Environmental Boundary Conditions for Long-term Hygrothermal Calculations

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ABSTRACT

This paper introduces a newly developed weather analysis computer tool, WeatherSmart. The main purpose of the tool is to facilitate the analysis of the outdoor weather data to obtain representative environmental boundary conditions. These conditions are, in turn, necessary for the analysis of long-term heat-air and moisture responses in building envelopes performed for thermal and moisture design. The environmental boundary conditions generated are location-specific and for the expected usage of the building considered.

Several approaches to characterize either the indoor or the outdoor environmental conditions are part of the program. The different approaches allow analysis of the environmental conditions that apply moisture and thermal loads on the particular envelope component being studied. Construction-dependent and independent methods for selecting the outdoor moisture reference years have been incorporated in the tool. The indoor environment, representing the expected usage of the building under consideration, is derived by two approaches for both controlled and uncontrolled indoor environments.

One case study performed using WeatherSmart to select outdoor moisture reference is presented. The case study represents an example of how the weather analysis tool is used to identify the outdoor moisture reference year for a particular location.

INTRODUCTION

An integrated hygrothermal, heat-air and moisture (HAM) package called *hygIRC* is currently under development at the Institute for Research in Construction of the National Research Council of Canada (see Figure 1). It is intended to be fully menu-driven, allowing users to perform several tasks in a user-friendly way. Part of the difficulty in using the most sophisticated HAM models, such as hygIRC, is that they require a large supply of input data prior to the simulations, resulting in a time-consuming pre-processing. The first version of a hygIRC module, *WeatherSmart*, has been developed to reduce the pre-processing time. It is a visual basic program developed at IRC/NRC. It is a stand-alone and modular program. This pre-processor allows analysis of several decades of exterior hourly weather data and obtains a representative exterior and interior moisture reference year for the location and the expected usage of the building considered.

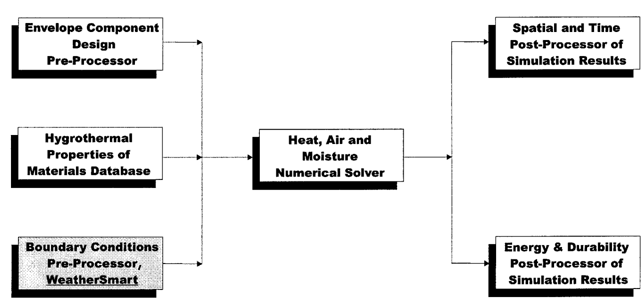

Figure 1 *IRC/NRC hygrothermal package, hygIRC, with its different modules.*

The main purpose of the pre-processor *WeatherSmart* is to generate two necessary input data files in hygIRC format for subsequent use in HAM simulations. The two input files might be one year or a combination of several years of hourly indoor

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and outdoor environment that will apply moisture and thermal loads continuously on both the exterior and interior boundaries of the envelope component under investigation. Once the commercially available weather data files are converted to hygIRC's format using *WeatherSmart*, as described later, it is technically possible to simulate the whole corresponding time period. However, long-term performance of building envelopes could be assessed safely by subjecting them to a couple of moisture-critical years of indoor and outdoor hygrothermal loads. Depending on the problem at hand, the time period necessary to assess the hygrothermal performance of envelope components could be two, three, or more years. Two or three years are usually enough to track and asses the hygrothermal levels over the years in the envelope components simulated. The subject of the present paper is to show examples of how moisture-critical years, i.e., "moisture reference year," are selected from multi-decades of hourly real recorded weather data using *WeatherSmart*.

The present paper will start by discussing the state of the art in terms of long-term hygrothermal boundary conditions, and the background in which *WeatherSmart* has been developed. Secondly, *WeatherSmart* and its options and modules are introduced. A case study, using *WeatherSmart* to define outdoor moisture reference years, MRY, is then described. The case study demonstrates the selection of five outdoor MRYs corresponding to five Canadian locations.

BACKGROUND

Detailed heat-air and moisture analysis using sophisticated hygrothermal modeling is an alternative way for researchers and engineers to design and predict long-term energy efficiency and service life of building envelopes. Many HAM models and packages with different degrees of sophistication are currently available commercially and within the research community. Review of some of the hygrothermal models and how the combined HAM transports in building envelopes are modeled can be found in Ojanen et al. (1994) and Hens (1996). Hygrothermal numerical models can predict the long-term thermal and moisture microclimate within building envelope components from which the energy efficiency and moisture durability can be derived. The history of using numerical-mathematical HAM models to simulate and predict long-term hygrothermal performance of building envelopes is very recent. Examples of several key answers that are still in the research stages, include

- accurate modeling of the combined heat-air and moisture transport in building envelopes;
- thorough characterization of the moisture and temperature-dependent hygrothermal properties, aging, and cyclic effects of porous building materials;
- development of sound durability criteria to predict envelope components' service life and the related subject discussed in the present paper;
- satisfactory definition of a set of representative environmental boundary conditions to be used for calculations.

