Standard Guide for
Characterization and Use of Hygrothermal Models for Moisture Control Design in Building Envelopes[1]

This standard is issued under the fixed designation E3054/E3054M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This guide offers guidance for the characterization and use of hygrothermal models for moisture control design of building envelopes. In this context, "hygrothermal models" refers to the application of a mathematical model to the solution of a specific heat and moisture flow performance issue or problem. Hygrothermal models are used to predict and evaluate design considerations for the short-term and long-term thermal and moisture performance of building envelopes.

1.2 Each hygrothermal model has specific capabilities and limitations. Determining the most appropriate hygrothermal model for a particular application requires a thorough analysis of the problem at hand, understanding the required transport processes involved, and available resources to conduct the analysis. Users of this guide can describe the functionality of the hygrothermal model used in an analysis in a consistent manner.

1.3 This guide applies to hygrothermal models that range from complex research tools to simple design tools. This guide provides a protocol for matching the analysis needs and the capabilities of candidate models.

1.4 This guide applies to the use of models that include all or part of the following thermal and moisture storage and transport phenomena: *(1)* heat storage of dry and wet building materials, *(2)* heat transport by moisture-dependant thermal conduction, *(3)* phase change phenomena (for example, evaporation and condensation), *(4)* heat transport by air convection, *(5)* moisture retention by vapor adsorption and capillary forces, *(6)* moisture transport by vapor diffusion (molecular and effusion), *(7)* moisture transport by liquid transport (surface diffusion and capillary flow), and *(8)* moisture (vapor) transport by air convection.

1.5 This guide does not apply to cases requiring analysis of the following: *(1)* convection that occurs in a three-dimensional manner or through holes and cracks; *(2)* hydraulic, osmotic, or electrophoretic forces; *(3)* salt or other solute transport; or *(4)* material properties that change with age.

1.6 This guide intends to provide guidance regarding reliability of input and how the corresponding results can be affected as well as a format for determining such information.

1.7 *Units*—The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

1.8 *This guide offers an organized characterization of hygrothermal models and does not recommend a specific course of action. This document cannot replace education or experience and should be used in conjunction with professional judgment. Not all aspects of this guide may be applicable in all circumstances. This ASTM standard is not intended to represent or replace the standard of care by which the adequacy of a given professional service must be judged, nor should this document be applied without consideration of a project's many unique aspects. The word "Standard" in the title of this document means only that the document has been approved through the ASTM International consensus process.*

1.9 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C168 Terminology Relating to Thermal Insulation

E283 Test Method for Determining Rate of Air Leakage Through Exterior Windows, Curtain Walls, and Doors Under Specified Pressure Differences Across the Specimen

[1] This guide is under the jurisdiction of ASTM Committee E06 on Performance of Buildings and is the direct responsibility of Subcommittee E06.41 on Air Leakage and Ventilation Performance.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

E331 Test Method for Water Penetration of Exterior Windows, Skylights, Doors, and Curtain Walls by Uniform Static Air Pressure Difference
E631 Terminology of Building Constructions
E2273 Test Method for Determining the Drainage Efficiency of Exterior Insulation and Finish Systems (EIFS) Clad Wall Assemblies
E2357 Test Method for Determining Air Leakage of Air Barrier Assemblies

2.2 *Other Standards:*

ANSI/ASHRAE 160-2009 Criteria for Moisture-Control Design Analysis in Buildings[3]
DIN EN 15026 Hygrothermal performance of building components and building elements - Assessment of moisture transfer by numerical simulation[4]
WTA Guideline 6-2-01 Simulation of Heat and Moisture Transfer[5]

3. Terminology

3.1 *Definitions:* For definitions of terms used in this guide, see Terminologies C168 and E631.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *air-leakage rate, n*—volume of air movement per unit time across the building envelope.

3.2.1.1 *Discussion*—this movement includes flow through joints, cracks, and porous surfaces, or a combination thereof. The driving force for such an air leakage in service can be mechanical pressurization and depressurization, natural wind pressures, or air temperature differentials between the building interior and the outdoors, or a combination thereof.

3.2.2 *analytical model, n*—model that uses closed form solutions to the governing equations applicable to hygrothermal flow and transport processes.

3.2.3 *building envelope, n*—boundary or barrier separating the interior volume of a building from the outside environment or different interior environment.

