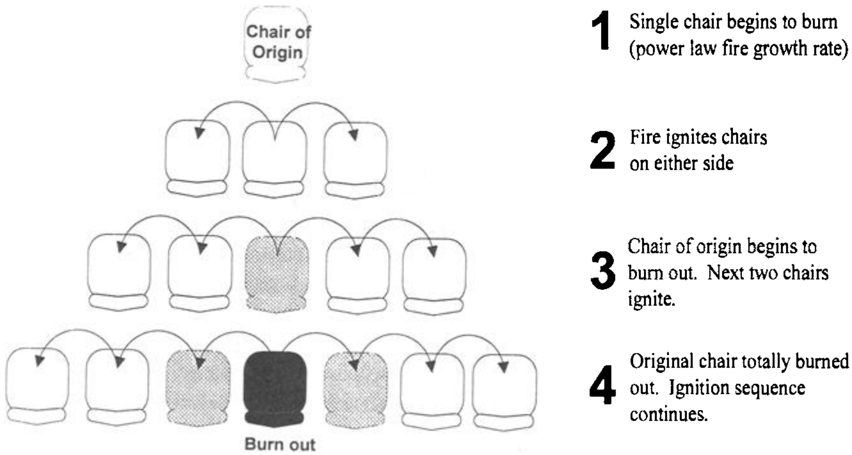


Figure 7 - *Successive Ignition of Chairs in an Aisle*

When calculating the heat release rate of such a fire, it is necessary to consider both the transient fire growth characteristics as well as the maximum steady state heat release rate for each chair. The proximity of the individual chairs further complicates formulation of such a design fire as a result of the high potential for successive ignition of adjacent fuel items.

A design fire methodology was developed whereby the heat release rate history for a single chair is used to calculate the ignition time of nearby chairs on either side of the original fuel package (assumed to be a single chair). The methodology assumes that the fire is likely to progress from chair to chair, gaining in intensity as each successive chair is ignited. The heat release rate of the fire is reduced as the available fuel is consumed, and "burn out" occurs. The ignition of adjacent aisles is considered and often ruled out because of the difficulty of igniting chair backings at distances typically observed in fixed seating arrangements.

The maximum steady state heat release rate for a single chair may be approximated using a methodology developed by Babrauskas*[1]*. Using a process of generic materials identification, a heat release rate per chair of 872 kW was found. The generic materials identification process considers the fabric, frame, padding, and style of a typical seat. In lieu of actual test data for the particular chair that will be used, this method seems to provide a conservatively high heat release rate.

Once the maximum steady state heat release rate has been determined, a fire growth rate must be assigned in order to calculate ignition of adjacent chairs. Assuming that fire-retardant fabrics and foams will be used, it is reasonable to characterize the fire growth rate as a medium (or moderate) power law function.

Next, a number of methods may be employed to calculate the time at which adjacent fuel items will ignite. The radiant ignition model within the FPETool*[11]* subroutine was utilized. This model predicts the heat release rate required to achieve a critical flux that could ignite nearby items. The time to ignition once the critical flux has been achieved has been assumed to be zero for ignition of chairs within the same aisle. As a consequence, once the heat release rate of a chair reaches the critical heat release rate as determined by FPETool, the chair is assumed to begin burning, following a similar power law relationship as the original chair.

The burnout time is simply calculated by estimating the mass of the prime combustible fuel (e.g. padding) and multiplying by the heat of combustion for that fuel divided by the maximum heat release rate that will be achieved. This time is then added to the time required to achieve the steady state heat release rate as determined from the power law relationship. The heat release rate history for a series of chairs is then found by alternatively considering the growth and successive ignition of chairs within an aisle while simultaneously considering the burnout time for each chair. A transient and average heat release rate during the time frame of interest (20 minutes) was then determined.

This resulted in a design fire of with a heat release rate of 4.5 MW. This was used as input in an axisymmetric plume equation to establish the smoke production of the fire and, consequently, the sizing of exhaust fans for smoke control.

Conclusion

Performance-based fire safety design requires design fire scenarios and design fire curves as input into the engineering process. ASTM currently has, and is in the process of developing, even more standards for collecting heat release data. The large-scale tests, although the most precise, are often impractical. Bench-scale tests, although more cost effective, are limited due to the lack of correlation methods to relate the bench-scale data to the burning behavior of large-scale fuel packages.

It appears that there is a great demand for the scientific understanding of small-scale burning behavior correlated to real-scale heat release to meet the evolution of performance-based fire safety design. Otherwise, design fire curves will not be left to calculation, but rather will be left to prescribed curves and fire scenarios based on building use and occupancy. ASTM could have a role on both fronts.

APPENDIX

References

[1] Babrauskas, V., "Burning Rates," *The SFPE Handbook of Fire Protection Engineering, Second Edition*, National Fire Protection Association, Quincy, MA, 1995, pp. 3-1 – 3-36.

[2] Pehrson, Richard, CFD Modeling Ph.D. Thesis of Furniture Fire Growth Comparison of Cone Data with Full Scale Furniture Calorimeter Data.

[3] Babrauskas, V. and Grayson, S. J., *Heat Release in Fires,* Elsevier Science Publishers, LTD, New York, 1992, p. 452.

[4] Evans, D. D., "Ceiling Jet Flows," *The SFPE Handbook of Fire Protection Engineering, Second Edition*, National Fire Protection Association, Quincy, MA, 1995, pp. 2-35, Equation (21).

[5] Evans, D. and Stroup, D., "Methods to Calculate the Response of Heat and Smoke Detectors Installed Below Large Unobstructed Ceilings." National Institute of Standards and Technology, NBSIR 85-3167, Gaithersburg, MD 1985.

[6] National Institute of Standards and Technology Web Site.

[7] Evans, D. D., "Ceiling Jet Flows," *The SFPE Handbook of Fire Protection Engineering, Second Edition*, National Fire Protection Association, Quincy, MA, 1995, pp. 2-32 – 2-39.

[8] You, H-Z, "Transient Plume Influence in Measurement of Effective Convective Heats of Rack Storage Fires," *FMRC* JI ON1JO.RA(2), 1989.

[9] Zalosh, Robert, "An Engineering Approach to Industrial Fire Protection," Unpublished, February 13, 1997, pp. 5-20 – 5-25.

[10] Sleights, J.E., "A Sprinkler Response to Computer Program for Warehouse Storage Fires," M.S. Thesis, Worcester Polytechnic Institute, December 1993.

[11] Deal, S., "Technical Reference Guide for FPE Tool, Version 3.2," National Institute of Standards and Technology, NISTIR 5486-1, Gaithersburg, MD, April 1995.

Brian Y. Lattimer[1]

Adaptation of Cone Calorimeter (ASTM E1354) Data for Use in Performance-Based Fire Protection Analysis

Reference: Lattimer, B. Y., "**Adaptation of Cone Calorimeter (ASTM E1354) Data for Use in Performance-Based Fire Protection Analysis,**" *ASTM's Role in Performance-Based Fire Codes and Standards, ASTM STP 1377,* J. R. Hall, Jr., Ed., American Society for Testing and Materials, West Conshohocken, PA, 1999.

Abstract: Performance-based fire codes and standards are being developed to augment or replace existing prescriptive fire codes and standards. In performance-based analysis, designers often use computerized fire models to evaluate proposed systems, but input data for these models is difficult to find in the literature. Bench scale test methods are a cost effective, time efficient way for developing such data; however, output data from standard test methods are not always adequate or in a form usable for analysis. This paper focuses on determining the necessary input data for fire growth and room fire models used in predicting fire development inside a building. ASTM E1354 Cone Calorimeter is one of the more common test methods used for determining material fire properties, and was used here to develop most of the input data. Recommendations are provided for additional calculations and test procedures that make standard output data from ASTM E1354 more usable in performance-based analysis.

Keywords: cone calorimeter, fire growth, flame spread, room fire model

Nomenclature

$\bar{c}$	coefficient of particulate extinction for smoke [- -]
f	fraction of mass burned [kg burned /kg total]
h	convective heat transfer coefficient [kW/(m^{2}K)]
ΔH_c	effective heat of combustion [kJ/kg]
Δh_g	effective heat of gasification [kJ/kg]
$k\rho C$	effective thermal inertia [kW/(m^{2}K)^{2}s]
K_m	specific extinction coefficient [m^2/kg]
m	material sample mass [kg]
$\dot{m}_{fuel}(t)$	instantaneous mass loss rate [kg/s]
$\dot{m}''_{fuel}(t)$	instantaneous mass loss rate per unit area [kg/(s m^2)]
$\overline{\dot{m}''_{fuel}}$	average fuel mass loss rate per unit area [kg/(s m^2)]
$\dot{m}_e(t)$	instantaneous mass flow rate in exhaust duct [kg/s]

[1]Hughes Associates, Inc., 3610 Commerce Drive, Suite 817, Baltimore, Maryland 21227.

$\dot{m}_i(t)$	instantaneous mass flow rate of species *i* [kg/s]
M	molecular weight [kg/kmol]
q''	heat flux [kW/m^2]
$\dot{Q}$	heat release rate [kW]
$\dot{Q}''$	heat release rate per unit area [kW/m^2]
$\overline{\dot{Q}''}$	test average heat release rate per unit area [kW/m^2]
t	time [s]
T	temperature [K]
Δt	sampling time interval [s]
$X_i(t)$	instantaneous combustion product mole fraction [kmol/kmol]
$Y_i(t)$	instantaneous combustion product yield [kg of product / kg of fuel]
$\overline{Y}_i$	test average combustion product yield
δ	material sample thickness [m]
ε	surface emissivity [- -]
λ	light source wavelength [m]
ρ	density [kg/m^3]
σ	Stefan-Boltzman constant [5.67 x 10^{-11} kW/(m^{2}K^4)]
$\sigma_f(t)$	instantaneous specific extinction area [m^2/kg]

Subscripts

a	ambient
air	air
CO	carbon monoxide
CO_2	carbon dioxide
f	from flame
final	value after test
fuel	fuel
i	a combustion product
ig	ignition
inc	imposed onto surface by external source
initial	value before test
j	a single data point during the flaming duration of the test [- -]
l	a particular fuel burning in the room [- -]
n	number of data points during the flaming duration [- -]
net	net onto surface
out	flame out
p	number of fuels burning in the room [- -]
peak	peak value
pyrol	flaming pyrolysis
smk	smoke
st	stoichiometric fuel-to-air ratio
tot	total

Introduction

Performance-based fire codes and standards are being developed to augment or replace the existing prescriptive fire codes and standards governing building design and construction. The analysis of fire development in a building often utilizes computer-based room fire models and fire growth models to determine conditions in the structure. Specifically, such an analysis uses a fire growth model (e.g. a flame spread model) to determine the heat release rate curve of the fire to be input into the room fire model (e.g. CFAST). To perform this analysis, these models require knowledge of flame spread properties, heat release rate and combustion product levels of the materials involved. Methods are developed in this paper to use standard and non-standard data from ASTM E1354 "Test Method for Heat and Visible Smoke Release Rates for Materials and Products Using an Oxygen Consumption Calorimeter" as input or to determine input for fire models.

Methodology Overview

Predicting the fire growth and conditions that develop in a building is an extremely complex process with many interdependent variables involved. A simplified engineering approach for modeling conditions in a building during a fire is provided in (Figure 1). The first step in the process is to determine the appropriate initiating source fire for the analysis. A fire growth model uses the selected source fire and data on combustible items in the room to determine if and when these items become involved in the fire, thus determining the heat release rate of the fire with time. The heat release rate from the fire growth model and the combustion product formation rates are input into a room fire model, which is used to determine the conditions that develop in the room during the fire. Gas temperatures inside the room during the fire may affect the ignition and flame spread along combustible items. To include this effect, gas temperatures from the room fire model need to be fed back into the fire growth model. This is shown in (Figure 1) as the arrow from the room fire model back to the fire growth model.

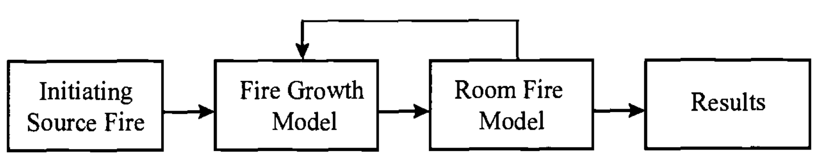


Figure 1 – *General Approach to Predicting Conditions in a Building during a Fire*

Input Data for Models in Performance-Based Fire Hazard Analysis

There are a variety of different fire growth and room fire computer models that are used in performance-based fire hazard analysis, each with its own assumptions and limitations. As a result, the input data necessary to run each of these models is not necessarily the same. This section attempts to capture input data that may be necessary for many of these models. Much of the material fire property data needed to run such models is not available in the literature, and bench scale tests are an economical means of developing such input data. ASTM E1354 is the most common test method used for developing this data, but specified output data is not always sufficient. Recommendations are provided in this section on test procedures and calculations that could be added to ASTM E1354 to develop some data necessary for fire model input.

Initiating Source Fire

The initiating source fire is the initial fire threat inside a room that may cause other items in the room to ignite and burn. Choosing an initiating source fire is one of the first steps in the analytical portion of a performance-based fire hazard analysis. The source fire is typically a burning item that may be found inside the room or a worst case, but plausible fire. Fire growth models and room fire models may require one or several of the following data, depending on the complexity of the model, to analytically describe the initiating source fire:

- heat release rate with time,
- heat of combustion,
- mass loss rate with time,
- combustion product (e.g. CO, CO_2, and smoke) yields.

In practice, the heat released by the initiating source fire is typically determined from either full-scale data on a burning item (s) or using engineering judgement. In the case where engineering judgement is used, the initiating source fire usually represents a worst case, but plausible fire.

Many fire models use control volume analysis to determine flow rates in and out of spaces. To ensure conservation of mass, some models may require the mass loss rate of the source fire with time. Mass loss rate can be determined either from a full-scale test, or calculated using the prescribed heat release rate and a heat of combustion,

$$\dot{m}_{fuel}(t) = \frac{\dot{Q}(t)}{\Delta H_c} \tag{1}$$

where $\dot{Q}(t)$ is the measured heat release rate of the source fire as a function of time. The effective heat of combustion for a representative sample of the initiating source fire fuel can be determined from ASTM E1354.

Models that are capable of calculating gaseous combustion product levels (CO, CO_2) need input on the amount of combustion product produced by the fire. This is typically expressed as a fraction of the fuel mass loss rate or a yield,

$$Y_i(t) = \frac{\dot{m}_i(t)}{\dot{m}_{fuel}(t)}. \tag{2}$$

For gaseous combustion products, Equation (2) can be rewritten in terms of measured quantities,

$$Y_i(t) = \frac{X_i(t)\dot{m}_e(t)(M_i/M_a)}{\dot{m}_{fuel}(t)} \tag{3}$$

Yields are calculated instantaneously because both the mass flow rate of the combustion product and the fuel mass loss rate are usually not constant during the test. Test average combustion product yields can be determined by averaging the instantaneous yields over the flaming duration of the test,

$$\bar{Y}_i = \frac{\sum_{j=1}^{n} Y_i(t_j)\Delta t}{(t_{out} - t_{ig})}. \tag{4}$$

No guidance on calculating gaseous combustion product yields is provided in ASTM E1354, even for cases where all the necessary measurements are being made. Procedures for calculating combustion yields could be added to the standard without compromising the accuracy of other measurements. The use of this combustion product yield data is, however, limited to overventilated fires. The combustion product levels produced by a room fire depend on whether the room is overventilated or underventilated [*1*]. The degree of ventilation can be determined by the global equivalence ratio of the room fire,

$$\phi = (\dot{m}_{fuel}/\dot{m}_{air})/(\dot{m}_{fuel}/\dot{m}_{air})_{st}, \tag{5}$$

which relates the actual fuel-to-air ratio to the stoichiometric fuel-to-air ratio. A room is overventilated when $\phi<1$, while a room with a $\phi>1$ is considered underventilated. Data from Reference [*1*] indicate that ventilation begins to affect combustion product yields when the global equivalence ratio is greater than approximately 0.6. For a room with a $\phi<0.6$, the combustion product yield data determined in a ASTM E1354 test is valid.

Some fire models may also be capable of predicting smoke levels. As with gaseous combustion product yields, input data for smoke is usually cast in terms of a yield as defined by Equation (2). Smoke measurements are currently required in ASTM E1354, but they are reported in terms of average specific extinction area, which is not readily useful for input data. The instantaneous specific extinction area, which is a measure of the area of light attenuated by the smoke normalized by the mass of fuel burned, values for smoke can be converted to a smoke yield with some assumptions about the optical properties of smoke. Relations in Reference [*2*] were used to relate the smoke specific extinction area to the smoke yield,

$$Y_{smk} = \left(\frac{\lambda\rho_{smk}}{\bar{c}}\right)\sigma_f. \tag{6}$$

ASTM E1354 requires a helium-neon laser ($\lambda=633\text{x}10^{-9}$ m) to be used to measure smoke attenuation. For this wavelength, it was determined in Reference [*3*] that for a wide range of fuels ρ_{smk}=1100 kg/m^3 and $\bar{c}$=7.0. Using these values, the following relation was developed to calculate smoke yield from specific extinction area:

$$Y_{smk}(t) = \frac{\sigma_f(t)}{10053} \quad (7)$$

Instantaneous smoke yields calculated with Equation (7) can be used to calculate the test average smoke yield using Equation (4).

Fire Growth Model

Several different fire growth models have been developed in recent years, some of which are not formally described in the literature. However, many of the models cited in the literature, Cleary and Quintiere [*4*], Mitler [*5*], Beyler *et al.* [*6*], Brehob [*7*] and Kulkarni, *et al.* [*8*], and Janssens [*9*], have many similarities. The backbone of each fire growth model is the ignition model, which ultimately determines the flame spread along a material. The ignition model is typically a heat transfer model used to determine material surface temperature due to some type of external heating, typically a time varying heat flux. Ignition is usually determined when the predicted surface temperature rises above the material ignition temperature. Once ignition is predicted, most of these models use the incident heat flux onto the material surface and data from the ASTM E1354 to determine the heat released by the material.