The hygrothermal environment within the envelope components predicted from HAM simulations is a function of the thermal and moisture loads that are applied at the exterior and interior boundaries of the structures simulated. Excessive or moderate thermal and moisture loads will result in a wrong estimation of the construction's hygrothermal performances and can lead to over- or underdesign of envelopes. Definition of *what* and *how much* should be the environmental boundary condition is still at the earlier stages of debate. Worldwide, there is no universal standard for the selection of boundary conditions that should be applied for both the interior and exterior surfaces of the assemblies. Until recently, years with the most complete hygrothermal weather data were arbitrarily used. A constant value of both indoor temperature and relative humidity for summer and winter periods was also common practice for the interior boundary conditions.

A lot of effort has been made during this last decade to formulate a general definition of and a method for defining a reference year as an outdoor boundary condition for moisture design and long-term hygrothermal performance (durability) of building envelopes. Consequently, several approaches were suggested and are available in the literature. Analysis of the published literature seems to agree on the following main criteria for selecting an exterior moisture reference year, MRY.

- The MRY should reflect the climatic variability of the considered building location (i.e., true frequencies, true sequences, and true correlation). This criterion is similar to that for constructing energy reference years (average years), such as test reference years (TRY) and design reference years (DRY). A real set of measured data would fulfill this requirement.
- MRYs should be a summary of the external climate for the considered geographic location. A year is a reasonable reference period for long-term hygrothermal simulations and durability analysis. This is also similar to the energy reference year.
- MRYs should impose a severe stress on the building structure in order to give a desired level of safety regarding moisture damage. Some authors qualify the MRY as a "worst year" in terms of moisture load for the location considered. This is a major difference from the energy reference years, TRY and DRY, which are synthetic mean values of the climatic parameters for the considered location. In fact, it has been shown that there is a significant difference in terms of hygrothermal response of building envelopes when using "average," TRY/DRY or moisture reference years (Sanders 1996).
- A return period of ten years is suggested for selecting reference years for hygrothermal calculations and design (Sanders 1996). In other words, severe hygrothermal stress occurs once every ten years. This is contrary to the situation for structural building design where a return period of 50 years is desired because of the relatively costly damages that might be caused by structural

failures. The severe year that occurs once every 10 years is called the "10%-level" year.

- MRYs should be location specific and not construction specific.

Even though there is rich literature related to the selection of an exterior moisture reference year, and sources agree on the previously mentioned criteria as a definition of MRYs, there is still no consensual method for identifying or selecting the worst or the 10%-level year. To select MRYs, moisture designers have a choice between two approaches: (1) the construction non-dependent methods involving only weather data analysis and (2) the construction-dependent methods, which involve some form of hygrothermal simulation.

- Construction non-dependent methods are based only on weather data analyses to identify the moisture reference year. The main advantage is they do not use any hygrothermal simulations to identify the worst or 10%-level moisture reference year—only weather statistics of the considered location are required.
- Construction-dependent methods are more sophisticated approaches. They make use of HAM models to select the worst or 10%-level moisture years among the weather data of a particular location. The concept is to use the moisture conditions within some typical constructions as the criteria to select a critical MRY. In most cases, MRYs are years when there is a combination of low outside temperatures and solar radiation and high relative humidity and wind-driven rain stress. However, the different types of construction will not behave in the same way for the same external weather load. Using several different constructions to identify a common reference year makes these methods non-construction-specific and implies that the varying effects on different types of constructions have been taken into account. Methods following this approach have been proposed for monthly-based MRYs by Sanders (1996) and hourly-based MRYs by Rode (1993) and Geving (1997).

The indoor environmental conditions are as critical as the exterior weather when estimating the structures of hygrothermal performance. Control of the indoor temperature at the desired levels is generally not an issue. Today's technologies to heat or cool indoor air are well developed and several devices capable of ensuring inhabitants' thermal comfort are available. The indoor temperature to be used for HAM calculations can therefore simply be supplied directly in the program. On other hand, indoor air humidity is very difficult to maintain and to control at the desired levels. This is particularly true for buildings located in non-coastal cold climates. Use of a constant value of humidity inside buildings during either the summer or the winter might lead to unrealistic calculation results and hygrothermal design. Some of the commercial buildings and most of the residential ones are still not equipped with indoor humidity control. Levels of indoor humidity in the later case can oscillate greatly depending on the outdoor weather, ventilation, building air tightness, and hygroscopic behavior of the inside building surfaces and furnishings. Three approaches are mainly suggested in the literature to define the interior air-humidity conditions. They are (1) using a statistical summary of large-scale indoor environment monitoring data, (2) employing indoor air-humidity models, and (3) applying the "worst" interior conditions corresponding to the maximum allowable interior moisture loads.