3.2.3.1 *Discussion*—For the purpose of this guide, the interior volume is the deliberately conditioned space within a building, generally not including attics, basements, and attached structures, for example, garages, unless such spaces are connected to the heating and air conditioning system, such as a crawl space plenum. The outside environment may be weather conditions or any other known conditions that the exterior of the building envelope is exposed to. An interior partition that separates two dissimilar environments such as a cold storage facility adjacent to an occupied office can be treated as a building envelope element for the modeling purposes.

3.2.4 *building envelope model, n*—portion of the building envelope, such as a wall, roof, floor, window, or door, or a combination thereof. The building envelope model comprises all of the components and materials as they are configured within the buidling envelope assembly (for example, the wall or roof assembly) at a given location.

3.2.5 *computer code (computer program), n*—assembly of numerical techniques, bookkeeping, and control language that represents the model from acceptance of input data and instructions to delivery of output.

3.2.6 *conceptual model, n*—interpretation or working description of the characteristics and dynamics of the physical system.

3.2.7 *finite difference model, n*—type of approximate, numerical model that uses a discretization technique to linearize the governing partial differential equations (PDE) consisting of replacing the continuous domain of interest by a finite array of spaced mesh or grid points (that is, nodes) spaced along the coordinate direction(s) of the one-, two-, or three-dimensional geometric coordinate system. The grid points define a set of control volumes representing volume-averaged subdomain properties. The derivatives of the PDE for each of these points are approximated using finite differences. The resulting set of linear or nonlinear algebraic equations are solved using direct or iterative matrix-solving techniques.

3.2.8 *finite element model, n*—type of approximate, numerical model that uses a discrete technique for solving the governing PDE wherein the domain of interest is represented by a finite number of mesh or grid points (that is, nodes), information between these points is obtained by interpolation using piecewise continuous polynomials, and the resulting set of linear or nonlinear algebraic equations is solved using direct or iterative matrix-solving techniques.

3.2.9 *functionality, n*—of a hygrothermal model, the set of functions and features the model offers the user in terms of building envelope framework geometry, simulated processes, initial and boundary conditions, and analytical and operational capabilities.

3.2.10 *hygrothermal model, n*—a mathematical model that includes various thermal and moisture transport mechanisms with boundary system performance under applied conditions to represent a building envelope system or subsystem.

3.2.10.1 *Discussion*—May be either steady-state or transient approach and may be based on equations derived from basic principles of physics, established engineering functional relationships, statistical interpretations of empirical data, or a combination of all of these approaches.

3.2.11 *hygrothermal model code, n*—computer code used in hygrothermal modeling to represent a non-unique, simplified mathematical description of the physical framework, geometry, active processes, and initial and boundary conditions present in a building system.

3.2.12 *model selection, n*—process of choosing the appropriate computer model as an analysis tool capable of simulating those characteristics of the physical system required to fulfill the project's objective(s).

3.2.13 *Moisture Reference Year, MRY*—a year of hourly weather data that have been selected for use in hygrothermal analysis.

[3] Available from American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. (ASHRAE), 1791 Tullie Circle, NE, Atlanta, GA 30329, http://www.ashrae.org.

[4] Available from Deutsches Institut für Normung e.V.(DIN), Am DIN-Platz, Burggrafenstrasse 6, 10787 Berlin, Germany, http://www.din.de.

[5] Available from WTA-Publications, Ingolstädter Straße 102, D-85276 Pfaffenhofen, Germany, http://www.wta-international.org/?L=2.

3.2.14 *numerical model, n*—model that uses numerical methods to solve the governing equations of the applicable problem.

3.2.15 *water penetration, n*—a process in which water gains access into a material or system by passing through the surface exposed to the water.

3.2.15.1 *Discussion*—For products with non-planar glazing surfaces (domes, vaults, pyramids, and so forth), the plane defining water penetration is the plane defined by the innermost edges of the unit frame.