Fire growth models may require some or many of the inputs listed below:

- material thickness, δ,
- material density, ρ,
- fraction of mass burned, f,
- heat of combustion, ΔH_c,
- ignition temperature, T_{ig},
- pyrolysis temperature, T_{pyrol},
- mass loss rate per unit area, $\dot{m}''$
- heat release rate per unite area, $\dot{Q}''$,
- heat of gasification, Δh_g, and
- effective thermal inertia, $k\rho C$.

Some of these inputs are repetitive but are listed for the reader to be aware that different models require different inputs. Many of these data can be acquired from the ASTM E1354 standard output or from additional tests using the ASTM E1354 test apparatus.

Material sample thickness is a required output from ASTM E1354. This thickness, the surface area and the initial mass of the sample can be used to determine a nominal density of the material, which is typically adequate for this application. The fraction of the initial mass burned during the test can be determined from initial and final sample mass data, which is currently required by ASTM E1354 as standard output. The addition of fraction of mass burned to ASTM E1354 would be useful for performance-based analysis, in addition to other applications. An effective heat of combustion is a standard output in ASTM E1354 and is adequate for use in performance-based analysis.

Critical to the accuracy of the ignition model contained within the fire growth model is an accurate determination of the ignition temperature. Ignition temperature can either be measured directly, or calculated using the critical heat flux and an energy balance at the material surface. Measurements of surface temperature during the test can be challenging. The most direct way is to use a thermocouple, but this may compromise the mass loss rate data. Optical pyrometers have been used to effectively measure surface temperatures, and can be located several meters away from the sample and still provide accurate surface temperature measurements. The key to the successful use of optical pyrometers is to have one that is capable of measuring radiation outside of the wavelengths where water vapor and CO_2 emit energy, and to have an idea of the surface emissivity. Many solid combustible materials have an emissivity of 0.85-0.95, especially after being heated for some period of time.

If the ignition temperature is not measured, the critical heat flux can be used to determine the ignition temperature. Graphical techniques have been developed for determining critical heat flux, and have been found to provide adequate predictions for well-behaved materials [*10*]. For materials containing fire retardant additives, the ignition time may be significantly influenced by chemical kinetics, causing error in predictions using heat transfer theory. Critical heat flux is more accurately determined experimentally. This can be done through a series of ignition tests using the ASTM E1354 cone calorimeter test apparatus. In these tests, a series of samples are exposed to different irradiance levels to determine the minimum irradiance (within 1 kW/m^2) at which ignition occurs in a specified time period. An energy balance at the material surface just prior to ignition,

$$q''_{cr} = h\left(T_{ig} - T_a\right) + \varepsilon\sigma\left(T_{ig}^4 - T_a^4\right), \tag{8}$$

can be used along with the critical heat flux to determine the ignition temperature. From Reference [*11*], the convective heat transfer coefficient is h =0.015 kW/(m^2 K) and the surface emissivity is ε=1.0. The pyrolysis temperature during flaming may also be measured directly during an ASTM E1354 test using a thermocouple or an optical pyrometer. Based on the above discussion, the addition of a surface temperature measurement to ASTM E1354 would provide valuable and insightful data that could be used in fire models.

After the material adjacent to the source fire ignites, calculations are performed in the models to determine the mass loss rate and the heat release rate of the material. Several approaches are used in existing fire growth models to determine these values. Some models use the mass loss rate data from ASTM E1354 tests to determine mass loss, and heat release rate data to determine heat released. The drawback to this approach is that, in more complex models where there is a wide range of incident heat fluxes onto the material, the program needs to interpolate between data performed at fixed incident fluxes. Many models use an average effective heat of gasification,

$$\Delta h_g = \frac{q''_{net}}{\dot{m}''_{fuel}} \quad , \tag{9}$$

to calculate average mass loss rate per unit area. Heat release rate would be calculated by

$$\dot{Q}'' = \Delta H_c \dot{m}''_{fuel} . \tag{10}$$

For well-behaved materials, the average effective heat of gasification is essentially a material property, like the average effective heat of combustion. To determine the average effective heat of gasification using the ASTM E1354 test data, the net heat flux to the surface would be divided by the measured mass loss rate. The net heat flux would be determined by the following equation,

$$q''_{net} = q''_{inc} + q''_f - \varepsilon\sigma\left(T^4_{pyrol} - T^4_a\right) \tag{11}$$

where ε=1.0, T_a=298 K, and q''_{inc} is equal to the irradiance level used in the test. Methods for calculating reradiation from the flame, q''_f, of plastics in the ASTM E1354 apparatus were developed in Reference [*12*], but no method has been developed for all materials. For these calculations, flame reradiation can be conservatively taken as zero.

An effective heat of gasification calculation in ASTM E1354 would be useful for input data into models. However, the heat flux to the material surface in the ASTM E1354 is not well defined or measured. As a result, including a calculation for effective heat of gasification in ASTM E1354 may not be appropriate.

The effective thermal inertia of the material can be determined graphically using the ignition data from ASTM E1354, as described in Reference [*10*]. The ignition model can also be used to iteratively determine the effective thermal inertia. This is done by determining the effective thermal inertia where the model adequately predicts the ignition data from ASTM E1354 at various irradiance levels.

Room Fire Models

There are several room fire models that are used in performance-based fire hazard analysis. As with fire growth models, the input variables necessary to run a room fire model may be somewhat different for each model. In general, room fire models may require some of the following fire data:

- fuel mass loss rate,
- heat release rate,
- heat of combustion, and
- combustion product yields.

Most fire growth models output fuel mass loss rate and heat release rate values for all items and individual items. Using these data, an effective heat of combustion for the fire can be calculated if still necessary for the model.

Combustion product yields for the entire fire, where more than one type of material may be burning, can be calculated using combustion product yield data for individual materials determined using ASTM E1354 and mass loss rates from the fire growth model. When multiple fuels are burning in the room, the instantaneous combustion product yield for the room fire is determined by summing contribution of each fuel to the total yield,

$$Y_{i,tot}(t) = \sum_{l=1}^{p} \bar{Y}_{i,l} \frac{\dot{m}_{fuel,l}(t)}{\dot{m}_{fuel,tot}(t)}, \tag{13}$$

where subscript l represents a particular fuel and p is equal to the total number of different fuels burning. The fuel mass loss rate for an individual item, $\dot{m}_{fuel,l}(t)$, and the total fuel mass loss rate of the room fire, $\dot{m}_{fuel,tot}(t)$, are outputs from the fire growth model. Average combustion product yields on individual items burning in the room, $\bar{Y}_{i,l}$, can be measured using the ASTM E1354 test apparatus. As noted previously, the combustion product yield data from ASTM E1354 is only useful when the fire is sufficiently ventilated, ϕ<0.6 for room fires.

Summary of Proposed Additions to ASTM E1354

The items shown in (Table 1) are the proposed additions to ASTM E1354. These additions would aid engineers in providing input into fire models commonly used in performance-based design.

Table 1 – *Proposed Additions to ASTM E1354*

Addition	Description
1	Methods and equations for measuring gaseous combustion product yields
2	Equation for converting specific extinction area of smoke to smoke yield
3	Calculation of fraction of mass burned
4	Surface temperature measurement

Predicting Conditions in a Full-Scale Room Fire with Combustible Walls

An example is presented in this section on the use of fire models to determine fire development in a room. This analysis demonstrates how both standard data from ASTM E1354 and nonstandard data taken using the ASTM E1354 test apparatus were used as model input in the analysis, and provides some insight on the type of results that can be achieved through such an analysis.

The analysis described in this section was performed to predict conditions that develop when a fire was placed in a room constructed of glass reinforced fire retarded vinyl ester composite. The initiating source fire was a 200 kW propane fire placed against a wall inside the room for five minutes. The room had dimensions of 2.44 m wide, 2.44 m deep and 2.44 m high with a 1.52 m high, 0.36 m wide door. The fire models used in this analysis were the fire growth model developed by Beyler *et al.* [*6*] and the room fire model CFAST [*13*]. The modeling results were compared with results from a full-scale fire test conducted by the Naval Surface Warfare Center, Carderock Division [*14*].

The first step of the modeling process was to gather and develop the necessary input data for the initiating source fire and the composite boundary. The necessary calorimeter data for propane was taken from Reference [*15*] and is shown in (Table 2). Standard output data from ASTM E1354 on the vinyl ester composite was taken from Reference [*16*], sample #1168, and is shown in (Table 3). Nonstandard data determined using the ASTM E1354 test apparatus is provided in (Table 4).

Heat release rate data for the composite material shown in (Table 3) does not increase with an increase in irradiance as expected. This was attributed to the

Table 2 – *Calorimeter Data for Propane* [*15*]

Parameter	Data
Effective Heat of Combustion, ΔH_c, [kJ/kg]	46 000
Average CO_2 Yield, $\bar{Y}_{CO_2}$, [kg/kg]	2.85
Average CO Yield, $\bar{Y}_{CO}$, [kg/kg]	0.005
Average Smoke Yield, $\bar{Y}_{smk}$, [kg/kg]	0.024

Table 3 –*Relevant ASTM E1354 Standard Output Data for Glass Reinforced Fire Retarded Vinyl Ester Composite* [*16*]

Parameter	Data at Specified Irradiance Setting*			Average
	25 kW/m^2	50 kW/m^2	75 kW/m^2	
Thickness, δ	0.0047	0.0047	0.0047	0.0047
Initial Mass, $m_{initial}$	0.093	0.081	0.093	0.089
Final Mass, m_{final}	0.066	0.055	0.063	0.061
Mass Loss Rate per Unit Area, $\dot{m}''_{fuel}$	0.012	0.013	0.018	- -
Time to Ignition, t_{ig}	214	52	30	- -
Test Peak Heat Release Rate, $\dot{Q}''_{peak}$	147	152	217	- -
Effective Heat of Combustion, ΔH_c	10 360	10 600	10 590	10 515
Specific Extinction Area, σ_f	1 340	1 525	1 570	1 480

*Data average of tests conducted in triplicate at each irradiance level

Table 4 – *Nonstandard Data Determined Using the ASTM E1354 Cone Calorimeter Apparatus*

Parameter	Data at Specified Irradiance Setting*			Average
	25 kW/m^2	50 kW/m^2	75 kW/m^2	
Fraction of Mass Burned, f	0.29	0.32	0.32	0.31
Test Average CO Yield, $\bar{Y}_{CO}$	0.11	0.12	0.12	0.12
Test Average CO_2 Yield, $\bar{Y}_{CO_2}$	0.48	0.43	0.43	0.45
Test Average Smoke Yield $\bar{Y}_{smk}$	0.13	0.15	0.16	0.15
Critical Heat Flux, $\dot{q}''_{cr}$		17		

*Data average of tests conducted in triplicate at each irradiance level

Table 5 – *Calculated Fire Properties of the Vinyl Ester Composite*

Parameter	Data at Specified Irradiance Setting		
	25 kW/m^2	50 kW/m^2	75 kW/m^2
Effective Heat of Gasification*, Δh_g	815	2 675	3 320
Nominal Density, ρ		1,920	
Ignition Temperature, T_{ig}		675	
Flaming Pyrolysis Temperature**, T_{pyrol}		725	
Effective Thermal Inertia, $k\rho C$***		0.55	

*Calculated using Equations (10) and (11)

**From data in Reference [1], taken to be 50 K higher than ignition temperature

***Deduced using ignition model

Table 6 – *Comparison of ASTM E1354 Cone Calorimeter Data and Model Predictions*

Irradiance	Time of Ignition [s]		Heat Release Rate [kW/m^2]	
[kW/m^2]	Data	Model	Data	Model
25	214	214	147	148
50	52	36	152	153
75	30	16	217	215

brominated fire retardant additive in the vinyl ester resin. The fire retardant also causes the elevated levels of CO and smoke, and a decrease in CO_2 production.

Data from (Tables 3 and 4) were used to calculate and determine the remaining input data shown in (Table 5). Values for effective heat of gasification are seen in (Table 5) to change with irradiance. This may be due to the fire retardant additives in the resin. The effective thermal inertia was deduced using the ignition model and the time to ignition data in (Table 3). The effective thermal inertia was chosen to provide an accurate determination of ignition time at 25 kW/m^2 because the vertical flame spread on flat walls is primarily driven by heat fluxes near this level.

Time to ignition and heat release rate data at various irradiance levels are shown in (Table 6) for data measured using ASTM E1354 and predictions using the model. Predictions of ignition data are exact at an irradiance of 25 kW/m^2 but are more conservative with an increase in irradiance. The model predicted the heat release rate data to within 1%.

The fire growth model was used along with the necessary input data to predict the flame spread and the heat release rate of the room fire. This version of the fire growth model is a one-dimensional model that determines vertical flame spread along a panel of known width and height. The model does not account for heating of the walls by the hot upper-layer. Flame spread on the ceiling was assumed to be similar to flame spread along a vertical wall. With this assumption, the height of the panel was assumed to be the height of the wall plus the length of the ceiling connected to the wall or 4.88 m. The width of the panel was determined from full-scale fire test damage [*14*]. Test observations indicated that a 0.75 m wide area from the floor to the ceiling was involved in the fire. With the burner being 0.49 m wide, vertical flame spread dominated the flame spread on the wall, as expected. Some damage was observed on the ceiling, but no dimensions of this damage were reported. From this data, the panel for the model was 0.75 m wide and 4.88 m high.

In the full-scale tests, the source fire reached 200 kW approximately 60 seconds after ignition. Therefore, the source fire heat release rate input into the flame spread model was increased from 0 to 200 kW over the initial 60 seconds and remained at 200 kW for the remaining 240 seconds of the exposure.

The predicted flame spread along the wall and ceiling is shown in (Figure 2) along with the flame spread along the wall measured in the tests using thermocouples. In the test, ignition was assumed to occur when the surface temperature reached the material ignition temperature. The model predicted that flame spread past the top of the wall and approximately 1.0 m along the ceiling. No measurements of flame spread were made on the ceiling, but post-test observations indicated some damage on the ceiling above the source fire [*14*].

The predicted heat release rate for the room fire is shown in (Figure 3). Just before the burner is shut off at 300 s, the wall and ceiling were predicted to contribute approximately 375 kW to the heat release rate of the room fire. Based on the mass loss rate values from the fire growth model, the global equivalence ratio was determined to be no greater than 0.85 during the simulation with values less than 0.6 for the initial 250 seconds. Effects of ventilation on combustion product yields were assumed to be small; therefore, cone calorimeter data were used to predict combustion product levels.

The conditions that develop inside the room during the fire were predicted using CFAST. The predicted temperatures and combustion product levels are shown in (Figures 3-5) along with levels measured during the test. The CO concentration data for this test series were not correct and are not shown in (Figure 4).

The predicted temperatures are shown in (Figure 3) to overestimate the measured temperatures by 60-180°C (25-70% error) while the source fire was burning. This is most likely due to using the peak heat release rate values in the analysis for a

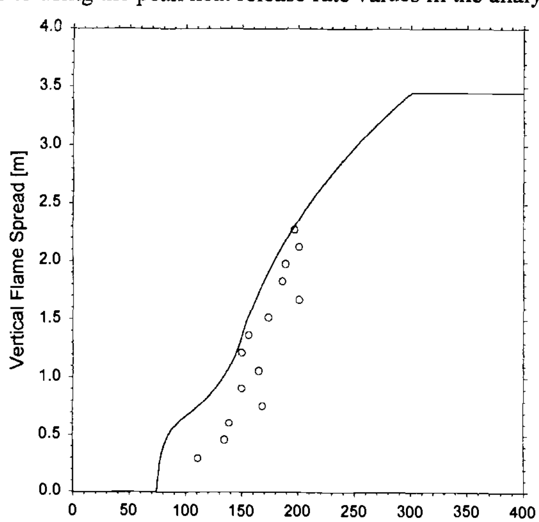


Figure 2 – *Predicted* (—) *and Measured* (O) *Flame Spread Along the Composite Wall*

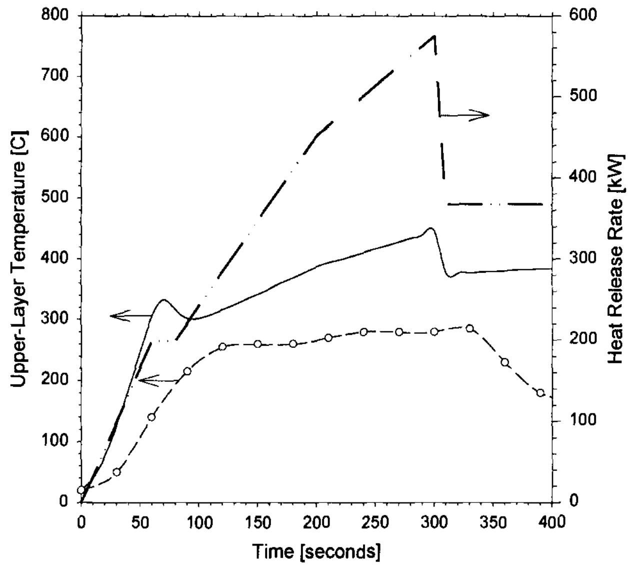


Figure 3 – *Predicted (–• •–) Heat Release Rate of the Room Fire, and Predicted (—) and Measured (–O–) Upper-Layer Gas Temperature*

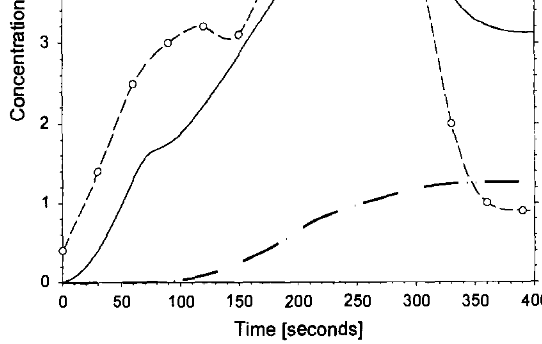


Figure 4 – *Predicted (—) and Measured (–O–) Upper-Layer CO_2 Concentration, and Predicted (–• •–) Upper-Layer CO Concentration*

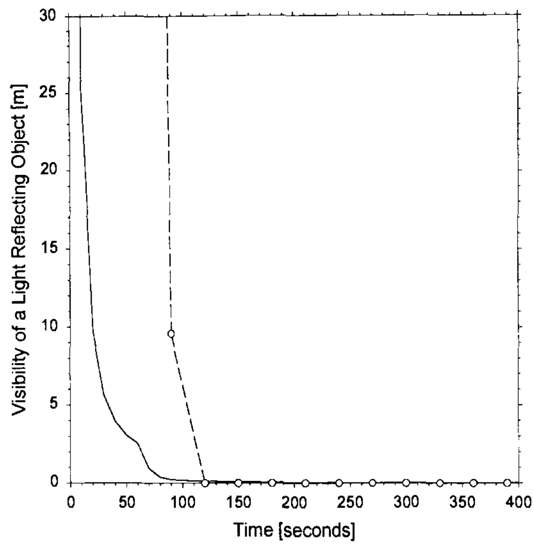


Figure 5 – *Predicted* (—) *and Measured* (–O–) *Visibility through the Upper-Layer*

conservative estimate of the system performance. In the test when the source fire is turned off, the temperature drops significantly and continues to decrease with time. Visual observations from the tests indicate that the wall fire self-extinguished [*14*]. In the simulation, the fire growth model assumes that once a section of the wall ignites it will burn until all material in that section is consumed. As a result, the predicted temperature remains relatively high after the source fire is turned off and then continues to gradually increase with time.