- Use of statistical data gathered from large-scale field monitoring seems to be the most tempting approach since it requires very little pre-processing. However, data of this nature are difficult to obtain and by nature they reflect the time period when the monitoring is performed. One recent example of large-scale monitoring data obtained from Western Europe (Sandberg 1995) is implemented in *WeatherSmart* and will be described later.
- Indoor air-humidity models are a higher-level approach compared to the above approach. Two types of models are suggested in the literature and both are based on a mass balance between the moisture gain and loss inside the building. They are (1) steady-state air-humidity models where the time-dependent effects of interior surface hygroscopicity, and sometimes condensation, are omitted, and (2) dynamic air-humidity models that account for the transient effects of hygroscopicity and sometimes surface condensation of interior surfaces. The latter involves solution of a differential humidity balance equation. Accurate use of dynamic humidity models presumes coupling the indoor-humidity and envelope heat-air and moisture transport equations. The indoor humidity is then a solved-for variable. This type of method is not considered in *WeatherSmart* and is not discussed in this paper. Interested readers are directed to Jones (1995). In the case of the steady-state models, air humidity is calculated directly from the knowledge of the exterior weather, moisture generation rate, expected air change in the building, and statistical field data describing moisture storage of interior surfaces and furniture. An example of this type of model is implemented in *WeatherSmart* and will be described later.
- Finally, the third approach has been suggested at the conclusion of the IEA Annex-24. The principal method is as follows: the maximum allowable indoor vapor pressure before a persistence of interstitial condensation inside a "benchmark construction" is calculated for three situations' so-called "pivot points." The three pivot points represent the limits between four indoor climate classes. Each indoor climate class is a worst-case scenario represented by constant values of temperature and humidity over the year. This approach is not implemented in *WeatherSmart an*d will not be discussed further. The interested reader is directed to Sanders (1996).

DESCRIPTION OF WEATHERSMART

WeatherSmart includes the latest knowledge to date in terms of selecting from multiyear weather data files an indoor and outdoor MRY that imposes the thermal and moisture load for the location considered. Figure 2 gives schematic details of the different modules built into *WeatherSmart.* Three main modules, the weather data format conversion module, exterior weather analysis module, and the indoor environment analysis module are included in the current version of the program. They are complementary, fully independent, and can be used in a random order.

Weather Data Format Conversion Module

Prior to proceeding with weather data analysis, the first step is the conversion of the commercially available weather data formats to a required format for subsequent hygrothermal analysis. The data format conversion module performs this task. The ASCII weather files that might be converted are one of the following four most common types:

1. Weather Year for Energy Calculations (WYEC format);
2. Weather Year for Energy Calculations Type-2 standard 166 character/record (WYEC2 format);
3. Canadian Weather for Energy Calculation from Environment Canada, CWEEDS/CWEC (WYEC2 format); and
4. ASHRAE weather files (WYEC2 format).

The hygIRC weather files generated by the module include hourly data of dry-bulb temperature, relative humidity, wind speed and direction, solar radiation, cloud coverage, and precipitation (rainfall). Quantitative rain data are not included in the energy-calculations-oriented weather files WYEC, CWEC, or WYEC2. They have to be provided separately and integrated in hygIRC global weather input files. A specific option is built into the tool to perform this task.

Exterior Weather Analysis Module

The exterior environment analysis module allows the generation of outdoor boundary conditions that apply the thermal, moisture, and air pressure loads on the exterior surface side of the building envelope under consideration. Both construction-dependent and independent methods are implemented in *WeatherSmart.*

Construction-Independent Methods to Select Outdoor MRYs. Three construction-independent methods to select the exterior MRY are included in the current version of *WeatherSmart*:

- the drying-out potential,
- exterior wetting potential, and
- the combined drying-out and wind-driven rain wetting potential.

The drying-out potential is analogous to the Π-factor method, suggested during the IEA Annex 24 activities (Hagentoft and Harderup 1996), to select the critical moisture year. It is defined by the mean value of the difference between the absolute humidity per unit volume at saturation (water vapor density), $d_{v,\,sat}$ in kg/m^3, at the outside wall surface, having a temperature T_s and the absolute humidity per unit volume in the external air, $d_{v,\,out}$ in kg/m^3 (see Equation 1). In other words, it is the mean value over a considered period for the absolute humidity gradients between the outer layer of a wall surface and the surrounding outside air.

$$\Pi' = \frac{}{d_{v,\,sat}(T_s) - d_{v,\,out}} \quad \left(\frac{kg}{m^3}\right) \tag{1}$$

The Π′-factor is small when there is a low potential for an assembly that got wet to dry out; it is large when the potential for drying out is high. The worst year according to this method would be the year with the smallest value of the Π′-factor.