3.3 *Symbols:*

q_v = mass flux rate of vapor flow (kg/m^2·s [lb/ft^{2}s])
X = vapor concentration (kg/m^3[lb/ft^3])
δ_p = water vapor permeability (kg/Pa·m·s [Perm-in])
h_e = specific latent heat of evaporation or condensation (J/kg [Btu/lb])
g_{air} = air mass flux (kg/m^{2}s [lb/ft^{2}s])
λ = thermal conductivity (W/mK [Btu/h·ft·°F])
m_{dry} = mass of dry material (kg [lb])
m_{wet} = mass of wet material (kg [lb])
P_{air} = air pressure (Pa [psi])
P_e = exterior air pressure (Pa [psi])
P_i = interior pressure (Pa [psi])
ρ_w = density of water (kg/m^3 [lb/ft^3])
ρ_s = dry density of material (kg/m^3 [lb/ft^3])
ρ_{air} = dry density of material (kg/m^3 [lb/ft^3])
c_w = specific heat capacity of liquid water (J/kgK [Btu/lb°F])
c_s = specific heat capacity of dry material (J/kgK [Btu/lb°F])
c_a = specific heat capacity of dry air (J/kgK [Btu/lb°F])
η = dynamic viscosity (s·Pa [lb·s/ft^2])
k_a = air permeability (m^2 [ft^2])
T = temperature (K [°F])
ϕ = relative humidity (-)
q_l = liquid transport flow (kg/m^{2}s [lb/ft^{2}s])
u = moisture content (kg/kg [lb/lb])
t = time (s) (s)
x = x–coordinate
D_ϕ = liquid conduction coefficient (kg/ms [lb/ft•s])

4. Significance and Use

4.1 This guide is intended to provide the framework for characterizing the functions of the hygrothermal model and the level of sophistication used as inputs for each analysis. Hygrothermal modeling has become an important practice in support of the decision-making design processes involved in moisture management of building envelope systems. Increasingly, hygrothermal models are an integral part of building envelope performance assessment, retrofit, and restoration studies and provide insight in the screening of alternative design approaches affecting water management of the envelope system. Hygrothermal models are used in decision making during the design process of building envelope systems. They may also be used to assess performance of the envelopes of existing buildings, or to predict envelope performance in buildings undergoing retrofit, change in use, restoration or flood remediation. It is, therefore, important to have a methodology to document the model used in a hygrothermal investigation. This documentation provides needed characterization of the hygrothermal model to assess its credibility and suitability. This becomes even more important because of the increasing complexity of the building envelope systems for which new hygrothermal models are being developed. There are many different hygrothermal models available, each with specific capabilities, operational characteristics, and limitations. If modeling is considered for a project, it is important to determine if a hygrothermal model is appropriate for that project, or if a model exists that can perform the simulations required in the project.

4.2 Quality assurance in a hygrothermal analysis using modeling is achieved by using the most appropriate model with all important transport mechanisms, initial conditions, and boundary conditions. A well-executed quality assurance program in hygrothermal modeling requires systematic and complete documentation of the model and the inputs followed by consistent reporting of the results. This guide sets forth a format for reporting hygrothermal modeling results.

5. Hygrothermal Model Analysis Inputs

5.1 There are many hygrothermal models available to simulate, describe, or analyze different building envelope systems and the moisture migration characteristics that affect their performance. Therefore, it is important to understand the performance characteristics for which the model is intended to represent and recognize the evaluation of the model is only relevant for the performance characteristics it addresses. If the appropriate analytical and input techniques are applied to the model, then the results obtained should provide a valid solution to address the system deficiencies. Fig. 1 displays the various inputs and outputs needed for hygrothermal simulations. The effectiveness of the results is largely a function of the degree to which the model represents the system studied. Additionally, the inputs (climate data, orientation inclination, and material characteristics) are not addressed. Their influence on the calculation results are, however, very important (often more important than the capability of the hygrothermal model). This standard is complimentary to the ASHRAE 160 Standard, DIN EN 15026, and WTA Guideline 6-2-01 that describes the design criteria for use in hygrothermal models.

5.2 A descriptive approach that can be used to classify hygrothermal models is discussed in the following. Fig. 2 describes graphically the descriptive approach proposed in this standard. Additional information related to the classification details are found in Karagiozis,[6] Trechsel (Chapter 1),[7] and Kuenzel.[8]

5.2.1 *Nature of Equations (D, S)*—Decision-making problems can be classified into two categories: deterministic or stochastic/probabilistic decision models. In deterministic

[6] Karagiozis, A., "Chapter 6--Advanced Numerical Models for Hygrothermal Research," in *Moisture Analysis and Condensation Control in Building Envelopes,* MNL 40, H.R. Trechsel, Ed., ASTM International, West Conshohocken, PA, 2001

[7] *Moisture Control in Buildings*, MNL 18, H.R. Treschel, Ed., ASTM International, West Conshohocken, PA, 1994.