The predicted CO_2 concentration data shown in (Figure 4) underestimates the measured levels during the initial 200 seconds of the test by 0.4-1.2% (10-60% error). During the last 100 seconds of the test when the source fire is burning, the model overestimates the concentration by 0-1.2% (0-30% error). CO_2 concentrations were overpredicted after the source fire was turned off due to the flame spread model not allowing the burning portions of the wall to go out before all combustible materials was consumed.

Predicted CO concentrations are shown in (Figure 4) to reach as high as 1.2%. This is 100% higher than CO levels measured in tests with non-combustible boundaries at a similar equivalence ratio where 0.6% CO was measured [*1*]. This was attributed to the high CO production rate of the composite material.

The predicted visibility through the smoke shown in (Figure 5) is lower than that measured in the test during the initial 100 seconds. However, the model predicted the time at which near zero visibility was reached to within 30 seconds of the data.

Conclusions

A variety of different fire models are currently being used in performance-based analysis to predict fire development in a building. As a result, the data input requirements for these models may vary from model to model. Many of the material fire property data necessary as model input were described in this paper. Much of this data can be developed either using standard output data from ASTM E1354 "Test Method for Heat and Visible Smoke Release Rates for Materials and Products Using an Oxygen Consumption Calorimeter", or from nonstandard data taken using the ASTM E1354 test apparatus. The following calculations and test methods used to develop nonstandard data are recommended for inclusion into ASTM E1354:

- test procedures and equations for measuring gaseous (CO, CO_2) combustion product yields,
- equation for converting specific extinction area of smoke to smoke yield,
- equation for calculating fraction of mass burned, and
- surface temperature measurement.

Effective heat of gasification of the material could also be added to the standard after additional work has been done to better characterize the net heat flux onto the sample during the test.

A performance-based analysis, which used fire models with fire property input data developed using ASTM E1354, provided conservative results of the conditions that developed inside a composite room containing a fire.

Acknowledgements

The author is grateful to Mr. Naeem Iqbal for performing the CFAST runs and Dr. Craig Beyler for his input on various aspects of this work. The author is thankful to Mr. Usman Sorathia at the Naval Surface Warfare Center, Carderock Division for the use of the cone calorimeter and full-scale test data.

References

[1] Gottuk, D.T. and Roby, R.J., "Effect of Combustion Conditions on Species Production," *The SFPE Handbook of Fire Protection Engineering*, Chapter 2-7, 2nd Edition, P.J. DiNenno, Ed., 1995.

[2] Östman, B.A-L., "Smoke and Soot," *Heat Release from Fires,* V. Babrauskas and S.J. Grayson, Eds., Elsevier, London, 1992, pp. 233-250.

[3] Newman, J.S. and Steciak, J., "Characterization of Particulates from Diffusion Flames," *Combustion and Flame*, Vol. 67, 1987, pp.55-64.

[4] Cleary, T. and Quintiere, J.Q., "A Framework for Utilizing Fire Property Test Data," *Fire Safety Science- Proceedings of the Third International Symposium*, G. Cox and B.Langford, Eds., 1991, pp.647-656.

[5] Mitler, H., "Predicting the Spread Rates of Fires on Vertical Surfaces," *23rd Symposium (International) on Combustion*, The Combustion Institute, Pittsburgh, Pennsylvania, 1990, pp. 1715-1721.

[6] Beyler, C. L., Hunt, S. P., Iqbal, N., and Williams, F.W., "A Computer Model of Upward Flame Spread on Vertical Surfaces," *Fire Safety Science - Proceedings of the Fifth International Symposium*, Y. Hasemi, Ed., 1997, pp. 297-308.

[7] Behob, E., "Upward Flame Spread on Vertical Walls with External Radiation," Ph.D. Thesis, Penn State University, Mechanical Engineering Department, 1994.

[8] Kulkarni, A., Kim, C., Kuo, C., "Turbulent Upward Flame Spread for Burning Vertical Walls Made of Finite Thickness," NIST-GCR-91-597, National Institute of Standards and Technology, May, 1991.

[9] Janssens, M.L., "Fundamental Thermophysical Characteristics of Wood and Their Role in Enclosure Fire Growth," Ph.D. Dissertation, University of Gent (Belgium), September, 1991.

[10] Delichatsios, M.A., Panagiotou, TH., and Kiley, F., "The Use of Time to Ignition Data for Characterizing the Thermal Inertia and the Minimum (Critical) Heat Flux for Ignition or Pyrolysis," *Combustion and Flame*, Vol. 84, 1991, pp.323-332.

[11] Quintiere, J. G. and Harkleroad, M. T., "New Concepts for Measuring Flame Spread Properties," *Fire Safety: Science and Engineering, ASTM STP 882*, T.Z. Harmathy, Ed., American Society for Testing and Materials, Philadelphia, 1985, pp. 239-267.

[12] Rhodes, B. and Quintiere, J. G., "Burning Rate and Flame Heat Flux for PMMA in a Cone Calorimeter," *Fire Safety Journal*, Vol. 26, 1996, pp.221-240.

[13] Peacock, R.D., Forney, G.P., Reneke, P., Portier, R., and Jones, W.W.,"CFAST, The Consolidated Model of Fire Growth and Smoke Transport," *NIST Technical Note 1299*, Building and Fire Research Laboratory, U.S. Department of Commerce, National Institute of Standards and Technology, Gaithersburg, MD, February, 1993.

[14] Rollhouser, C.M., Beck, C.P., Sorathia, U., Ness, J., Purcell, R., Beitel, J., Scheffey, J.L., Williams, F.W., and Kay, D.H., " Large Scale Fire Testing of a Glass-Vinyl Ester Composite Module," NSWCCD-TR-64-96/13, U.S Navy, Naval Surface Warfare Center, Carderock Division, 1998.

[15] Tewarson, A., "Generation of Heat and Chemical Compounds in Fires," *The SFPE Handbook of Fire Protection Engineering*, Chapter 3-4, P.J. DiNenno, Ed., National Fire Protection Association, Quincy, MA, 1995.

[16] Sorathia, U., Ness, J., and Blum, M., "Fire Safety of Composites in the US Navy," *Composites : Part A. Applied Science and Manufacturing*, Elsevier Science, Ltd., 1999, pp. 707-713.

Marc L. Janssens[1]

Computer Fire Model Selection and Data Sources

Reference: Janssens, M. L., "**Computer Fire Model Selection and Data Sources,**" *ASTM's Role in Performance-Based Fire Codes and Standards, ASTM STP 1377*, J. R. Hall, Jr., Ed., American Society for Testing and Materials, West Conshohocken, PA, 1999.

Abstract: Performance-based fire codes specify performance goals and objectives, and permit, or even encourage, the use of modern tools, such as computer fire models, to demonstrate that minimum performance requirements are met. Computer models that are "acceptable" for this purpose must be suitable for the intended use, well documented, and adequately evaluated. ASTM developed four standard guides to facilitate computer fire model selection and identification of sources of data for model input and evaluation. The ASTM guides address evaluation of the predictive capability, documentation, and uses and limitations of computer fire models. One guide also deals with data for models. The ASTM guides are briefly described, and their use is illustrated with an example of a simple compartment fire model, FIRM-Q.

Keywords: computer fire models, model documentation, model evaluation, model validation, model verification, performance-based codes, performance-based design

Introduction

Fire safety provisions in traditional building codes are primarily based on performance in standard fire tests and prescriptive requirements. Performance-based codes set performance goals and objectives, but do not exactly specify how these objectives have to be met. They permit, and even encourage, the use of modern tools, such as computer fire models, to demonstrate that the minimum performance requirements are met. Computer models that are "acceptable" for this purpose must be suitable for the intended use, well documented, and adequately verified. Over the past 10 years, ASTM Committee E 5, Subcommittee 39 on Fire Modeling has developed four standard guides to facilitate computer fire model selection and identification of sources of data for model input and evaluation. Subcommittee E05.39 was merged into Subcommittee E05.33 on Fire Safety Engineering in 1996. E05.33 currently has the responsibility for maintaining the guides.

---

[1]Manager, Southwest Research Institute, 6220 Culebra Road, San Antonio, TX 78238

The ASTM Guide on Evaluating the Predictive Capability of Deterministic Fire Models (E 1355) was first published in 1990, and was completely revised in 1997. The ASTM Guide for Documenting Computer Software for Fire Models (E 1472), first published in 1992, requires that computer fire model documentation consist of the following three parts: the technical documentation, a user's manual, and a programmer's guide. The technical documentation describes the theoretical and mathematical foundations of the model. The user's manual provides instructions for installing and operating the software. Sample runs shall be included to allow the user to verify correct operation of the program. The programmer's guide includes the source code and instructions for users who want to customize the program. The ASTM Guide on Data for Fire Models (E 1591) was published in 1994, and describes methods for obtaining data for input for computer fire models, and includes numerous references to the open literatures where values can be found. The most recent ASTM Guide on Uses and Limitations of Deterministic Fire Models (E 1895) was completed in 1998.

Some background information concerning computer fire modeling will be provided in the next section. This is followed by a discussion of the main issues pertinent to the selection of a computer model for a particular application. The ASTM guides greatly facilitate the selection process, and are briefly discussed in subsequent sections. Identification of sources of data for model input and evaluation is also addressed. Finally, the use of the ASTM guides is illustrated with an example of a simple compartment fire model, FIRM-Q.

Computer Fire Modeling

What Is a Computer Fire Model?

The term *fire model* is defined in ASTM Terminology of Fire Standards (E 176) as "A physical representation or set of mathematical equations that approximately simulate the dynamics of burning and associated processes." A salt water experiment is an example of a physical model that has often been used to study fire-induced plume and vent flows [*1, 2*]. Mathematical models range from relatively simple formulae that can be solved analytically, to extensive hybrid sets of differential and algebraic equations that must be solved numerically on a computer, *i.e.*, by using a computer fire model. The term "computer fire model" can therefore be described as a computer program that numerically solves a set of mathematical equations, which approximately simulate the dynamics of burning and other fire processes for a set of user-specified input variables that describe the geometry, configuration, materials involved, etc.

Types of Computer Fire Models

Compartment Fire Models—The most commonly used computer fire models simulate a fire in an enclosure. Zone models as well as field models are used for this purpose. Post-flashover zone models are based on the assumption that the gas temperature inside the enclosure is uniform. Therefore, only one zone is considered. Pre-flashover zone models are (usually) based on the assumption that gases inside an enclosure form two distinct zones: a layer of hot gases beneath the ceiling, and a layer of cool air between the hot layer and the floor. The temperature and composition of each layer is considered uniform. The system of zone model equations express conservation of mass and energy for each zone. Enclosure fire models usually do not predict the fire itself, but estimate the effects of a user-specified fire in terms of gas temperatures, surface heat fluxes, etc. Field fire models are applications of Computational Fluid Dynamics (CFD) codes. They predict the fire-generated flow field and temperature distribution in a spatial region of interest by solving the conservation equations of mass, momentum, and energy with the appropriate boundary conditions. Many enclosure fire models have been extended to simulate the spread of fire and smoke through multi-room structures.

Materials and System Response Models—A second category of computer fire models are those that predict how materials and systems respond when exposed to certain fire conditions. Sprinkler and detection activation models fall in this category. Other examples are procedures to calculate ignition of exterior siding materials exposed to the radiant heat from a fire in a neighboring building, models to assess the loadbearing capacity of structural elements and assemblies exposed to fire, etc.

Use of Computer Fire Models

Computer fire models are used primarily for two purposes: for reconstruction and analysis of fires, and for fire-safe design of (part of) a structure, e.g., for performance-based code compliance. It is unwise in either case to rely on model calculations only. Nature is extremely complex, and computer models (even field models!) often provide a rather crude approximation of the real world, and have significant limitations. A discussion of the use and limitations of computer fire models can be found in ASTM E 1895. Computer fire models are best used as part of a tool kit, together with results from experiments, data from the literature, experience, statistical data, etc. Models can greatly, but not totally, eliminate the need for expensive full-scale tests. Some full-scale data will always be needed to provide a level of confidence in the predictive capability of a model. Moreover, models also require small-scale data describing the relevant physical and chemical characteristics of materials exposed and/or contributing to a fire.

Computer Fire Model Selection

Several surveys have been published [*3-5*], and should be consulted to determine which models are available for a particular task. The following questions need to be considered to narrow down the list of candidates:

1. Does the model address the physical and/or chemical phenomena of interest? For example, a two-zone multi-room fire model is not very suitable to predict smoke flow in a long corridor, because zone models assume that the upper layer depth is uniform across the entire ceiling of the room. A field model, or perhaps a zone model enhanced with corridor flow algorithms would be much better choices.
2. What is the cost of the computer model? The price of computer model software ranges from zero (many of the models developed at the National Institute of Standards and Technology, or NIST, are available free of charge [*6*]) to $50,000+

(yearly license for top-of-the line CFD code). Hardware requirements and user qualifications also affect the cost. There is an inverse correlation between accuracy/completeness/fidelity/versatility and cost. Usually, the objective is to find the least expensive tool that can adequately do the job.

3. Is the source code available? Often a model is rejected because it lacks certain important features. For example, a model that assumes the fire is located in the center of the room is not suitable to simulate the effects of a burning object against a wall or in a corner. However, if the source code is available, the user can make modifications to address the effect of location on entrainment. The source code issue will be discussed more in detail below for the example model FIRM-Q.
4. What is the predictive capability of the model? In other words, what are the accuracy and uncertainty of the model? This is probably the most important question. ASTM E 1355 provides specific instructions on how to evaluate the predictive capability of a computer fire model.

Computer fire model selection may involve an iterative process. For example, an initial evaluation could indicate that the predictive capability can be improved by changing the source code. The model would have to be re-evaluated after the changes are made.

Evaluating the Predictive Capability

The evaluation process, according to ASTM E 1355, consists of four steps:

1. Define the scenarios for which the evaluation is to be conducted.
2. Validate the theoretical basis and assumptions used in the model.
3. Verify the mathematical and numerical robustness of the model.
4. Evaluate the model, *i.e.*, quantify its uncertainty and accuracy.

Step 4 is usually based on a comparison between model output and experimental data, and provides an indirect method for validation (Step 2) and verification (Step 3) of a model for the scenarios of interest (Step 1). It is generally assumed that the model equations are solved correctly, and the terms validation and evaluation are therefore often used interchangeably. The four steps in the model evaluation process as described in ASTM E 1355 are discussed in some detail below.

Define Scenarios and Review Documentation

The first step of the process consists of a review of the model documentation and a description of the fire scenarios for which the evaluation is to be conducted. Sufficient documentation is necessary to determine whether the model is suitable for the intended use, *i.e.*, the simulation of fire scenarios of interest. ASTM E 176 defines the term "fire scenario" as "Detailed description of conditions, including environmental, of one or more stages from before ignition to the completion of combustion in an actual fire, or in a full-scale simulation." Model documentation prepared according to the guidelines in ASTM E 1472 contains all the elements needed for a proper evaluation.

Validation

Ideally, a model should be validated by an independent expert who has not been associated with the development of the model. In practice, often only the model developer has enough incentive to conduct such a tedious and time consuming task. The validation process consists of a detailed review of the theoretical basis of the model, and an assessment of the correctness of the assumptions that are made and the approaches that are used.

Verification

A model is verified by assessing its mathematical and numerical robustness. Verification can be performed by comparing model output to analytical solutions of simple problems for which such solutions exist, *e.g.*, steady problems, by checking the computer source code for irregularities and inconsistencies, and/or by investigating the accuracy and convergence of the numerical solutions of the model equations.

Evaluation

A model is evaluated on the basis of a comparison between its output and experimental data for the scenarios of interest.

Types of Evaluations—A distinction can be made between three types of evaluations:

1. *Blind Evaluation.* The person performing the evaluation is provided with a basic description of the problem, and must develop appropriate inputs from the limited information that is provided. A blind evaluation does not only assess the model, but also tests the ability of a user to develop appropriate input data.
2. *Specified Evaluation.* The person performing the evaluation is provided with a detailed description of all model inputs. A specified calculation is primarily an evaluation of the underlying physics of the model.
3. *Open Evaluation.* The person performing the evaluation is provided with the most complete information, including experimental data and the results of blind and specified calculations.

At least one of the three types of evaluations should be performed to compare different models, and to determine which model is most suitable for simulating a particular scenario. Working Commission 14 of the Conseil International du Bâtiment (CIB W14) conducted a major program that involved the three types of evaluations to compare more than two dozen models in their ability of simulating a series of single compartment fire tests conducted at the technical research Center of Finland (VTT) [7].

Sources of Experimental Data for Model Evaluation—There are four major sources of experimental data for model evaluation:

1. *Standard Tests.* Standard test data are useful for the evaluation of models that predict how a material or assembly performs in the test. Only a few standard test procedures involve a room, and most standard test data are

therefore not applicable for the evaluation of compartment fire models. The ASTM Guide for Room Fire Tests (E 603) provides general guidelines for conducting full-scale fire experiments, and is perhaps the most useful standard test procedure in terms of generating data suitable for compartment fire model evaluation.

2. *Tests Conducted Specifically for this Purpose.* Due to the high cost, it is very unusual that full-scale tests are conducted specifically to provide data for evaluation of a particular model. If experiments are conducted, they should be designed judiciously to assure the data produced by the tests affords the best data for comparison. For example, a model that does not calculate layer species concentrations certainly would not require any experiments where these data are measured.
3. *Test Data in the Literature.* For obvious reasons, the open literature is by far the most common source of data for model evaluation. Useful data are provided in the papers by Peacock *et al.* [*8*] and by Sardqvist [*9*].
4. *Fire Experience.* Fire risk assessment involves a very large number of deterministic computer fire model runs, and can be used to evaluate the model by comparing the results of the risk assessment to fire statistics. Compartment fire models are useful tools in the reconstruction of fires, and can be evaluated by checking whether model predictions are consistent with the timeline and other pieces of information in the fire investigation report.

Accuracy and Uncertainty of Fire Models—Two factors contribute toward the uncertainty and accuracy of fire models when quantified by comparing model predictions with experimental data:

1. *Model Uncertainty.* This is primarily due to the uncertainty of model inputs. Sensitivity analyses are used to identify the critical input parameters, *i.e.*, parameters for which small deviations result in large changes in model output. The critical input parameters must be specified with much greater care than the parameters to which the model is relatively insensitive. A sensitivity analysis of a complex model might involve a very large number of runs to assess the effect of all input parameters individually, and of possible interactions between different parameters. Peacock and Breese reported that a study involving the systematic variation of the input parameters of the Harvard Fire Code would require up to 3,192 computer runs [*10*]. This is clearly an effectively impossible requirement. Fortunately, special mathematical techniques, such as Latin Hypercube Sampling, can be used to drastically reduce the number of computer model runs without losing much information.
2. *Experimental Uncertainty.* Full-scale fire test data are generally accepted without question. However, such data are subject to uncertainties. Therefore, discrepancies between model predictions and experimental data might be, at least partly, due to measurement errors. There are procedures to determine the precision of standard test methods on the basis of interlaboratory trials or round robins, e.g., see ASTM Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method (E 691). Custom non-standard full-

scale fire experiments are usually not repeated for cost reasons. However, the uncertainty of custom test data is comparable to that of standard full-scale fire tests. Round robins of standard full-scale fire test methods have shown that the uncertainty of some measurements may be as high as ± 30 % [*11*].

Comparing Model Output to Experimental Data

There are many problems in comparing the results from fire model simulations to data from full-scale fire experiments. Some of the problems are due to the differences between the form of the recorded experimental data and the form needed for comparison with model predictions. For pre-flashover zone models, the compartment is divided into two distinct zones, a lower cool layer and a hot upper layer. In reality, there is no such clear and sharp change distinguishing the lower and upper layers. To use experimental data for comparison with zone model results requires that the experimental data be cast into an idealized form, *i.e.*, isothermal upper and lower layers separated by a sharp interface (Figure 1). A detailed discussion on the subject of transforming room fire test data so that they are suitable for comparison with results from zone model simulations can be found in [*12*].

Perhaps the most common method for comparing experimental data and model results is through graphical methods. Two variables are plotted against each other for both the experimental data and model predictions. Graphs of layer temperatures,

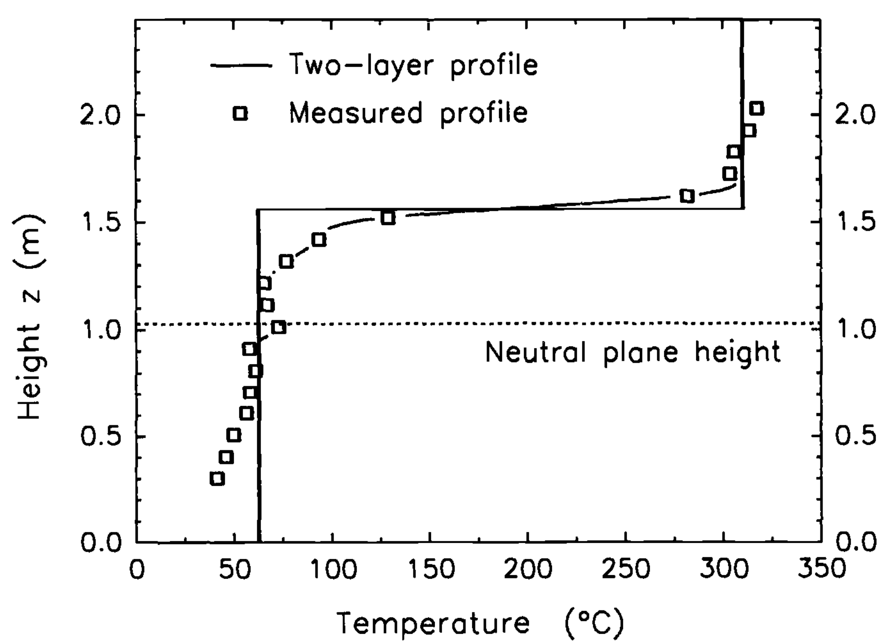


Figure 1 — *Comparison Between Measured and Predicted Temperature Profiles*

interface location, and vent flows as a function of time are the most widely used. Although there are well-established statistical methods to quantify the agreement between two curves, they are not very well known, and evaluations based on such comparisons are therefore quite often subjective. This is an area where better practices exist, and more universal compliance with these practices is urgently needed.

Example: Evaluation of FIRM-Q

The FIRM-Q Model

FIRM-Q is single-room fire model based on ASET *[13]*, supplemented with algorithms to calculate the flow through a vent in a vertical wall of the compartment. The FIRM-Q model is a revision of the Fire Investigation and Reconstruction Model by Birk *[14]*. The problem modeled by FIRM-Q is that of a single item burning in the center of a room with a vent in a vertical wall (Figure 2). The fire is specified by the user in the form of a heat release rate vs. time curve. A user-defined fraction, L_c, of the heat release rate is lost through the walls of the compartment. The fraction of heat that is released in the form of radiation, L_r, is also specified by the user. FIRM-Q predicts the consequences of the fire in terms of upper layer temperature (T_u), layer interface height (Z_i), and mass flows through the vent ($\dot{m}_a$, $\dot{m}_l$, and $\dot{m}_u$). Extensive documentation and an evaluation of the predictive capability of FIRM-Q are provided elsewhere by the author of this paper *[15]*. A summary is presented below.

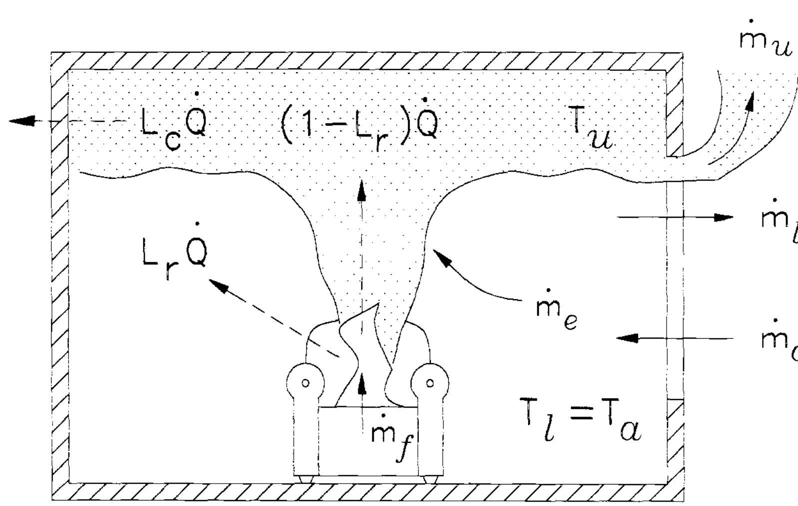


Figure 2 -- *Problem Modeled by FIRM-Q*

Documentation

The FIRM-Q documentation consists of three parts, as specified in ASTM E 1472.

Validation

There is no independent validation, but guidelines are provided for user validation.

Verification

Proven numerical methods are used to solve the algebraic vent flow equation (bisection method), and the ordinary differential equations for conservation of mass and energy of the upper layer (4th order Runge-Kutta with step size control).

Evaluation

Type of Evaluation—Because the evaluation is provided by the model developer, it is an open evaluation.

Accuracy And Uncertainty of FIRM-Q—Sensitivity analysis was conducted by varying input variables ± 20% from a base case. The model seems to be insensitive to changes in room area and fuel height, but it is most sensitive to soffit height, total heat loss fraction, and heat release rate.

Comparison of Predictions With Experimental Data—No funds were available to conduct tests, specifically to evaluate FIRM-Q, therefore, data were obtained from the literature. Two data sets obtained at the National Institute of Standards and Technology (NIST, previously the National Bureau of Standards or NBS) were selected.

Single Room With Furniture—Six tests were conducted with a loveseat (F31) or armchair (F21) inside a compartment with a doorway or window in the front wall [*16*]. The data are available from NIST in the form of "Fire Data Management System" (FDMS) ASCII data files [*17*]. The dimensions of the room were 2.26 x 3.94 x 2.31 m. Various door and window configurations were used. FIRM-Q predictions were made on the basis of measured and estimated heat release rates. The estimates were based on Babrauskas' triangular heat release rate model for upholstered furniture [*18*]. Upper layer temperature predictions are in reasonable agreement with the measurements (Figure 3). The predictions are higher during the peak burning period. This can be explained by the fact that FIRM-Q assumes that all combustion takes place inside the compartment. During the peak burning period, flames emerged from the compartment, which invalidates the assumption.

Steckler's Steady Vent Flow Experiments—The second set of experiments were conducted by Steckler to measure fire-induced flows through room openings. The dimensions of the test room were 2.8 x 2.8 x 2.13 m. Various door and window configurations were used. The fire was a 0.3-m diameter methane burner with constant

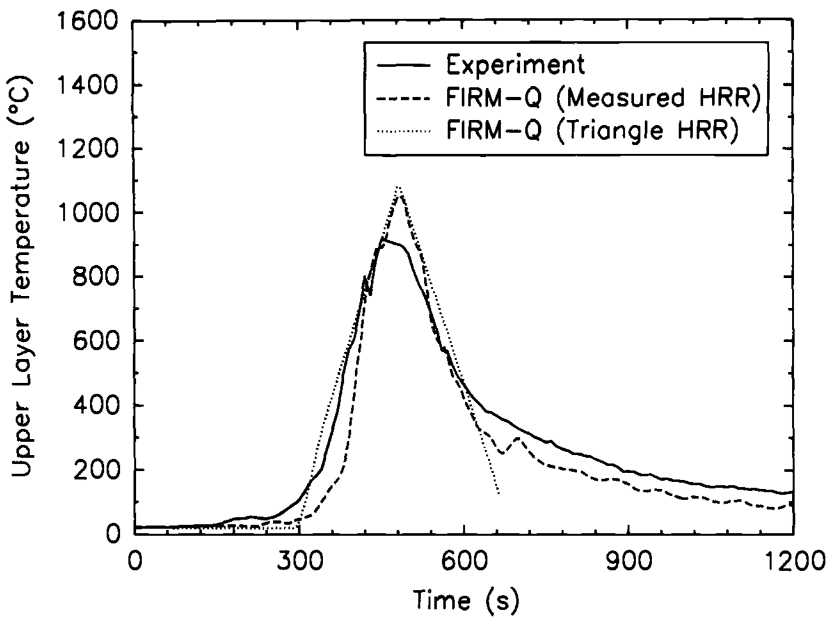


Figure 3 — *Comparison of Predictions and Measured Temperatures for Test #1*

heat output of 31.6, 62.9, 105.3, or 158.0 kW. The burner was located in the center of the room for most tests. The compartment was well insulated, and steady conditions were reached in a few minutes. The test duration was 10 minutes. Quintiere et al. reported that the flame in Steckler's experiments leaned over due to the incoming flow of ambient air. This increases the entrainment rate and lowers the upper layer temperature compared to a vertical flame. FIRM-Q was changed to account for this effect. Figure 4 shows that the upper layer temperature predictions of the modified version are in much better agreement with the measurements. Field models automatically account for this effect because they are based on more fundamental equations, and do not rely on flame and plume entrainment correlations.

Data Sources

Sources of experimental data for model evaluation are discussed in the previous section. In addition, computer fire models typically require physical, chemical, and flammability properties of materials involved in a fire. ASTM E 1591 describes how many of these properties can be measured, and includes numerous references to the open literature where property values can be found.

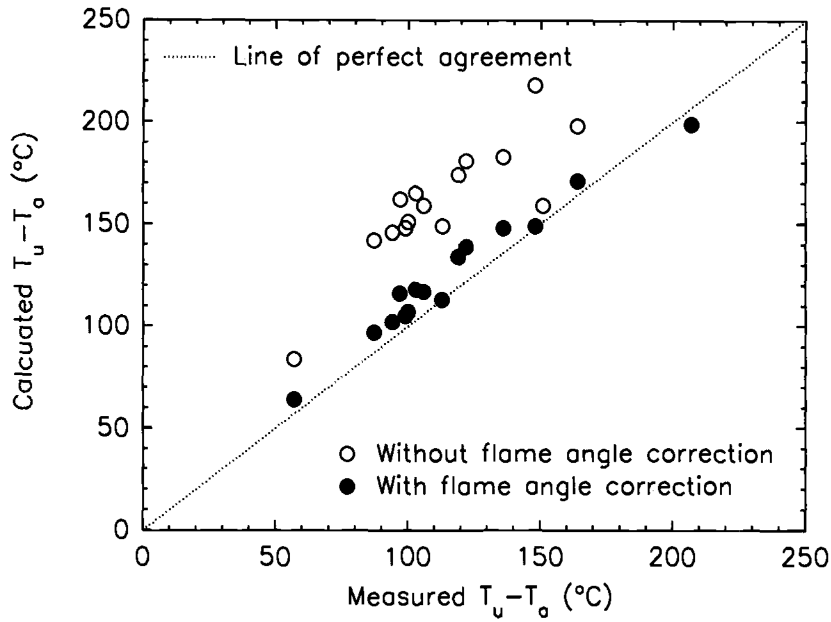


Figure 4 — *Effect of Flame Tilting on Upper layer Temperature Predictions*

Conclusions

The ASTM fire modeling guides help fire model developers and users in documenting and evaluating fire models, and in finding sources for model input data. Model uncertainty is primarily due to uncertainty in the input data, and sensitivity analyses are essential to identify the critical parameters. A balanced approach that combines experimental evaluations with computer fire model assessments is recommended for both analysis and performance-based design. ASTM provides standard test procedures for both types of data that are needed: small-scale data for model input, e.g., ASTM Test Method for Heat and Visible Smoke Release Rates for Materials and Products Using an Oxygen Consumption Calorimeter (E 1354), and large-scale data for model evaluation, e.g., ASTM E 603. Full-scale fire test data also have some uncertainty, which may be as high as ± 20-30%.

Acknowledgments

The author wishes to thank all that have contributed during his tenure as chairman of E05.39 to the development of the ASTM fire modeling guides, in particular Dr. Andy Fowell, Mr. Dan Gemeny, Dr. John Hall, Dr. Jim Mehaffey, Mr. Rick Peacock, Ms. Sharon Steele, Dr. Jack Watts, and Dr. Robert White.

References

[1] Prahl, J., and H. W. Emmons, "Fire Induced Flow Through an Opening," *Combustion and Flame*, Vol. 25, 1975, pp. 369-385.

[2] Steckler, K. D., Baum, H. R., and Quintiere, J. G., "Salt Water Modeling of Fire Induced Flows in Multi-Compartment Enclosures," NBSIR 86-3326, National Bureau of Standards, Washington, DC, 1986.

[3] Friedman, R., "An International Survey of Computer Fire Models for Fire and Smoke," *Journal of Fire Protection Engineering*, Vol. 4, 1992, pp. 81-92.

[4] Janssens, M., "Room Fire Models, Part A: General," Chapter 6 in *Heat Release in Fires*, V. Babrauskas, and S. Grayson, Ed., Elsevier, New York, 1992, pp. 113-157.

[5] Sullivan, P., Terro, M., and Morris, W., "Critical Review of Fire-Dedicated Thermal and Structural Computer Programs," *Journal of Applied Fire Science*, Vol. 3, 1993-94, pp. 113-135.

[6] "FAST: Engineering Tools for Estimating Fire Growth and Smoke Transport," CD ROM, National Institute of Standards and Technology, Gaithersburg, MD, 1998.

[7] Keski-Rahkonen, O., "CIB W14 Round Robin of Code Assessment: A Comparison of Fire Simulation Tools," in *Proceedings of the Conference on Fire Safety Design of Buildings and Fire Safety Engineering*, Oslo, Norway, August 19-20, 1996, pp. 1-14.

[8] Peacock, R., S. Davis, and V. Babrauskas, "Data for Room Fire Model Comparisons," *Journal of Research of the National Institute of Standards and Technology*, Vol. 96, 1991, pp. 411-462.

[9] Särdqvist, S., "Initial Fires: HRR, Smoke and CO Generation from Single Items and Room Fire Tests," LUTVDG/TVBB-3070SE, Lund University, Sweden, 1993.

[10] Peacock, R., and Breese, J., "Computer Fire Modeling for the Prediction of Flashover," NBSIR 82-2516, National Bureau of Standards, Washington DC, 1982.

[11] Beitel, J., "International Fire Standards Project Report, Interlaboratory Test Program, Proposed ASTM Standard Method for Room Fire Test of Wall and Ceiling Materials and Assemblies," PCN 33-000012-31, ASTM, Institute for Standards Research, Philadelphia, PA, 1994.

[12] Janssens, M., and Tran, H., "Data Reduction of Room Tests for Zone Model Validation," *Journal of Fire Sciences*, Vol. 10, 1992, pp. 528-555.