[8] Künzel, H.M., "Simultaneous Heat and Moisture Transport in Building Components--One and Two-Dimensional Calculation Using Simple Parameters," Dissertation, University of Stuttgart, 1994.

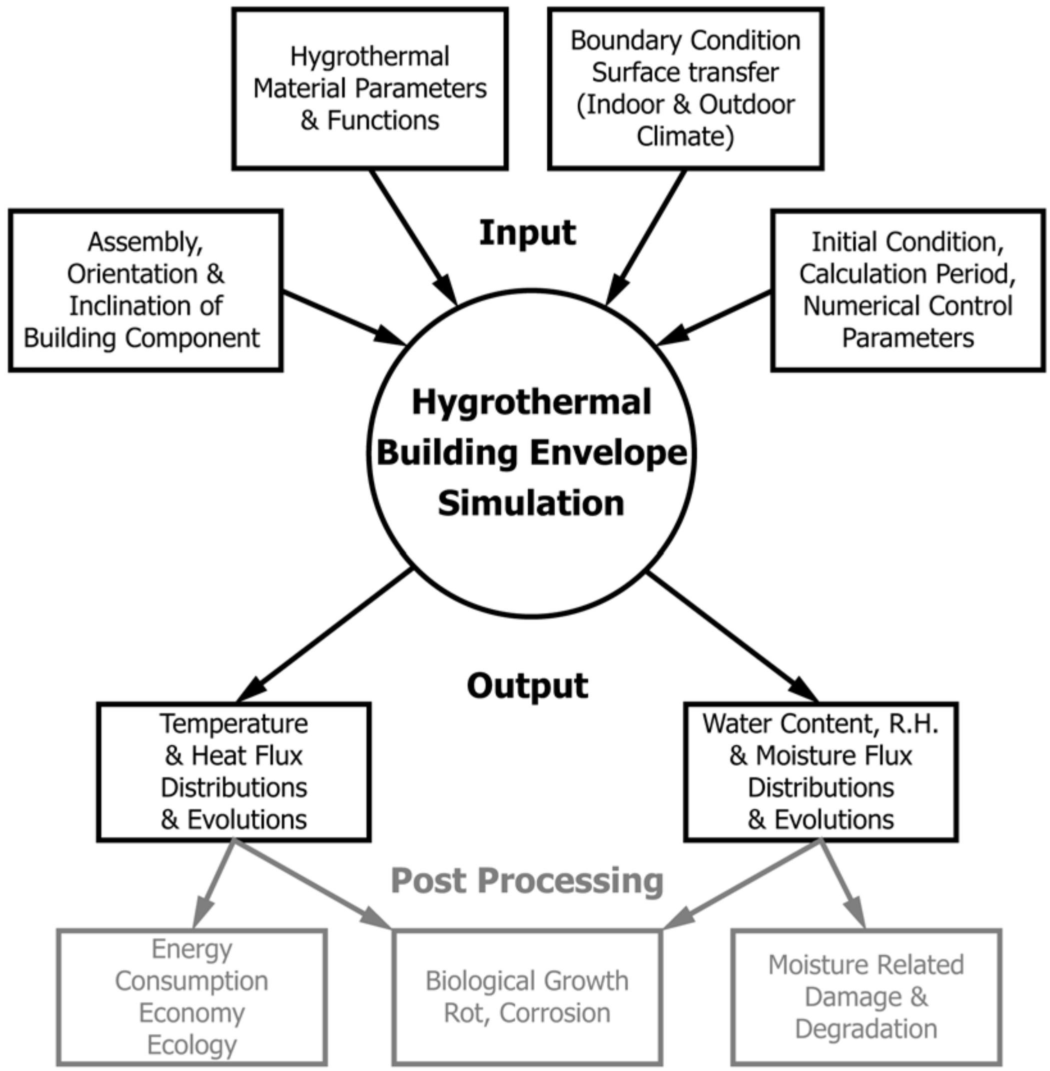

FIG. 1 Input and Output Chart for Hygrothermal Simulations

models, point value results are expected; therefore, the outcome is deterministic. This depends largely on how influential the uncontrollable factors are in determining the outcome of a decision and how much information the decision maker has in predicting these factors. When there could be a range of correct answers for a particular problem, then the analysis is stochastic. Models can therefore be:

5.2.1.1 *Deterministic (D)*—A single value solution to the equation set, or

5.2.1.2 *Probabilistic (S)*—Statistical variation of solution values to the equation set.

5.2.2 *Temporal Nature (ST, T)*—Two types of temporal models can exist. The first type defined as steady state is when all transport processes achieve a state in which equilibrium occurs. The second type defined as transient state occurs when the transport processes are transitioning between two steady states. Hygrothermal transport in building applications is primarily a transient condition. Below the distinguishing features are presented in a 1-D diffusion transport framework.

5.2.2.1 *Steady-State (ST) (Time-Invariant Hygrothermal Models):*

Energy Transport:

$$\left(c_s\rho_s + \cancelto{0}{c_w\rho_w}\right)\cdot\frac{\partial T}{\partial t} = -\frac{\partial q}{\partial x} + S \quad (1)$$

Moisture Transport:

$$\cancelto{0}{\rho_s\frac{\partial u}{\partial t}} = -\frac{\partial}{\partial x}\left(\underbrace{-\delta_p\frac{\partial P_v}{\partial x}}_{q_v}\underbrace{-D_\phi\frac{\partial \phi}{\partial x}}_{q_l} + \underbrace{g_{air}\,X}_{q_{air}}\right) \quad (2)$$

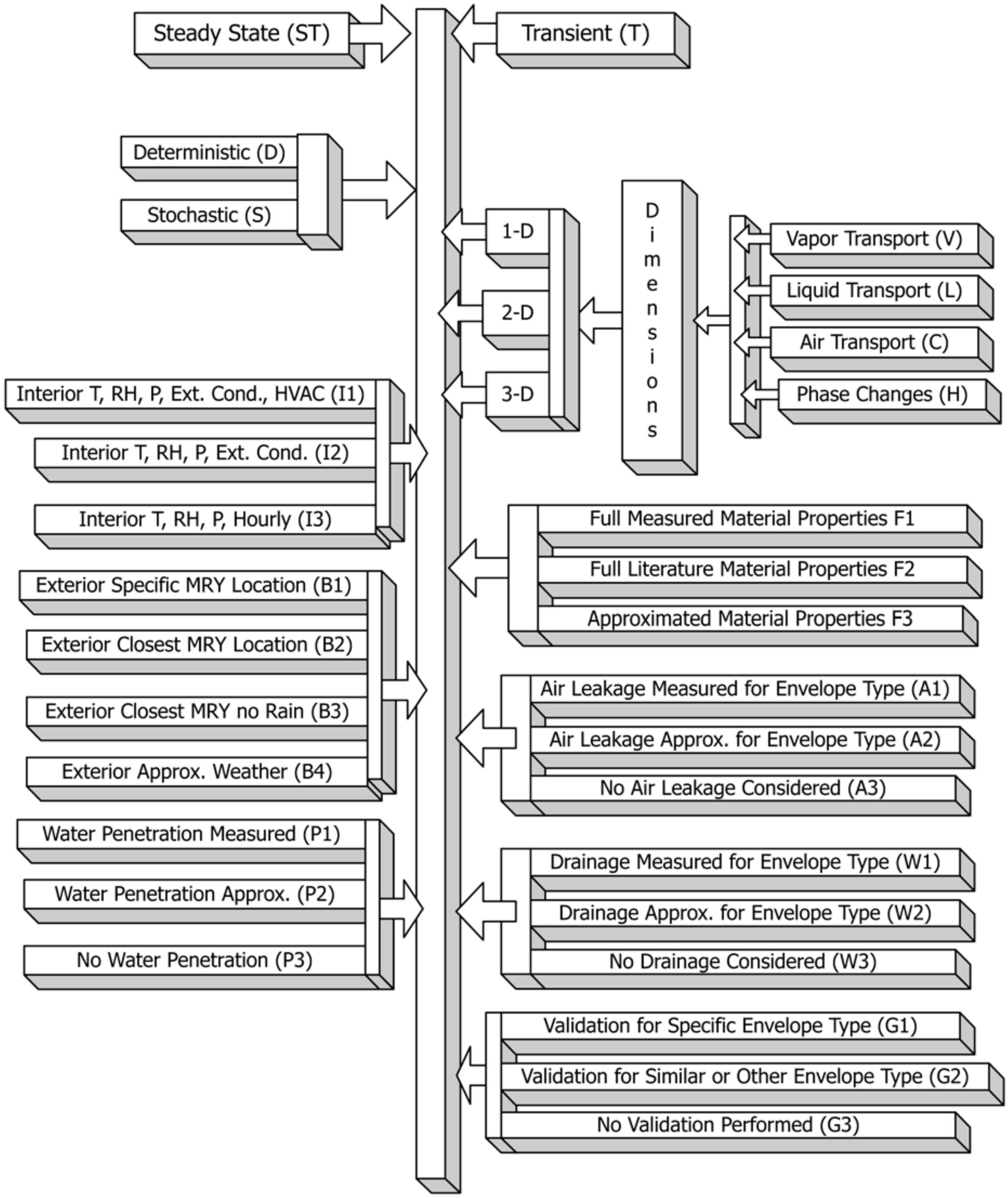

FIG. 2 Flow Chart for Hygrothermal Modelling Analysis

where:

$$q = q_{cond} + q_{air} \tag{3}$$

and the diffusion heat flow rate (sensible) is given by:

$$q_{cond = -\lambda(u)\frac{\partial T}{\partial x}} \tag{4}$$

while the convection heat flow rate (air flow transport) is given by:

$$q_{air} = c_a \quad g_{air} \quad T \tag{5}$$

The source S is the latent heat of evaporation or condensation times the moisture content change due to water vapor movement.

$$S = -\frac{\partial q_v}{\partial x} h_e \tag{6}$$

The moisture content is defined as:

$$u = \frac{m_{wet} - m_{dry}}{m_{dry}} \tag{7}$$

in both the vapor and the capillary regimes.

5.2.2.2 *Transient (T) (Time-Dependent Hygrothermal Models):*

1–D Energy Transport:

$$\left(\underbrace{c_s \cdot \rho_s}_{Volumetric\ heat\ capacity\ of\ solid\ matrix} + \underbrace{c_w \cdot \rho_w}_{Volumetric\ heat\ capacity\ of\ water}\right) \cdot \frac{\partial T}{\partial t} = -\frac{\partial q}{\partial x} \quad (8)$$

1–D Moisture Transport:

$$\rho_s \frac{\partial u}{\partial t} = -\frac{\partial}{\partial x}\left(\underbrace{-\delta_P \frac{\partial P_v}{\partial x}}_{q_v} - \underbrace{D_\phi \frac{\partial \phi}{\partial x}}_{q_l} + \underbrace{g_{air} X}_{q_{air}}\right) \quad (9)$$