[13] Cooper, L. Y., "Estimating Safe Available Egress Time from Fires," NBSIR 80-2172, National Bureau of Standards, Washington, DC, 1980.

[14] Birk, D.M,, *An Introduction to Fire Modeling*, Technomic Publishing Co., Lancaster, PA, 1990.

[15] Janssens, M.L,, *An Introduction to Fire Modeling (Second Edition)*, Technomic Publishing Co., Lancaster, PA, 1999.

[16] Peacock, R.D., Davis, S., and Babrauskas, V., "Data for Room Fire Model Comparisons," *Journal of Research of the National Institute of Standards and Technology*, Vol. 96, 1991, pp. 411-462.

[17] Babrauskas, V., Peacock, R.D., Janssens, M.L., and Batho, N., "Standardization of Formats and Presentation of Fire Data: The FDMS," *Journal of Fire and Materials*, Vol. 15, 1990, pp. 85-92.

[18] Babrauskas, V., and Walton, W. D., "A Simplified Characterization of Upholstered Furniture Heat Release Rates," *Fire Safety Journal*, Vol., 11, 1986, 181-192.

[19] Steckler, K. D., Baum, H. R., and Quintiere, J. G., "Fire Induced Flows Through Room Openings - Flow Coefficients," NBSIR 83-2801. National Bureau of Standards, Washington, DC, 1984.

[20] Quintiere, J. G., Rinkinen, W. J., and Jones, W. W., "The Effect of Room Openings on Fire Plume Entrainment," *Combustion Science and Technology*, Vol. 26, 1984, pp. 93-201.

Alliances and Activities of Other Groups

Morgan J. Hurley[1]

SFPE's Fire Model Evaluation Initiative: How ASTM Has Helped And Can Help

Reference: Hurley, M. J., "**SFPE's Fire Model Evaluation Initiative: How ASTM Has Helped and Can Help,**" *ASTM's Role in Performance-Based Fire Codes and Standards, ASTM STP 1377*, J. R. Hall, Jr., Ed. American Society for Testing and Materials, West Conshohocken, PA, 1999.

Abstract: SFPE is nearing completion of its first computer model evaluation: DETACT-QS. DETACT-QS was chosen because of the model's simplicity, limited scope of application and widespread usage. The product of this review will be an evaluation report for use by users of the model, and reviewers of designs and submissions that are based on the model. The evaluation of DETACT was guided by the ASTM Standard Guide for Evaluating the Predictive Capability of Deterministic Fire Models (E 1355). This paper discusses the evaluation of DETACT in accordance with ASTM E1355, how ASTM has facilitated this effort, and identifies areas where ASTM could assist with future evaluation efforts.

Keywords: Computer fire models, model evaluation.

Introduction

The 1991 Conference on Firesafety Design in the 21st Century set the following national goal: "By the year 2000, the first generation of an entirely new concept in performance-based building codes be made available to engineers, architects and authorities having jurisdiction ... in a credible and usable form." [1] Five strategies were identified for achieving this goal, one of which was "The usefulness, assumptions and limitations of engineering tools used ... must be critically reviewed and documented by an independent and respected group of skilled engineering experts." [1]

In June of 1995, the Society of Fire Protection Engineers formed a task group to evaluate the scope, applications and limitations of computer models intended for use in the engineering evaluation and design of fire and life safety measures. The task group is composed of volunteer members from the United States, Canada, and New Zealand. Task group members come from academia, code enforcement, consulting, and research.

The task group's first objective was to identify an evaluation methodology and select a model to use as a test case. DETACT-QS was selected based on its simplicity, limited scope of application and widespread usage. DETACT-QS is a model for predicting the response of detectors to an arbitrary heat release rate history [2].

[1] Technical Director, Society of Fire Protection Engineers, 7315 Wisconsin Ave., Suite 1225W, Bethesda, MD, 20814-3202

After examining several approaches to evaluating computer models, the Task Group decided to follow E-1355. The guide "provides a methodology for evaluating the predictive capabilities of a fire model for a specific use." Specifically the method addresses four areas of evaluation: 1) model definition and evaluation scenarios, 2) verification of theoretical basis and assumptions used in the model, 3) verification of the mathematical and numerical robustness of the model, and 4) quantification of the uncertainty and accuracy of the model predictions.

The resulting evaluation report is intended to supplement the model's user's guide by demonstrating the capabilities and limitations of the model and highlighting underlying assumptions that are important for users to consider when applying the model.

Evaluation

DETACT-QS versions 1.2 (SI units) and 1.3 (English units) were "evaluated" as defined in ASTM E-1355. The evaluation report follows ASTM E-1355 (applicable sections of ASTM E 1355 are indicated below in parentheses.) As of the writing of this paper, all of the sections indicated below are complete, except for the last four (Model Evaluation, Quantifying Model Evaluation, Summary of Analysis and List of Limitations/Guidelines). The evaluation is expected to be completed in early 1999. The evaluation report is organized as follows:

- Introduction
- Model Description (Section 7.1 of ASTM E-1355)
- Evaluation Scenarios (Section 7.2)
- Theoretical Basis for Model (Section 8)
- Mathematical Robustness (Section 9)
- Model Sensitivity (Section 10)
- Model Inputs
- Model Evaluation (Section 11)
- Quantifying Model Evaluation (Section 11.3.6)
- Summary of Analysis
- List of Limitations/Guidelines

Introduction

The introduction describes the need, appropriate use and the purpose of the evaluation report. The evaluation is intended for use only by persons competent in the field of fire safety and is intended only to supplement the informed judgement of the qualified user. While the purpose of the evaluation is to provide information on the technical features, theoretical basis, assumptions, limitations, sensitivities, and guidance on the use of DETACT-QS, the evaluation is limited to the range of full-scale experiments used for comparison.

Model Description

The model description is derived from the model's original documentation. DETACT-QS was developed to calculate the response time of thermally activated detectors and smoke detectors installed under large, horizontal, unobstructed ceilings for fires with user defined, time dependent heat release rate curves [2].

DETACT-QS consists of an empirically derived algorithm that predicts the maximum temperature and velocity of fire plumes and ceiling jets for a user-specified ceiling height and radial distance from the plume centerline. A lumped mass, convection heat transfer algorithm is used to predict the thermal detector activation time.

The model description section also includes definitions, minimum hardware and operating system requirements, assumptions inherent in the model, input data requirements, and a list of references.

Evaluation Scenarios

The evaluation was conducted for "unobstructed" (30 m x 30 m) ceilings in heights ranging from 3.0 m to 12 m and in a 9.2 m x 5.6 m x 2.4 m (height) compartment. The details of the scenarios used are described in the "Evaluation Scenario Model Inputs" section below.

Theoretical Basis for the Model

DETACT-QS calculates quasi-steady gas flow temperatures and velocities based on the energy release rate at each time step. The thermal element is considered to be a lumped mass, and radiative and conductive heat transfer into and from the element is ignored. A logic flowchart is provided in this section of the evaluation report to illustrate the algorithm used in DETACT-QS.

Mathematical and Numerical Robustness

The mathematical robustness of the model was evaluated by conducting a "numerical test" as defined in ASTM E 1355. The model's algorithm was programmed into a mathematical solver following the logic flow chart. The predictions of the model and the solutions derived using the mathematical solver were compared for level of agreement.

Model Sensitivity

The results of a sensitivity analysis are used to demonstrate the relative magnitude of change that can be expected by changing an input parameter. Some input parameter changes will result in small or insignificant changes in model predictions while others may result in large changes in the predicted values. A sensitivity analysis can be used to [ASTM E 1355]:

- Determine the dominant input variables
- Define an acceptable range for each input variable
- Quantify the sensitivity of output variables to input variables
- Inform users about the level of care to be taken in selecting input data

Individual input parameters were varied to determine the effect on output, with the resulting sensitivity expressed as a percentage change in output per percent change in input. Input values were individually varied +/- 10% for a detector actuation temperature of 74° C, radial distances of 0.4 m & 11 m, response time indexes of 28 $m^{1/2}$-$s^{1/2}$ & 83 $m^{1/2}$-$s^{1/2}$, an initial room temperature of 21° C, ceiling heights of 2.4 m & 12 m and slow, medium, fast and ultra-fast heat release rates. (Figure 1) illustrates the results of this analysis.

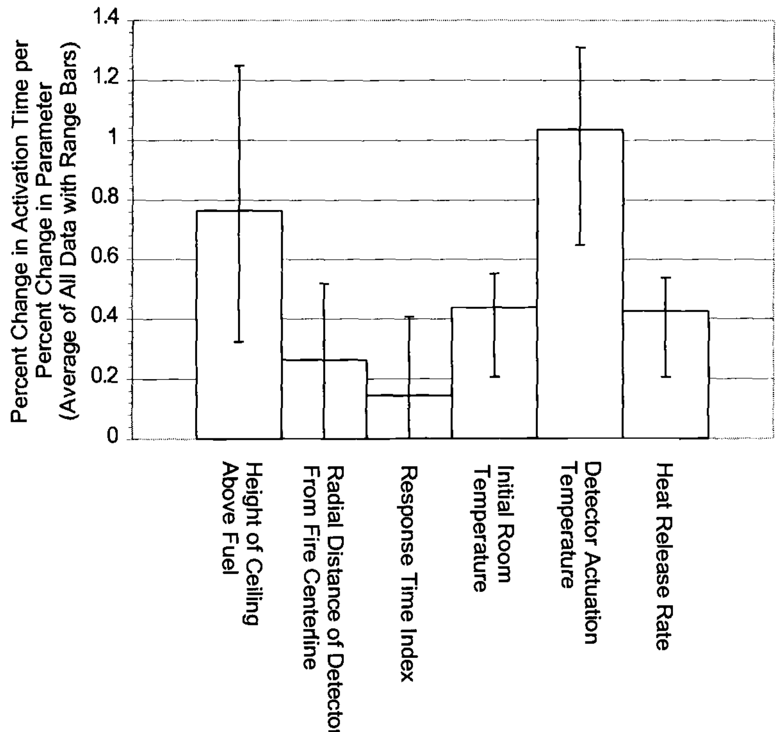


Figure 1 – *Sensitivity of DETACT-QS*

Evaluation Scenario Model Inputs

ASTM E 1355 identifies three possible sources of data to evaluate fire models: comparison with standard tests, comparison with full-scale tests conducted specifically for the evaluation, and comparison with previously published full-scale data. Three sets of full-scale test data will be used to evaluate DETACT-QS: one set of previously published data [3], and two sets of full scale data from tests conducted specifically for this evaluation [4, 5]. The previously published tests utilized a 9.2 m x 5.6 m x 2.4 m (height) compartment, 68° C sprinklers with an RTI of 55 $m^{1/2}$-$s^{1/2}$ and "slow," "medium" and "fast" growth fires as defined in NFPA 72 [6] with a maximum heat release rate of 1055 kW. The tests conducted specifically for the evaluation were under an "unobstructed" (30 m x 30 m) ceiling with heights ranging from 3.0 m to 12 m, "medium" and "ultra-ultra fast" ($\dot{q} = 1.7(t^2)$) fire growth rates with maximum heat release rates ranging from 847 kW to 10 MW, and disk thermocouples with RTI's of 32, 164 & 287 $m^{½}$-$s^{½}$.

Model Evaluation

These data sets will be evaluated using "specified calculations" as defined in ASTM E 1355. Initially, the task group planned to also conduct "blind calculations;" however, the data set that was planned for this evaluation was found to be unacceptable due to abnormalities in the conduct of the tests. The "blind calculations" did reveal a variety of treatments of fires that are located in corners or against walls, where the heat release rate is typically adjusted by a "location factor" [7]. However, the variety in treatments likely stems from the model's documentation not addressing these scenarios.

Quantifying the Model Evaluation

The model predictions will be examined to determine how well the model predicted results within a reasonable level of agreement to the actual test results. In this case, reasonable agreement is defined as predictions that are within the range of values, for a given scenario, provided by a limited series of replicate validation tests. For DETACT-QS the output parameters evaluated will be the detector actuation time, the fire plume and ceiling jet gas temperature and the detector temperature. One possible result of the evaluation may be a combination of geometries and heat release rates where model predictions yield "reasonable agreement" with the test data.

Summary

The summary section will contain a summary of the analysis and a list of limitations and guidelines for use of the model. This section of the evaluation is targeted at a wide audience to include qualified users as well as non-users who may need to evaluate building designs based on the output of the model.

How ASTM Has Helped

ASTM assisted this evaluation in a number of invaluable ways. Before the task group could evaluate a model, they needed to decide *how* to evaluate the model. It was extremely beneficial to have ANSI-approved procedures to follow instead of having to develop their own procedures.

Secondly, the 1992 version of ASTM E-1355 was not as extensive as the 1996 draft. ASTM provided a draft standard to SFPE for use by the task group during their evaluation. This facilitated the task group by providing more detail in how an evaluation should be conducted without having to wait until the next edition of ASTM E-1355 was published.

The ASTM Standard Guide on Documenting Computer Software for Fire Models (ASTM E 1472) defines minimum information that should be provided in a model's documentation. Although not used in this evaluation since DETACT-QS was written before publication of ASTM E 1472, this standard will be useful in evaluating the adequacy of documentation in future model evaluations.

The definition of a common set of terminology related to fire modeling, both in ASTM E 1355 and in the ASTM Terminology Related to Fire Standards (ASTM E 176) ensures that terminology is used in a consistent manner.

Additionally, the ASTM Standard Guide for Data for Fire Models (ASTM E1591) provides useful guidance to model users for determining applicable input data for specific model runs.

How ASTM Can Help

A standard on reporting of fire test data would be useful. During the evaluation, it was occasionally difficult to compare data from different test series. For example:

- Data would be reported graphically in some test series and numerically in others, where the scale of the graph made it difficult to accurately interpret data.
- Greater detail regarding test instrumentation would be helpful, particularly for items that are not standard "apparatuses" (e.g., thermocouples, sensors, etc.)

An ASTM standard on reporting of fire test data would alleviate these difficulties and ensure that data from different test series or from different labs could be considered on the same basis.

Summary

There will be increasing need for reliable calculation methods and data as fire protection engineering evolves from specification-based to performance-based. Organizations such as SFPE and ASTM can facilitate this evolution by activities such as those mentioned in this paper.

References

1 *Proceedings*, Conference on Firesafety Design in the 21st Century, May 8-10, Worcester Polytechnic Institute, Worcester, Massachusetts.

2 Evans, D.D., and Stroup, D.W., *A Method to Calculate the Response Time of Heat and Smoke Detectors Installed Below Large Unobstructed Ceilings, NBSIR 85-3167*, U.S. National Institute of Standards and Technology (formerly National Bureau of Standards), Gaithersburg, MD, 1985.

3 Vettori, R. *Effect of an Obstructed Ceiling on the Activation Time of a Residential Sprinkler, NISTIR 6253*, National Institutes of Standards and Technology, Gaithersburg, MD: 1998.

4 Sheppard, D. "Fire Environment Tests Under Flat Ceilings," Underwriters Laboratories, Northbrook, IL: 1997.

5 Sheppard, D. "Fire Environment Tests Under Flat Ceilings," Underwriters Laboratories, Northbrook, IL: 1998.

6 NFPA 72, *National Fire Alarm Code*, National Fire Protection Association, Quincy, MA: 1993.

7 Mowrer, F. & Williamson, R. "Estimating Room Temperatures from Fires Along Walls and in Corners," *Fire Technology*, Vol. 23, May 1987.

Eric R. Rosenbaum[1]

The SFPE Design Guide for Performance-Based Design: A Key Element in Performance-Based Fire Codes and Standards

Reference: Rosenbaum, E. R., **"The SFPE Design Guide for Performance-Based Design: A Key Element in Performance-Based Fire Codes and Standards,"** *ASTM's Role in Performance-based Fire Codes and Standards, ASTM STP 1377*, J. R. Hall, Jr., Ed., American Society for Testing and Materials, West Conshohocken, PA, 1999.

Abstract: Performance-based codes are currently a part of the regulatory landscape. In order to develop a methodology to perform performance-based designs (PBD), the Society of Fire Protection Engineers (SFPE) with the assistance of a grant from the National Fire Protection Association (NFPA) has developed *The SFPE Design Guide for Performance-Based Design*. The following issues will be addressed as they relate to the SFPE Design Guide: (1) the status of performance-based codes, (2) the status and content of the SFPE Design Guide, (3) the interrelation of the SFPE Design Guide and ASTM Standards, and (4) areas that need to be addressed further in order to assist the fire protection engineers in PBD.

The model building codes and NFPA all required PBD for certain areas and allow PBD as a viable alternative to prescriptive codes. In an effort to standardize an approach to PBD, the SFPE has developed a Design Guide. ASTM Standards correlate with the design guide. In addition, ASTM Standards provide tests that allow the collection of data for input into the PBD process. The most important advancement for ASTM Standards is to further develop, standardize, and increase the amount of information available from small, intermediate, and large scale tests and to coordinate the data with criteria demanded in the PBD process and approaches recommended by fire protection engineers.

Keywords: performance-based design, building codes, design process, international building codes

[1]Director, A&E Services, Hughes Associates, Inc., 3610 Commerce Drive, Suite 817, Baltimore MD 21227-1652

Introduction

Performance-based codes are currently a part of the regulatory landscape. In order to develop a methodology to perform performance-based designs (PBD), the Society of Fire Protection Engineers (SFPE) has developed *The SFPE Design Guide for Performance-Based Design* (hereafter referred to as the SFPE Design Guide) [1].

The following issues will be addressed as they relate to the SFPE Design Guide:

1. The status of performance-based codes,
2. The status and content of the SFPE Design Guide,
3. The interrelation of the SFPE Design Guide and ASTM Standards, and
4. Areas that need to be addressed further in order to assist the fire protection engineers in PBD.

The SFPE Design Guide was developed by a task group with the assistance of (1) a grant from the National Fire Protection Association (NFPA) and (2) the efforts of the SFPE.