5.3 *Physics used in the Code (Saturated and Unsaturated Flow) (V, L, C, Z, H)*—Moisture as a liquid, an adsorbate, or a vapor can move through porous materials. Water vapor transport is driven by vapor pressure differences, while liquid water flows through porous materials either by capillary suction or external pressures, or both. The convective flow of air transports moisture in the form of water vapor. The governing equations for the specific physical transport processes are given in the following:

5.3.1 *Vapor Transport (V):*

$$g_v = -\delta_P \frac{\partial P_v}{\partial x} \quad (10)$$

5.3.2 *Liquid Transport (L):*

$$g_1 = -D_\phi \frac{\partial \phi}{\partial x} \quad (11)$$

5.3.3 *Air Transport (C):*

$$g_{air} = -\rho_{air} \cdot \frac{k_a}{\eta} \frac{\partial}{\partial x} P_{air} \quad (12)$$

5.3.4 *Phase Changes (H):*

$$S = -h_e \frac{\partial g_v}{\partial x} \quad (13)$$

5.4 *Dimensionality (D1, D2, D3)*—The dimensionality of the hygrothermal models indicates how many spatial coordinate directions are accounted for in the analysis. Most hygrothermal models only account for one coordinate; however models do exist that accommodate 2- and even 3-dimensions. If one uses a 3-dimensional model using only the 1-dimensional features, then the simulation is 1-dimensional.

5.4.1 1-Dimensional (D1).

5.4.2 2-Dimensional (D2).

5.4.3 3-Dimensional (D3).

5.5 *Material Property Inputs (F1, F2, F3)*—The required hygrothermal properties needed for modeling the heat and moisture performance are the dry density, the porosity, the vapor transport coefficient for vapor diffusion, liquid transport coefficient for capillary transport (drying and wetting), air permeability, sorption and suction isotherms for moisture retention properties, thermal conductivity, and heat capacity. Material level information is needed for each material, and inadequate information for even one material degrades the quality of the analysis. Based on the quality of input and level of knowledge of the material properties used in the modeling analysis, the following classification can be implemented:

5.5.1 *Precisely Known Hygrothermal Properties with Time Stamp (Full Functional Properties) F1*—Documented material properties from specific manufacturers are used for the envelope system modeled with time stamp or material properties tests performed from material samples used in the design. Measured material property data are available for the full hygroscopic and capillary regime without gaps.