Status of Performance-Based Codes

Performance-based codes are used throughout the world. Several examples exist of criteria that utilizes the expanding knowledge of the science behind fire protection engineering. In Europe, Australia, New Zealand, and several other areas performance criteria are utilized for the evaluation of fire safety within a structure. In the United States, the application of performance criteria has always been available through equivalency approaches. However, explicit allowance of PBD as code compliance is provided in many jurisdictions.

An example of PBD in the United States is smoke control analysis. NFPA Standard 92B (1995) and two of the model building codes mandate some form of performance-based analysis of smoke control systems.

NFPA Standard 101 (1997), "The Life Safety Code," and the International Codes Council (ICC) are in the process of allowing performance-based approaches to demonstrate compliance with the Code. If adopted, the 2000 edition of NFPA 101 and the ICC will provide explicit criteria that allows the PBD approach in lieu of compliance with the criteria in the majority of the other sections of the code.

Other examples of PBD include

1. Guidance for fire detector spacing in NFPA 72 (1996),
2. Hanger criteria in NFPA 13 (1996), and
3. Sprinkler system design criteria in NFPA 13D (1996).

The Status and Content of the SFPE Design Guide

SFPE Design Guide Purpose

In order to document a procedure for executing PBD, the SFPE determined that a SFPE Design Guide would be developed. The purpose of the SFPE Design Guide is to outline a process to fire safety engineering. A "qualified engineer" is the target audience for the SFPE Design Guide. However, it is also anticipated that others may use the guide (e.g., Authorities Having Jurisdiction) to verify that an approach presented follows a logical approach. A "qualified engineer" is defined as follows [1]:

> "An engineer, by education, training and experience: (1) possesses a working knowledge of the nature and characteristics of fire and related hazards as well as how fires originate, develop and spread; (2) understands hazards and risk; (3) understands fundamental fire prevention, detection, control and extinguishment systems and practices, including the role of manual fire response; and (4) understands the impact of fire and fire effluents on buildings, processes, systems, and people."

Development Process for SFPE Design Guide

The approach utilized to develop the SFPE Design Guide originated with the establishment of a task group. The task group included engineers from around the world. Membership was open and all that requested to participate were allowed.

The initial assignment of the task group was to review existing fire protection engineering guidelines from within North America and around the world in order to limit duplication of efforts. International guides reviewed included the Nordic [2], Australian [3], and New Zealand [4] documents. After these documents were reviewed a draft outline was produced that was then expanded into the first draft of the SFPE Design Guide by regional subgroups. Since the original draft, the SFPE Design Guide has undergone three review cycles including several task group meetings, which reviewed the document in detail.

In January 1999, the SFPE Design Guide was released for public comment. Comments were received and are being processed by the task group. A final document is expected to be available in the summer of 1999.

Content of SFPE Design Guide

The SFPE Design Guide defines a process for executing a performance-based design. The process is documented in (Figure 1). The process is essentially a methodology to solve a problem.

The initial step involves defining the project scope. Included in the scope is identifying building features desired, constraints, and people who have an interest in the project. One of the most important elements to the process is the determination of who

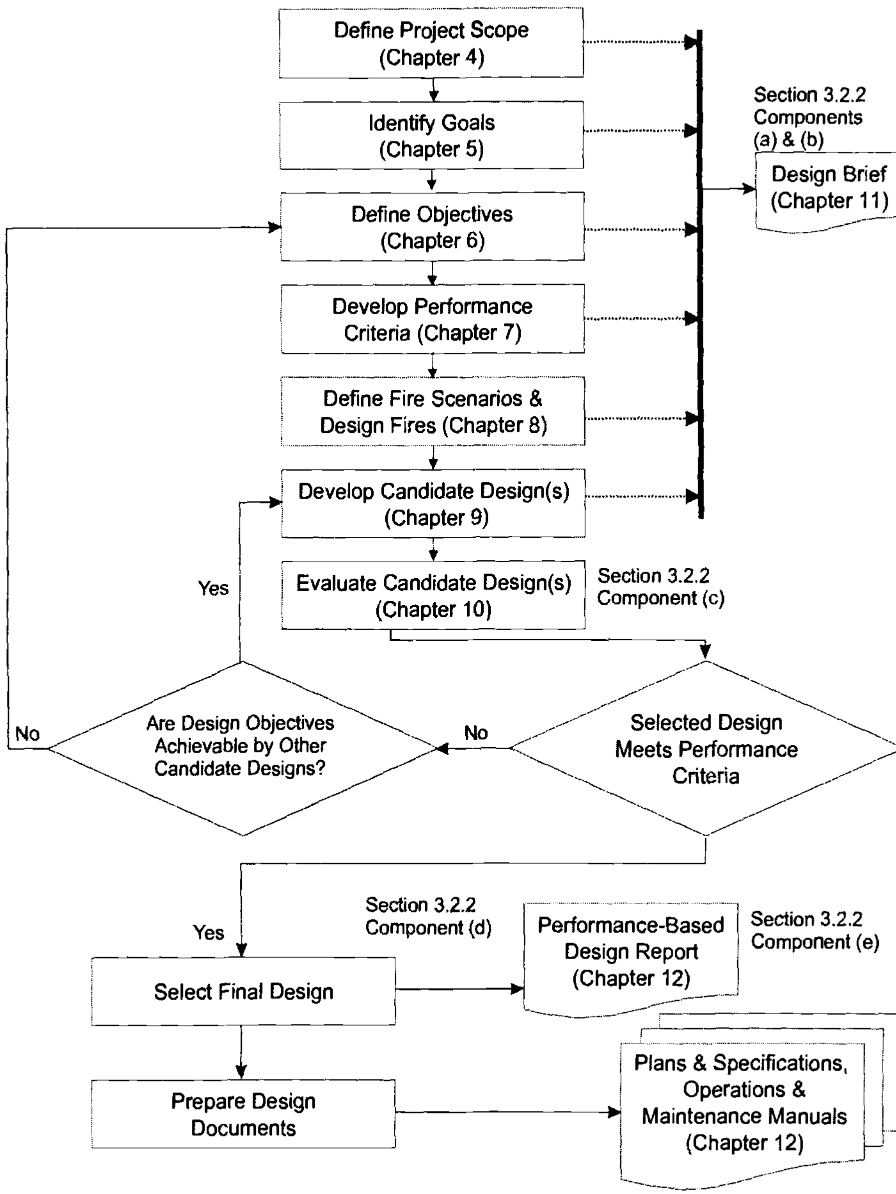


Figure 1- *Steps in the Performance-Based Analysis and the Conceptual Design Procedure for Fire Protection Design*

the interested parties, i.e. the stakeholders, are in the project. Potential stakeholders include the following:

- building owner
- building manager
- design team
- jurisdictional authorities
  - fire
  - building
  - insurance
- accreditation agencies
- construction team
  - construction manager
  - general contractor
  - sub contractors
- tenants
- building operations and maintenance
- fire service

Once the scope of the project is defined, the goals and objectives must be determined. The end result of the determination of the goals and objectives is that performance criteria must be established. The performance criteria are determined as a basis to evaluate the design. The criteria should be in terms that can be evaluated utilizing engineering methodology.

After establishing performance criteria, fire scenarios must be developed. Fire scenarios are the descriptions of possible fire events and consist of fire characteristics, building characteristics, and occupant characteristics. Fire scenarios are then filtered to determine which will be evaluated. For example, a trash can fire may be part of a fire scenario, but due to its limited relative impact to other scenarios, a trash can fire may not be evaluated. The evaluated fire scenarios are labeled as design fire scenarios.

Preliminary designs to address fire safety issues are then developed and are called trial designs. Trial designs include fire safety systems, construction features, and/or personnel or process operations that are intended to result in meeting the performance criteria.

Trial designs are then evaluated against each design fire scenario. All trial designs that meet performance criteria can be considered as final design options. The final design can then be chosen from all successful trial designs based on cost, ease of installation, aesthetic qualities, or other factors.

Guidance on documentation of the analysis process and design approaches is provided throughout the guide. Documentation includes preparation of a design brief early in the process to document decisions of the stakeholders prior to the completed analysis. Preparation of a performance design report and operation and maintenance manuals are also discussed.

The SFPE Design Guide provides flowcharts, figures, guidance, and examples in each step of the process. The SFPE Design Guide also provides a matrix of the interaction of the various systems and potential evaluation parameters used as performance criteria. Guidance includes references to appropriate documents to obtain additional information on how to perform parts of the analyses. The guide does not mandate a specific approach or approve methodologies, but references appropriate resources such as the SFPE Handbook, NFPA Handbooks or Standards, and ASTM Standards.

The Interrelation of the SFPE Design Guide and ASTM Standards

The SFPE Design Guide and ASTM Standards interrelate at several levels. The overall approach documented in the SFPE Design Guide, ASTM E 1546-93, "Development of Fire-Hazard-Assessment Standards," and ASTM E 1776-96, "Development of Fire-Risk-Assessment Standards," provide overall guidance on an approach to performance-based analyses. The review of ASTM Standards is not meant to be exhaustive, but a potential overview of the document's interaction.

Global Correlation between the SFPE Design Guide and ASTM Standards

The SFPE Design Guide, ASTM E 1546-93 and ASTM E 1776-96, each define a process for performing a hazard or risk based analysis. The approach to analyzing a problem is expected to correlate relatively well between documents developed even by separate groups, (Figure 2) documents the correlation of the procedures established from the SFPE Design Guide and ASTM E 1546-93. The correlation of the two methods can result in an interpretation that allows the methodologies to be considered equivalent. More information is proposed to be provided in the SFPE Design Guide, but that is expected when one document is significantly greater in volume than the other is.

The different focus of the documents and the lack of criteria on documentation in ASTM E 1546-93 are the significant differences. The SFPE Design Guide primarily applies to the analysis of buildings. ASTM E 1546-93 focuses on the hazard assessment of products and has a more microscopic approach for specific product related items. However, the SFPE Design Guide addresses all the pertinent issues identified and more. In addition, the SFPE Design Guide provides guidance on documentation of the analysis as the procedure progresses.

ASTM Standards potentially provide input or assistance to three of the process steps identified in the SFPE Design Guide:

1. Develop Performance Criteria,
2. Develop Design Fire Scenarios, and
3. Evaluate Trial Designs.

The primary area that ASTM Standards provide input to is "Evaluate Trial Designs." Many of the ASTM tests provide a measure of potential hazard associated with a product. Some of these test data can be specifically applicable to a performance-based analysis of a situation. Many of the fire test standards recognize their usefulness as

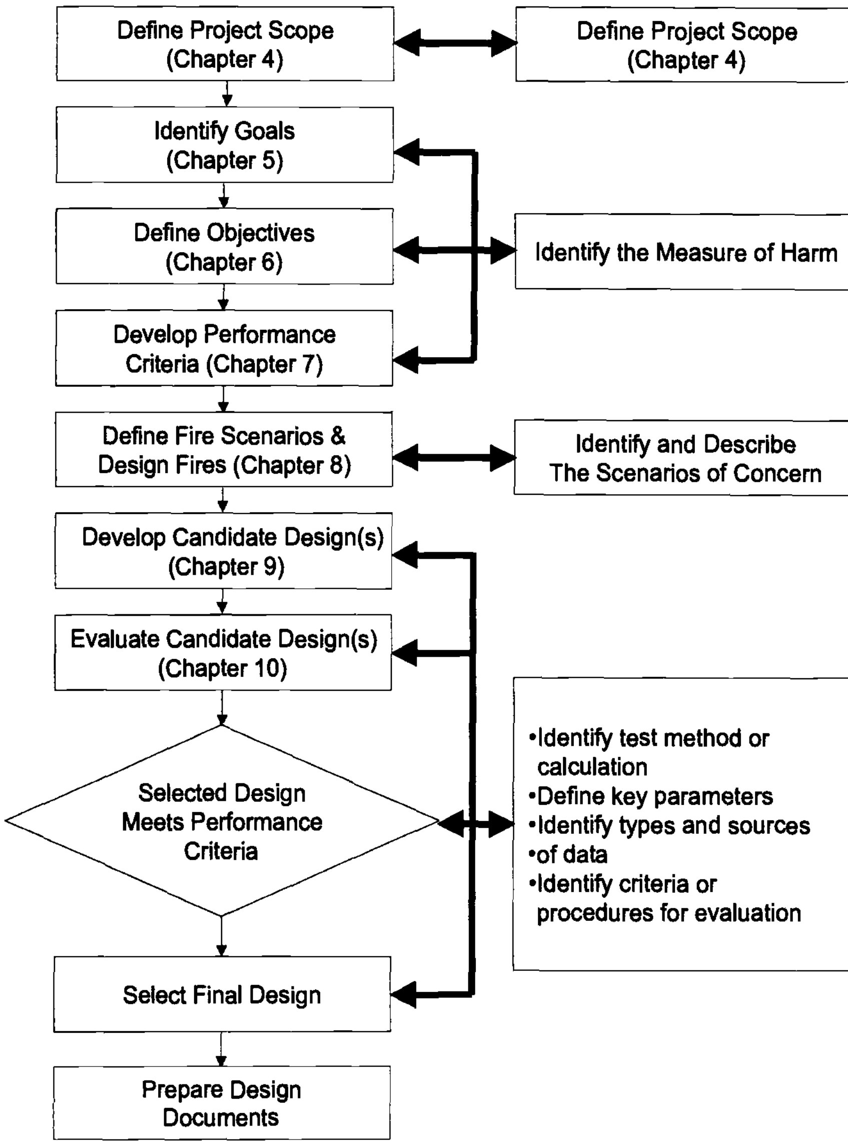


Figure 2 – *Correlation of Procedures Established in SPFE Design Guide and ASTM E 1546-93*

inputs to a performance-based design as documented in the following statement in the Scope section of the standards:

> "This Standard should be used to measure and describe the response of materials, products, or assemblies to heat and came under controlled conditions and should not be used to describe or appraise the fire-hazard or fire-risk of materials, products, or assemblies under actual fire conditions. However, results of the test may be used as elements of a fire-hazard assessment or a fire-risk assessment which takes into account all of the factors which are pertinent to an assessment of the fire hazard or fire risk of a particular end use."

For example, the following test standards provide data or methodologies that can be utilized:

1. ASTM E 1354-97, "Heat and Visible Smoke Release Rates for Materials and Products Using an Oxygen Consumption Calorimeter," provides input for analysis of fire hazards created by burning of specific fuels;
2. ASTM E 119-98, "Fire Tests of Building Construction and Materials," provides input information on how to obtain data (i.e., temperature across a member) and how certain building assemblies respond to a specific fire scenario; and
3. ASTM E 800-95, "Measurement of Gases Present or Generated During Fires," provides input to methodologies that identify gases of concern for fire scenarios.

The development of test standards that allow the gathering of data for a PBD is the primary area of assistance that ASTM can provide the practicing fire protection engineer.

Other ASTM Standards also provide assistance in the evaluation of candidate designs. ASTM E 1591-94 discusses data for fire models. ASTM E 1355-97 discusses the predictive capability of fire models. ASTM E 1895-97 discusses uses and limitations of fire models. All of these Standards may assist the engineer in the PBD. However, all of this data should be available from the documentation available in primary references or is more the responsibility of the practicing engineer to verify.

Developing performance criteria and developing design fire scenarios are other potential areas of needed information on which ASTM Standards may provide guidance. For example, ASTM E 119-98 establishes failure criteria for construction assemblies. ASTM E 1529-93 establishes a temperature exposure for a hydrocarbon pool fire. Once again, all of these data should be available from the documentation available in primary references or is more the responsibility of the practicing engineer to verify.

In summary, ASTM Standards that provide a methodology to obtain data and results that can be utilized by a fire protection engineer are important elements to a PBD.

Areas That Need to Be Addressed Further in Order to Assist the Engineers in PBD

The SFPE Design Guide and ASTM Standards provide necessary inputs to the PBD process. Significant amounts of other information are required in order to support the capabilities of the fire protection engineer. Additional information required includes the following:

1. Validation of fire models;
2. Recommended approaches for calculations of hazards,
3. Development of hazard limits or pass/fail criteria for fire scenarios in different performance areas;
4. Developing, standardizing, and increasing the amount of information available from small, intermediate, and large scale tests; and
5. Coordinating the data available from tests with criteria demanded in Items 1-3.

Items 1-3 are goals of current or future SFPE task groups. Item 4 and 5 are the area of expertise of ASTM. The interaction of these two societies should develop PBD for the next decade.

Summary

PBD is a part of the regulatory environment. The model building codes and NFPA all required PBD for certain areas and allow PBD as a viable alternative to prescriptive codes. In an effort to standardize an approach to PBD the SFPE has developed a Design Guide. ASTM Standards correlate with the design guide. In addition, ASTM Standards provide tests that allow the collection of data for input into the PBD process. The most important advancement for ASTM Standards is to further develop, standardize, and increase the amount of information available from small, intermediate, and large scale tests and to coordinate the data with criteria demanded in the PBD process and approaches recommended by fire protection engineers.

References

[1] Society of Fire Protection Engineers, "The SFPE Engineering Guide to Performance-based Fire Protection Analysis and Design -- Draft for Comments," The SFPE Task Group on Performance-based Analysis and Design, Society of Fire Protection Engineers, Bethesda, MD, December 1998.

[2] Nordic Committee on Building Regulations, NKB Fire Safety Committee, *Performance Requirements for Fire Safety and Technical Guide for Verification by Calculation*, NKB Committee and Work Reports, 1994:07 E, Monila Oy, Helsinki, 1995.

[3] Fire Code Reform Centre Ltd, *Fire Engineering Guidelines*, Standards Australia, Strahfield, Australia, 1996.

[4] Centre for Advanced Engineering, *Fire Engineering Design Guide*, A.H. Buchanan, Ed., University of Canterbury, Christchurch, New Zealand, July 1994.

John M. Watts, Jr.[1]

The Role of ASTM Standards in NFPA Performance-Based Codes

Reference: Watts, J. M., Jr., "**The Role of ASTM Standards in NFPA Performance-Based Codes**", *ASTM's Role in Performance-Based Fire Codes and Standards, ASTM STP 1377*, J. R. Hall, Jr., Ed., American Society for Testing and Materials, West Conshohocken, PA, 1999.

Abstract: The National Fire Protection Association (NFPA) develops full-consensus codes and standards in a process that differs in several ways from ASTM. They have recently established an initiative to develop performance-based options for NFPA documents. The most visible effort to date is the promulgation of a proposed performance-based approach for NFPA 101, the *Life Safety Code*®. This paper introduces the NFPA code writing process and its performance-based activities. The performance-based option for the year 2000 edition of the *Life Safety Code*® is outlined, indicating where ASTM standards are referenced. Experience with developing this product has identified several obstacles in the evolution of performance-based fire safety codes. Proposals are suggested for considering these obstacles as opportunities for ASTM standards development.

Keywords: ASTM, codes and standards, fire safety, life safety, NFPA, performance-based

Introduction

The National Fire Protection Association (NFPA) is a nonprofit organization with approximately 68,000 members. Membership represents a broad range of interests including fire officials, firefighters, building officials, manufacturers, insurance representatives, design architects, engineers, educational institutions, varied government officials, fire researchers, and practically anyone who has an interest in fire safety. About ten percent of the membership is from outside the United States, representing more than seventy countries. Basic technical activity of NFPA involves development, publication, and dissemination of current consensus standards. The more than 291 NFPA technical documents are developed by 211 Technical Committees made up of more than 5500 individuals.

[1]Director, Fire Safety Institute, P.O. Box 674, Middlebury, VT 05753, USA, www.middlebury.net/firesafe

Code- and Standard-making Process

The process for promulgating and changing NFPA technical documents is summarized in Figure 1. A proposal for a new document or a change to an existing document may be submitted by any interested individual. The appropriate technical committee will discuss, develop, and revise the proposal. It will then vote on adoption of the proposed or revised standard. The document and results of the committee's vote are then published in a semiannual report identified as "Report on Proposals". A copy of this report is made available to any interested party. Each recipient of the report is encouraged to submit their views on the document in a comment with appropriate explanation. The committee then acts on each of these comments to accept it or reject it. Accepted comments may also be revised by the committee. In any case, every comment received along with the corresponding action by the committee is then published in a second document, identified as "Report on Comments".

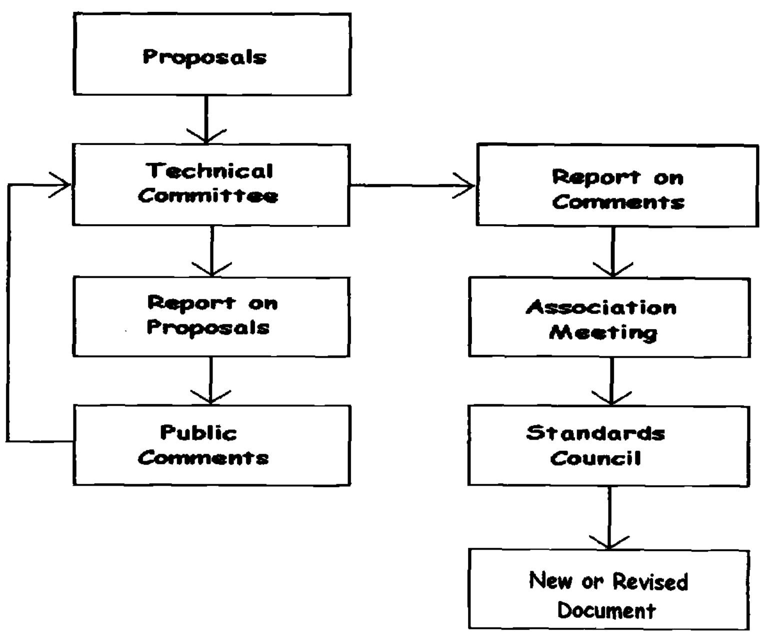


Figure 1 - *NFPA document process*

Again, a copy of the Report on Comments is made available to interested parties. Submitters of comments then have the right to present their comment to the Association members at either the annual (spring) or fall meeting where the committee's report will be voted on by the body of assembled members. Usually, members will endorse action of the technical committee, for it is understood that the technical committee should have both the thoroughness and expertise to deal with that particular subject. Yet, many times the body assembled will favorably receive a motion based on a comment from the floor and reverse a technical committee action. A thirteen-member Standards Council that reviews procedural actions of committees and reports to the Board of Directors of the NFPA makes the final determination for issuance of a new fire standard or revision of an existing one.

Performance Initiative

In 1993, NFPA established an in-house task group to study the implications of performance-based design and NFPA's role in the development of performance codes and standards [*1*]. In consequence of this study, NFPA is pursuing a dual-track approach for its codes and standards. Many future NFPA documents will include both performance-based and prescriptive-based options. Maintaining both prescriptive and performance options within a single document is intended to formalize the options, keep both approaches on a par, and encourage mutual improvements in the codes and standards [*2*].

In the future, NFPA documents will include sections on fire safety goals, objectives, assumptions, fire scenarios, and evaluation. While incorporation of these elements is prompted by the development of the performance-based option, many of these aspects will also apply to the prescriptive option and their consideration will help the prescriptive requirements to become more scientifically based.

NFPA intends to pursue a managed evolution in the development of codes and standards with performance-based options, however, the ultimate pace is subject to availability of appropriate evaluation tools. It is recognized that other groups have more experience in some aspects of performance-based design. NFPA is actively seeking partners to assist with those areas of special expertise and expects to rely on documents from other organizations to address aspects such as guidance on calculation methods and models [*3*].

The incorporation of formalized performance-based options into NFPA codes and standards lies with the respective technical committees. However, NFPA has created an infrastructure to provide overall support for committees pursuing a performance-based option. A performance-based support team has been established that also serves as an agent of the Standards Council. The staff support team will provide technical support to committees, encourage a degree of consistency among documents, provide orientation briefings to interested parties, and produce guides and other technical aids, e.g., [*4,5*].

No timetable exists for incorporating performance-based options in NFPA documents [*6*]. Any NFPA Technical Committee can pursue this option. The Committee that has been working the longest and hardest on development of a performance-based approach is the Technical Committee on Life Safety Fundamentals [*7*].

Life Safety Code

Similar to the model building codes but unique in several ways, is the National Fire Protection Association's *Life Safety Code* (NFPA 101, *Code for Safety to Life from Fire in Buildings and Structures*, 1997 Edition). The *Life Safety Code* is a product of the NFPA Committee on Safety to Life, first appointed in 1913 after the disastrous Triangle Shirtwaist fire that killed 146 factory workers in 1911. The Committee's first standard was the 1918 *Factory Exits Code*. This was shortly followed by publication of a *School Exits Code and* subsequently, a *Department Store Exits Code*. The requirements for these and other occupancies were combined with specifications for building construction and automatic fire protection into the *Buildings Exit Code* adopted and published in 1927. During the next thirty-seven years, there were eighteen published revisions of this code, greatly expanding its content. Various additional studies of fire disasters, most notably the 1942 Coconut Grove night club fire in Boston, led to significant revisions. In 1963 the document was reorganized and renamed the *Code for Safety to Life from Fire in Buildings and Structures*, or simply, the *Life Safety Code*. Since then, there have been an additional ten new editions that bring us to the 1997 edition in effect today.

Now, a significant change is proposed for the year 2000 edition to develop a performance-based alternative for the *Code*. The NFPA Technical Committee on Life Safety Fundamentals proposed a preliminary version of a performance-based life safety code in 1996 [*8*]. This committee has fire protection engineers, code enforcement officials, and persons with special expertise and has now developed a proposal for a performance-based design option in the *Code*. Their work follows the guidelines proposed by the NFPA in-house Task Group on Performance-Based Codes and Computer Fire Models and has been greatly assisted by the Performance-Based Support Team.

In the performance-based design option, fire safety goals and objectives are translated into performance criteria. Fire models and other calculation methods are then to be used in combination with the building design specifications, specified fire scenarios, and explicit assumptions, to calculate whether the performance criteria are met. If the criteria are met, then compliance with the *Code* under the performance-based design option has been achieved.

Goals and Objectives

Explicit statements of the goals and objectives of the *Code* are provided up front, in Chapter 1 of NFPA 101. The goal statements are:

1. The goal of this *Code* is to provide an environment reasonably safe from death and injury in fire and similar emergencies by (a) protecting occupants not intimate with initial fire development, and (b) improving the survivability of occupants intimate with initial fire development.

2. A goal is also to provide for reasonable safe emergency and nonemergency crowd movement where applicable.

The objectives that are to be achieved to meet these goals cover occupant protection, structural integrity, and system effectiveness. The three stated objectives of the *Life Safety Code* are:

1. A structure shall be designed, constructed and maintained to protect the occupants not intimate with the initial fire development for the time needed to evacuate, relocate, or defend in place.

2. Structural integrity shall be maintained for the time needed to evacuate, relocate, or defend in place the occupants not intimate with the initial fire development.

3. Systems utilized to achieve the goals shall be effective, maintained, and operational.

Design Options

In the NFPA dual-track approach, there are two design options to accomplish the stated goals and objectives. In the prescriptive-based design option, compliance is achieved by meeting the requirements of specified construction characteristics, limits on dimensions, protection systems, or other features, but without explicit reference to how these provisions collectively achieve the explicitly stated fire safety goals. With the new performance-based design option, compliance is achieved by showing that a proposed design will meet specified fire safety goals using appropriate evaluation methods.

The performance-based design option is delineated in a separate chapter of the *Code* and consists of nine sections; General Requirements, Performance Criteria, Design Specifications, Assumptions, Scenarios, Data, Methods for Assessing Performance, Safety Factors, and Documentation. Each of these will be discussed briefly.

1. General Requirements

The introductory section of the performance-based option includes aspects such as verification through third-party review and definitions specific to the performance-based approach.

2. Performance Criteria

The performance objectives of the *Code* require that measurable life safety criteria be stated. These were developed in terms of time and incapacitation. To meet the specified design objectives, each occupant's calculated time to move to a safe location must be less than that occupant's time to incapacitation. The time to incapacitation for an occupant is calculated as that occupant's time to reach a fractional effective dose (FED) of 1.0, calculated according to NFPA 269, *Standard Test Method for Developing Toxic Potency Data for Use in Fire Hazard Modeling*, 1996 edition.

3. Retained Design Specifications

An important consideration in the transition from prescriptive to performance-based codes is the completeness of the treatment. Many specific requirements in the *Life Safety Code* are not readily addressed by the commonly available computer models and calculation methods. This section of the performance-based design chapter identifies prescriptive requirements that will be needed to fill gaps not covered by current modeling techniques. These include changes in level in means of egress, guards, doors, stairs, ramps, fire escape ladders, alternating tread devices, capacity of means of egress, impediments to egress, illumination of means of egress, emergency lighting, and marking of means of egress.

These are items that are intuitively significant and may have scientific validity at a component level, but they are unsubstantiated as to the level of their value to life safety as a system, e.g., the prescriptive detail of stair construction has no established quantitative relationship to life safety from fire. (An implicit assumption of present codes is that stairs designed for safe normal use are optimal in an emergency.) Such requirements must continue to be specifically addressed in the *Code* until they are incorporated into the modeling and calculation procedures used to determine system performance. If ASTM were to develop standards that defined these life safety components, they would be widely referenced by many performance-based codes. Such standards might be similar to ASTM E 985 - 96, *Standard Specification for Permanent Metal Railing Systems and Rails for Buildings*.

4. Assumptions

Assumptions regarding characteristics of the building or its contents, equipment, or operations not inherent in the design specifications, but that affect occupants' behavior or the rate of hazard development need to be explicitly identified. These include assumptions about the building dimensions, construction materials, furnishings, spatial geometry, number of openings and sizes of openings, and other details that are input into calculations or models. Such assumptions may be necessary to decide how quickly fire and its effects will spread (e.g., doors normally open vs. normally closed). Issues of reliability are a major part of this group of assumptions.

One of the most important sets of assumptions in the performance-based approach to life safety defines the occupants at risk. Assumed characteristics of the buildings occupants that affect rates of response, susceptibility to products of combustion, and rate of travel must be explicitly identified. Assumptions regarding occupants are needed so that the assessment can calculate for each occupant whether, and if so when, the occupant will act in response to the fire; what actions the occupant will take and how effectively, with particular attention to speed of movement; and any occupant characteristics that affect survivability, e.g., fire conditions that will lead to loss of life [9]. A guide on occupancy classification for performance-based design is needed. One place to start would be the recently discontinued ASTM E 931 - 94, *Standard Practice for Assessment of Fire Risk by Occupancy Classification.*

Another category of assumptions are those regarding emergency response personnel. Prescriptive codes ignore the services of the local fire department. When outside emergency services are included in a performance design proposal, stating assumptions regarding the availability is necessary, speed of response, effectiveness, roles, and other characteristics of the emergency response.

5. Scenarios

Fire scenarios provide the fire challenge or "load" against which one determines whether the performance criteria are met. Fire models and other calculation methods are used to determine whether the building design will achieve the performance criteria, given each of the fire scenarios. The scenarios are generated from a set of code specified initial fire conditions that are critical to the outcome of a fire. These include location and early rate of heat or smoke development. A guide to the development of fire scenarios for performance evaluation of buildings would be a critical document that ASTM could develop.

6. Data

A complete listing of input data requirements for all models, engineering methods, and other calculation or verification methods required or proposed as part of the performance-based design is required. It is specified in the performance-based design option that input data for computer fire models should be obtained according to ASTM E 1591- 94, *Standard Guide for Data for Fire Models*. A similar guide for evacuation models is necessary.

7. Methods for Assessing Performance

This section identifies appropriate characteristics of fire models and calculation methods selected to evaluate performance. A fire model is a structured approach to predicting one or more effects of a fire. Due to the complex nature of the principles involved, models are often packaged as computer software. Attached to the fire models will be any relevant input data, assumptions and limitations needed to implement the model properly.

Calculation methods are tools that permit a proposed solution to be assessed regarding the applicable fire safety goals, assumptions and fire scenarios. Calculation methods contain scientific and mathematical relationships needed to model the behavior of certain aspects of a fire event, such as the growth and spread of the fire, the generation of harmful products, the response of fire protection systems, the behavior of occupants or others, or the impact of the fire on exposed people or property. Calculation methods are useful in codes and standards if they permit the user to assess whether or predict when a critical event will be reached (e.g., the achievement of the fire safety goals or the failure of the fire safety design).

It is not deemed appropriate for the *Life Safety Code* to prescribe specific methods by name. Instead, the *Code* directs users to appropriate sources of accepted engineering practices for performing the needed calculations. When the performance objectives and criteria, and the input data of scenarios, assumptions, and the proposed design itself are stated explicitly and quantitatively, modeling can be used to predict performance.

It is anticipated that the fire protection engineering community will develop resources, in a form suitable for reference by the *Code*. Then a user will take from the *Code* clear guidance on the performance outcome values that need to be calculated and the input data to be developed and used, and will take from the fire protection engineering resources clear guidance on how to predict performance outcomes from input data.

Before a particular fire model or calculation method is used, its purpose and limitations must be known. The technical documentation needs to identify any assumptions included in the evaluation clearly. The models and methods used to evaluate performance should be appropriate to the fire scenarios selected. Use and limitations of fire models can be determined according to ASTM E 1895 - 97, *Standard Guide for Determining Uses and Limitations of Deterministic Fire Models*. A similar guide for evacuation models would be appropriate.

8. Safety Factors

A safety factor is an adjustment made to reflect uncertainty in the assumptions made, the tools and methods used, and the limiting value of a parameter or item being measured. Safety factors may be present in many components of an analysis or design. Careful attention should be given to both the lack of safety factors and the possibility that multiple safety factors are present. Safety factors are used to account for uncertainty in assumptions, single-valued data, and deterministic models.

Computer fire models should be evaluated for their predictive capability according to ASTM E 1355 - 97, *Standard Guide for Evaluating the Predictive Capability of Fire Models*. Such evaluation should include scenarios specific to the application and may require a sensitivity analysis be conducted to study the impact of variation of assumptions or input data. A similar guide for evacuation models is necessary. There is also a need for explicit guidance in developing safety factors for performance-based fire safety design. Perhaps this could evolve from ASTM E 1369 - 93, *Standard Guide for Selecting Techniques for Treating Uncertainty and Risk in the Economic Evaluation of Buildings and Building Systems*.

9. Documentation

A performance-based design option needs to be documented in a manner acceptable to the authority having jurisdiction. Documentation to be included with a performance-based design submitted for approval covers the people and the process. The performance-based design should be prepared by persons with qualifications acceptable to the authority having jurisdiction. These qualifications should include experience, education, and credentials that show knowledgeable and responsible use of applicable models and methods. There are also specific requirements to document the design evaluation process as described above. Fire models are specified to be documented following ASTM E 1472 - 92, *Standard Guide for Documenting Computer Software for Fire Models*, where applicable. A similar guide for evacuation models would facilitate evaluation of performance-based designs.

Summary

A performance-based design option has been proposed for the year 2000 edition of NFPA's *Life Safety Code*. The *Code* outlines essential components to be addressed in demonstrating that a proposed design will meet the specified fire safety goals and objectives. The performance-based alternative will provide the authority having jurisdiction with guidelines while not unduly restricting the flexibility of the designer. The proposed procedure has not been pilot or field tested *per se*, but is considered representative of current performance-based design practice. Current equivalency concepts would apply to both the prescriptive-based and performance-based design options. It is the intent of the *Life Safety Code* to facilitate more widespread acceptance of performance-based fire safety design.

These proposed revisions to the *Life Safety Code* appear in the "Report on Proposals for the 1999 Fall Meeting" [*10*], which is available to the public from NFPA. Comments on the proposal will be reviewed by the Committee and a Report on Comments will be issued prior to the vote by the NFPA membership at the Fall Meeting next year. If approved, the performance-based option in NFPA 101 will be released in January 2000.

Lack of consistency in criteria, parameters, and documentation can inhibit acceptance of performance-based fire safety design. Standardizing some aspects of performance-based design can facilitate the review process. The more codified the process is, the more readily acceptable to the authority having jurisdiction.