5.5.2 *Properties Taken from Handbook or Open Literature (Literature Data) F2*—In this case, complete material property data are taken from the open literature and used in the modeling analysis. The data are well documented accompanied with a testing time stamp. All prominent functional dependencies are available and used in the modeling analysis. Data for all transport coefficients and storage functions are taken from literature. Single sample origin and dates are not necessarily available.

5.5.3 *Properties Are Approximated from Multiple Sources and Functional Dependencies Not Known for All Properties or Other Conditions F3*—Data for all transport coefficients and storage functions are taken from the open literature. Generic property data are used as sample origin is not defined, and multiple origins and testing dates may have been used.

5.6 *Boundary Conditions:*

5.6.1 *Exterior Environmental Loads (B1, B2, B3, B4)*—A number of important exterior environmental conditions that contribute to the exterior loading of the envelope systems are: temperature (T), relative humidity (RH), solar radiation (Q), cloud index (CL), wind speed (W), wind orientation (F), and rain (R). Furthermore, the exterior loading of the building envelope depends on the height, the orientation, and the inclination of the exterior surface of the building envelope. Based on the level of knowledge available for these loads, the following classification is provided:

5.6.1.1 Hourly local moisture reference year weather (MRY) conditions for the specific site is used (T-RH-Q-CL-W-F-R = B1),

5.6.1.2 Hourly local MRY weather conditions for the closest site to the one modeled is used (T-RH-Q-CL-W-F-R = B2),

5.6.1.3 Hourly local MRY weather conditions for the closest site to the one modeled but no rain data available (T-RH-Q-CL-W-F = B3), and

5.6.1.4 Approximated hourly local MRY weather conditions for the specific site is used or other conditions (T-RH-Q-CL-W-F-R = B4).

5.6.2 *Interior Environmental Loads (L1, L2, L3)*—Interior conditions such as temperature (Ti), relative humidity (RHi), pressure (Pi), and equipment operational specifics (Hi) are commonly used by models. The equipment operational information includes information on the time-dependent occupational characteristics (information on loads). Based on the level of knowledge available for these loads, the following classification is provided:

5.6.2.1 Measured or interior conditions values dependent on exterior climate and whole building HVAC characteristics and interior loads (Ti, RHi, Pi, Hi) (L1), 5.6.2.2 Interior condition values dependent on exterior climate (Ti, RHi, Pi) (L2), and

5.6.2.3 Approximated interior conditions (Ti, RHi) (L3).

5.7 *Building Envelope Systems and Subsystems*—In many building envelope situations, additional information may be required as inputs to the models that describe particular performance of the envelope system or subsystem. Such properties are:

5.7.1 *Air Leakage Characterization (A1, A2, A3)*—The air tightness of the particular building envelope system may be used in the hygrothermal modeling activity. The air tightness for assemblies, Test Method E2357, or components, Test Method E283, inclusion can be prescribed in the following manner:

5.7.1.1 Measured air leakage of envelope system as designed (A1),

5.7.1.2 Air leakage approximated values of building envelope from literature (A2), and

5.7.1.3 No air leakage values used (A3).

5.7.2 *Drainage Characterization (W1, W2, W3)*—The drainage properties within an envelope system, Test Method E2273 may be included in the hygrothermal modeling analysis of a particular project in the following manner:

5.7.2.1 Measured liquid water drainage properties for specific envelope system (W1),

5.7.2.2 Data taken from open literature for specific envelope system (W2), and

5.7.2.3 No drainage data taken into account (W3).

5.7.3 *Water Penetration Characterization (P1, P2, P3)*—The water penetration characteristics of building envelope systems, Test Method E331 or variant with water penetration quantification may be introduced into a hygrothermal modeling analysis in the following manner:

5.7.3.1 Measured water penetration for the specific envelope system (P1),

5.7.3.2 Data taken from open literature for specific envelope system (P2), and

5.7.3.3 No water penetration taken into account (P3).

5.8 *Model Envelope Validation (G1, G2, G3)*—In many circumstances where permitted, the envelope system may have been field or laboratory tested. While this is the most preferable approach, many times this is not practical because of financial and time constraints. However, validation is important to check the applicability of the model to capture all system and subsystem characteristics. Depending on the level of validation performed, three classifications are defined:

5.8.1 Measured field validation data for envelope system (G1),

5.8.2 Measured laboratory data for specific or similar type (G2), and

5.8.3 No field testing and validation (G3).

6. Documentation Approach of Modeling Application

6.1 The detailed documentation of input and output data of numerical simulations is an essential prerequisite to assess and check the calculation results. As a rule, the documentation should be such that any professional repeating the simulations as documented can obtain identical results. This format discussed in the following is not intended to limit the items reported but rather provide a guideline dictating a minimum standard. The reporting of the modeling activity should include the following items:

6.2 *Problem Description*—The problem description includes all the information needed before the start of the modeling simulations. A brief paragraph shall include the scope and purpose of the hygrothermal analysis.

6.3 *Scope and Purpose of the Hygrothermal Analysis:*

6.3.1 Provide the problem and reason for using hygrothermal simulation,

6.3.2 Provide the construction details of the building component under investigation and identify each material element by manufacturers product,

6.3.3 Provide pertinent background information,

6.3.4 Provide output parameters required and monitoring position locations, and

6.3.5 Provide the time frame duration of simulation.

6.4 *Initial Conditions:*

6.4.1 Provide the initial temperature distribution,

6.4.2 Provide the initial moisture distribution,

6.4.3 Provide the start and end date of the simulation, and time step.

6.5 *Boundary Conditions:*

6.5.1 Provide information on the source and method used for interior conditions,

6.5.2 Provide information and method used for the exterior climate conditions, and

6.5.3 Provide information on the surface transfer coefficients.

6.6 *Material Parameters:*

6.6.1 Provide documentation of inputted material properties by tables and graphs,

6.6.2 Provide documentation of the sources of material property data and date, and

6.6.3 Provide assumptions and approximations.

6.6.4 If known, provide the test method and sample preparation used to obtain material properties.

6.7 *Building Envelope Characterization Inputs:*

6.7.1 Provide documentation of the testing method used to measure the air leakage as per 5.7.1,

6.7.2 Provide documentation of the testing method used to measure the drainage characterization 5.7.2,

6.7.3 Provide documentation of the testing method used to measure the water penetration as per 5.7.3.

6.8 *Hygrothermal Model Classification*—This section should contain all information related to the documentation and classification of the hygrothermal model. Examples include the following:

6.8.1 Name and version of software,

6.8.2 Define and report the classification of the particular application based on this ASTM guide (A1-D3-…….),

6.8.3 Discretization (numerical grid),

6.8.4 Time intervals (time steps),

6.8.5 Numerical control parameters (accuracy of solution), and

6.8.6 Validation of the model for specific application (classification type).

7. Reporting of Hygrothermal Model Results

7.1 This section contains all the relevant information about the display, evaluation, and interpretation of the calculation results. It is recommended that the following format be used:

7.1.1 *Display of Results:*

7.1.1.1 The calculation results shall be documented in a form that conveys all the essential information concerning the hygrothermal performance of the component under study. This may be done by showing graphs and tables of:

(1) Transient distributions (profiles),

(2) Variation with time at specific locations or integrated over material layers,

(3) Peak values (minimum, maximum),

(4) Average values at points and layers and surfaces of interest, and

(5) Relevant hygrothermal variables and boundary conditions such as:

(a) Temperature, heat flux,

(b) Water content, moisture flux,

(c) Relative humidity, and

(d) Vapor pressure.

7.1.1.2 The selection of graphs and tables to be displayed depends on the problem, the analysis, and the conclusion.

7.1.2 *Interpretation of the Results*—The documentation of the results should be followed by an interpretation of their practical meaning. This may be done by at least one of the following items:

7.1.2.1 Comparing the resulting hygrothermal conditions with specific limits,

7.1.2.2 Checking the risk of moisture accumulation by comparing the total moisture content in the construction after one cycle with the initial condition,

7.1.2.3 Evaluating the moisture tolerance of the construction (drying potential), and

7.1.2.4 Introducing the transient results into a post process model (for example, for mold or algae growth, rot, or corrosion).

8. Keywords

8.1 building envelope; hygrothermal model; moisture control design

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(1) Salonvaara, M., "RP-1325--Environmental Weather Loads for Hygrothermal Analysis and Design of Buildings," ASHRAE, 2011.