There are several specific areas in which guidance documents such as those presently promulgated by ASTM would enhance the development of NFPA performance-based codes. These include:

- Standard guides for evacuation models (uses and limitations, data, predictive capability, and documentation).
- Standards on life safety products and components that are not part of a performance model (e.g., stairs, ramps, fire escape ladders, alternating tread devices, illumination of means of egress, emergency lighting, marking of means of egress, etc.)
- Standard for classification of building occupancy for performance-based fire safety design.
- Standard for development of fire scenarios for performance evaluation of buildings.
- Standard for developing safety factors for performance-based fire safety design.

References

[1] "NFPA's Future in Performance-Based Codes and Standards: Report of the NFPA in-house Task Group", National Fire Protection Association, Quincy, MA, July 1995.

[2] Puchovsky, Milosh, "NFPA's Objectives in Pursuing Performance-Based Codes and Standards", Proceedings, 1996 International Conference on Performance-Based Codes and Fire Safety Design Methods, Society of Fire Protection Engineers, Boston, 1997, pp. 181-187.

[3] Puchovsky, M.T., "Developing Performance-Based Codes One Step at a Time", NFPA Journal, Vol. 90, No. 1, 1996, p. 46.

[4] "Performance-Based Primer #1, Goals, Objectives, and Criteria", National Fire Protection Association, Quincy, MA, September 1997.

[5] "Performance-Based Primer #3, Fire Scenarios", National Fire Protection Association, Quincy, MA, September 1998.

[6] Puchovsky, Milosh, "Performance-Based Fire Codes and Standards", Section 10, Chapter 13 in A.E. Cote, Ed., *Fire Protection Handbook*, 18th ed., National Fire Protection Association, Quincy, MA, 1996.

[7] Beller, Douglas, "Overview of NFPA 101 Life Safety Code Performance-based Activities", Proceedings, Fire Risk and Hazard Assessment Research Application Symposium, National Fire Protection Research Foundation, June 1998.

[8] Watts, John M., Jr., "Performance-Based *Life Safety Code*", Proceedings, 1996 International Conference on Performance-Based Codes and Fire Safety Design Methods, Society of Fire Protection Engineers, Boston, 1997, pp. 159-169.

[9] Beller, D.K., and J.M. Watts, Jr., "Human Behaviour Approach to Occupancy Classification", Human Behaviour in Fire - Proceedings of the First International Symposium, University of Ulster, Northern Ireland, pp. 83-92.

[10] "Report on Proposals: For the 1999 Fall Meeting", National Fire Protection Association, Quincy, MA, 1998.

Beth A. Tubbs[1]

The ICC Performance Code Effort and Its Relationship to ASTM

Reference: Tubbs, B. A., **"The ICC Performance Code Effort and Its Relationship to ASTM,"** *ASTM's Role in Performance-Based Fire Codes and Standards, ASTM STP 1377,* J. R. Hall, Jr., Ed., American Society for Testing and Materials, West Conshohocken, PA, 1999.

Abstract: The International Code Council is working to develop a performance-based code system that will start with a clear definition of the intent of the code, followed by approved methodologies that allow the use of prescriptive codes and performance-based design. Standardized approaches to performance-based designs are lacking and many code officials are reluctant to allow the use of such a design; e.g. a design using a computer fire model for analysis. Groups like ASTM can play a vital role in formalizing the performance-based design process as it relates to fire. ASTM 1591, Guide for Data for Fire Models, provides a standardized methodology to evaluate data appropriateness for use in modeling. In the future, ASTM 1546, Guide for Development of Fire-Hazard-Assessment Standards, may provide a similar sense of security regarding fire-hazard-assessment methodologies.

Keywords: building performance code, approved methods, international code council, authoritative consensus documents, individually substantiated design methods.

Introduction

Much of the ICC performance initiative is heavily focused on setting up frameworks for a performance-based system to be successful. This paper will show in general terms how ASTM may play a role in ICC's efforts. A background as to the progress and direction of the ICC effort, a discussion on how compliance may be achieved under the performance-based code approach, and the potential relationship with ASTM in this effort will be provided. It should be noted that this paper is the opinion of the author and not necessarily that of the ICC Building and Fire Performance Committees.

Background

The International Code Council (ICC) was founded in 1994 with the mission of

---

[1]Staff Engineer, International Conference of Building Officials, 5360 Workman Mill Road, Whittier, CA 90601.

promulgating a comprehensive and compatible regulatory system for the built environment through consistent performance-based regulations that are effective and efficient and that meet government, industry and public needs. In keeping with their mission they formed two committees which are the Building Performance Committee and the Fire Performance Committee. The Building Performance Committee began its work in August of 1996 and has published a Preliminary Committee Report [1] which contains a draft code and commentary. The Fire Performance Committee began its work in August of 1997 and is currently in the process of drafting a Performance Fire Code and commentary. This draft is due to be released in the summer of 1999 in the form of a report.

The Building Performance and Fire Performance Committees are going in the same direction, both philosophically and in terms of the development process. The draft performance building code is more advanced in the process and so provides a clear illustration of the common direction both documents are following.

The performance building code can be divided into three main parts (Figure 1). Chapter 1 is the administrative portion of the code, which provides tools for designers and enforcers to ensure that the correct process is being utilized and the appropriate design methodologies are being applied. This portion of the code is equivalent to the administrative portion of a prescriptive building code but is geared towards a performance approach.

Chapter 2 sets a framework to determine the acceptable level of impact that events such as a fire, earthquake or a toxic gas release can have on a building. This particular portion of the code drives the overall design of the building, essentially setting performance design levels. It should be noted that Chapter 2 is where the link is made between the design and construction industry and the policy makers. The design and construction industry need guidance and feedback regarding what society expects from its buildings in order to put together criteria for a design methodology. This particular link is stressed, since the purpose of building codes is to provide health, safety, public welfare and a level of comfort that reflects society's needs. Such decisions should not be made by designers, but such information is necessary in order for design methodologies to be developed and applied.

The final portion of the document consists of Chapters 3 through 13, which set the qualitative, topic-specific intent statements for the code. This portion of the code essentially expands on the term "equivalent" used within the alternate materials and methods section of the prescriptive code. Chapters 3 through 13 are to be more closely linked with Chapter 2 in the future.

It is expected that a final report will be provided in the year 2000 by both the Fire and Building Performance Committees. It should also be noted that these committees have a significant amount of overlap. Both codes are interested in the prevention and management of fire, means of egress and hazardous materials.

Also, in a performance code environment, a building code will be more concerned with maintenance than the prescriptive approach has been in the past. This concern is related to looking at a building as a system rather than just a series of components. The two committees are aware of these overlap issues and will be addressing these links through a correlation committee.

Achieving Compliance

As noted the performance building code can be divided into three parts, including administration, performance design levels, and topic-specific intent statements. All three parts play an important role in the use of such a document, but the key element that provides the mechanism for application and enforcement of the document is the administrative portion. Also, the last part of the administrative component, acceptable methods, is the place where help from ASTM is most clearly relevant.

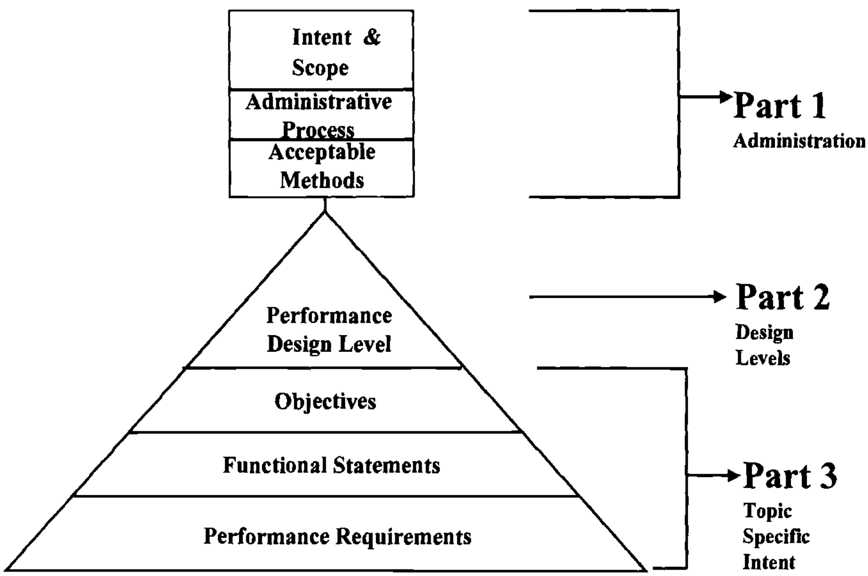


Figure 1 - *Three Part Structure of Performance Building Code*

The administrative component was felt to be essential to the success of a performance-based code system because it tells the designer how to prove and the enforcer how to check that the requirements of parts 2 and 3 have been met. In fact, in the current code system, it is already possible to do a performance-based design through the alternate materials and methods section. One of the stumbling blocks with that system is a lack of tools or guidelines concerning how the alternate design process is to occur [*2*].

Intent and Scope

The administrative provisions begin with intent and scope statements, similar to what is found in the current prescriptive codes. They simply provide guidance on what the code is intended to cover and to what extent. The intent and scope statements are as follows:

Intent - To provide a reasonable level of health, safety and welfare, and to limit damage to property from events that are expected to impact buildings and structures.

Accordingly, this code intends to provide for:

1. An environment free of unreasonable risk of death and injury from fires;
2. A structure that will withstand reasonable loads associated with the normal use, and wind, snow, flood or earthquake of the severity associated with the location in which the structure is constructed;
3. A design that provides reasonable means of egress and access;
4. Reasonable arrangements to limit the spread of fire both within the building and to adjacent properties;
5. Adequate ventilation and sanitation facilities to maintain the health of the occupants; and
6. Adequate arrangements for natural light, heating, cooking and other amenities needed for the comfort of the occupants [*1*].

Scope - To achieve its intent, this code provides requirements for buildings and structures and includes provisions for structural strength, stability, sanitation, means of access and egress, light and ventilation, safety to life and protection of property from fire and, in general, to secure life and property from other hazards affecting the built environment. This code includes provisions for the use and occupancy of all buildings, structures, facilities and premises, their alteration, repair, maintenance, removal, demolition, and the installation and maintenance of all amenities including, but not limited to, such services as the electrical, gas, mechanical, plumbing and vertical transportation systems [*1*].

Administrative Procedures

Next in the administrative section are the administrative procedures. These procedures essentially walk through the entire design, construction, inspection and maintenance process. More specifically, these provisions provide requirements for qualifications, the initial submittal, documentation, design review, construction, maintenance, and guidance for when a building is remodeled, renovated or added to or has a change of use.

First, the submittal provisions ask for specific information on methodologies used for each aspect of the design, ask where special inspections are necessary, and require that the submittals be coordinated by a single qualified person. Second, the documentation provisions require certain types of documents to be kept on the premises of the building to show that testing and verification have been completed in accordance with approved construction documents. For example, if a suppression system is part of the performance design, documentation related to its installation and subsequent maintenance may need to be kept on file. In addition, if there are any features of the building that, if changed, would alter the performance of the building, then documentation must be present for the life of the building.

Next, the review portion of the administrative provisions provides the mechanism by which verification of design compliance is accomplished, traditionally by the code official. Also, the concept of third-party or peer review is provided as an additional tool for the review process.

Another important aspect of a successful compliance process is assurance that the construction follows the approved design documents. This aspect is covered under the construction section, which requires consideration of verification tests and special inspections for systems, such as smoke control to demonstrate that they operate as designed.

The construction provisions essentially deal with quality assurance. The maintenance provisions require that the building be maintained to the approved construction documents. This section even goes as far as suggesting that the building owner be responsible for this maintenance. This concept is one that other countries utilize. Requiring the owner to make sure the maintenance is accomplished shifts the liability from the public officials, designers and contractors to the building owner. As noted, a performance building code will emphasize maintenance much more than will traditional prescriptive codes. Such maintenance may not simply focus on fire safety but could deal with systems such as HVAC.

Finally, this section requires that, if any changes are made to the building, the existing construction documents be evaluated and, if necessary, changed.

Many of the issues covered by the administrative process provisions are important in today's prescriptive code environment. In many ways, a performance-based code simply emphasizes the need for these activities to occur. Specifically calling out these issues within the code will provide more structure to the process. As noted, the lack of detail in the process guidelines is one of the weak links in the current section allowing alternate materials and methods in the prescriptive codes.

Acceptable Methods

The last portion of the administrative chapter provides a framework for determining whether a design methodology is acceptable. The section on acceptable methods provides several approaches that a designer can utilize in order to undertake a design. The first method is to use the prescriptive codes, such as the International Building Code™ [2] and associated codes. The second method is to use an "authoritative consensus document," which is defined in the draft performance code as the following:

Authoritative Consensus Document - A document containing a body of knowledge commonly used by practicing architects or engineers. It represents the state of the art including accepted engineering practices, test methods, criteria, loads, safety factors, reliability factors and similar technical matters. The document portrays the standard of care normally observed within a particular discipline. The content is promulgated through an open consensus process conducted by recognized authoritative professional societies, codes or standards organizations, or governmental bodies. These documents are normally adopted by reference by the International Codes[*1*].

The concept of an authoritative consensus document is that design methods that have undergone a suitable review and are thereby accepted as standard of practice should be accepted for design purposes in the respective technical fields. The advantage of having designated authoritative consensus documents is that jurisdictions will feel more

---

[2]International Code Council, Falls Church, Virginia

comfortable with documents that have been more widely accepted.

An offsetting concern is that a list of approved documents may inhibit innovative ideas and create a new form of prescriptive system. This concern can be addressed with flexibility, and so a second category of methods has been identified, "individually substantiated design methods." This allows recognition of newer, less widely used approaches if they satisfy certain criteria. In addition, some documents, such as handbooks, that are not developed through consensus processes, can be used.

It should be emphasized that the acceptable methods are simply methods and not design solutions. The actual design solutions must be evaluated on a case by case basis.

Additionally, part of choosing the appropriate design methodology is understanding the level of performance desired for the particular situation. As noted, Part 2 provides a framework to choose such design levels. This framework will create a demand for design methods that specifically link to these design levels. Because the framework is itself new, none of these compatible design methods have yet been constructed, except in the seismic design area.

Acceptable Methods and ASTM

The potential link between ASTM and ICC's performance-based codes initiative comes at the point where acceptable methods are identified. The acceptable methods are where the actual design occurs. As noted, in order to show compliance with the performance-based provisions of the code, one may choose a prescriptive approach, make use of an authoritative consensus document or an individually substantiated design method. Performance-based design methods, whether authoritative consensus documents or individually substantiated design methods, should ideally be linked with the design performance levels of Part 2.

Design Methods

The ASTM standard guides can be very beneficial in producing such approaches as well as with the application of such methodologies. More specifically, ASTM E 1546, Guide for Development of Fire-Hazard-Assessment Standards, and ASTM E 1776, Guide for Development of Fire-Risk-Assessment Standards, can be excellent tools both when drafting a performance-based design method and when reviewing whether or not a method is appropriate. Having a standardized approach to constructing and reviewing would-be acceptable design methods can provide a comfort level to those who design to the code and those who enforce it. The current format of the guidelines may be slightly cumbersome for such reviews, but the concepts covered within the documents are appropriate.

Appropriate Fire Models

At a more detailed level, while compiling or applying hazard- or risk-based design methods, ASTM E 1355, Guide for Evaluating the Predictive Capability of Fire Models, can be used to determine whether a particular fire model is appropriate for use in a particular design method. Also, ASTM E 1355 can help a reviewer of a design solution to see whether a model is appropriate for their particular application. For instance, if flame spread is of concern, a post-flashover model will probably not be appropriate as it focuses on a stage of fire development after the role of flame spread is critical.

Documentation

Also, when the function of the model is not well described, it may be used for an inappropriate application. Clear documentation would state that a model, for example, is intended to measure smoke generation or flame spread. ASTM E 1472, Guide for Documenting Computer Software for Fire Models, can standardize documentation, which would provide a level of comfort to those reviewing and utilizing such software that all the key elements have been addressed. Documentation is a vital part of the design process, and a standardized form will help provide a level of familiarity whenever a computer fire model is used. The user will know where to find pertinent information about a model even when it is the user's first time applying the model. This leaves less room for misapplication of models.

Input Data

In addition to determining which model is appropriate, it is also extremely important that the user utilize the correct input data. Computer fire models are an object of great concern to many jurisdictions and many in the fire protection field. Due to the vagueness of some of the documentation, there is a concern that the user of the model simply manipulates the data to arrive at results that best fit their needs or simply does not understand the appropriate data to input. If the documentation includes ranges of appropriate data and examples of application, the likelihood that inappropriate data will be used is lessened and the ability to detect inappropriate data use is improved. ASTM E 1591, Guide for Data for Fire Models, provides necessary guidance in this area. It explains both what the variables mean and how to determine the information. Specific guidance is also given with respect to applicable tests. This type of information is beneficial in a couple ways. First, it informs the necessary dialogue between reviewer and modeler about the significance of, and perhaps difficulty in determining, certain variables. Second, the guide helps tie data required by models to appropriate test methods. This is important because it is sometimes difficult to decipher which of the many test methods available provide output relevant to particular applications. For instance, appropriate guidance clarifies that data from a fire resistance test is not related to flame spread.

Summary

As the ICC moves closer to the development of a framework for a performance-based system, the need will grow for tools that will complete the system. The ASTM guide and test standards with respect to fire can play a vital role in this process. The most effective form of linkage is to link guide and test standards to the performance levels and design objectives that the ICC performance building code and perhaps fire code create. More specifically, ASTM E 1546 and ASTM E 1776 can be utilized as a way of standardizing the development and review of performance-based methods that link with design performance levels established by the performance code. Also, guide documents such as ASTM E 1355 and ASTM E 1591 will assist in the appropriate application of fire models that are generally used as tools within performance-based design method.

References

[1] ICC Building Performance Code Committee, "Preliminary Committee Report," International Code Council, Falls Church, VA, 1998.

[2] Weber, Robert D., "ICC Performance Code: Guidelines for Use," Building Standards, International Conference of Building Officials, January-February, 1998.

ISBN 0-8031-2620-4