The exterior wetting potential module is the second construction-independent method that is implemented in the current version of *WeatherSmart.* The module involves only weather data analysis and requires the wind speed-direction and horizontal rainfall hourly data. Through the wetting potential module, the amount of the horizontal rainfall and

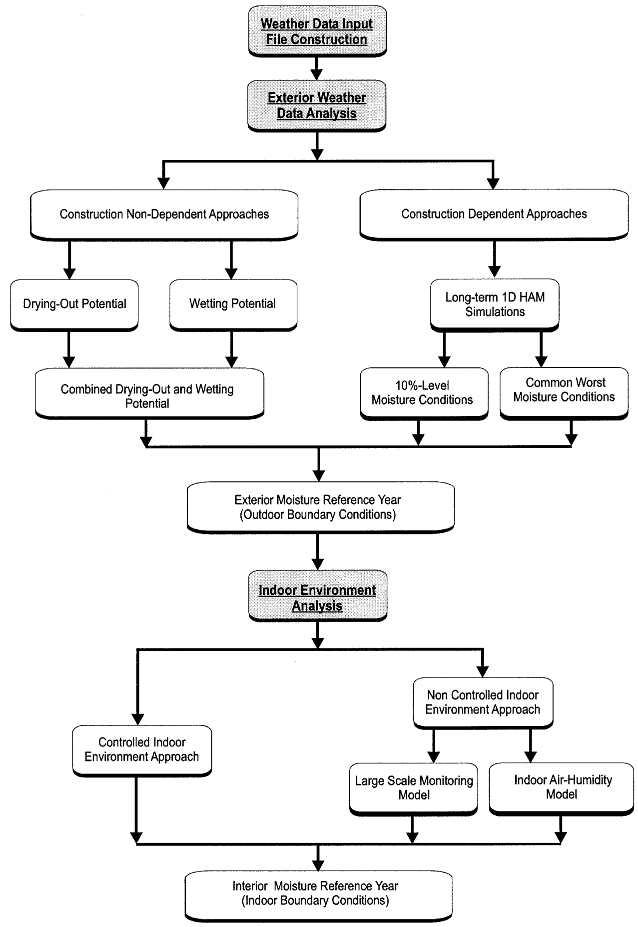

Figure 2 *WeatherSmart and its different modules.*

vertical rainwater passing throughout a vertical plane, vertical rain, can be quantified for each year that constitutes the weather data set. Each year of the data set is characterized by two values: total yearly sum of horizontal rainfall and total yearly sum of the vertical rainfall passing on a vertical plane. The user can select the MRY as being the year of the data set with the maximum rainwater falling on a horizontal plane or the year with the maximum rainwater passing through a vertical plane.

The amount of vertical rain is estimated by Lacy's modified correlation (Lacy 1965) given in Equation 2. For practical reasons, this correlation can be approximated with an error of less than 10% up to winds of 10 m/s. The amount of the yearly horizontal rainfall is obtained by simply summing the recorded rainfall precipitation included in the weather data files. The effect of the orientation of a fictitious vertical surface relative to the wind direction, Θ, has been included in Lacy's original correlation. The vertical surface can be oriented in any direction for analysis. Lacy's correlation predicts the amount of rainwater that a stand-alone driving-rain gauge would measure given out, the wind speed-direction, and horizontal rainfall data taken from the weather file. The surface orientation, Θ, is included for parametric analysis and is not necessary to segregate among the years.

$$r_v = 2/9\ V_{10} r_h^{8/9} \cos(\Theta) \qquad (2)$$

where

r_v = vertical rain (kg/m^{2}h),

V_{10} = wind velocity measured at the reference level, 10 m above the ground (m/s),

r_h = rainfall on a horizontal surface (kg/m^{2}h),

Θ = angle between the wind direction and the normal of the vertical plan.

The third construction-independent method—the combined drying-out and wetting potential method—has been implemented in *WeatherSmart*. It yields identification of the year, among others, of the data set that is the least forgiving if any envelope components gets wet, and at the same time, the most critical in terms of wetting the exterior facade of the envelope components by wind-driven rain. The MRY identified here is the year that has a bad drying-out and a exterior high wetting potential. It is simply the year that yields the greatest value of the product of the yearly vertical rain and the inverse of the Π'-factor.

Construction-Dependent Method To Select Outdoor MRYs. Two modules are included in *WeatherSmart* to identify the MRY using a construction-dependent method analogous to the approach suggested in IEA Annex-24 (Sanders 1996) and by Geving (1997).

- One-dimensional numerical HAM solver that predicts the moisture environments within the selected envelopes for a prescribed time period.
- A moisture load analysis module, by ranking all the years of the data set, identifies the worst moisture years as well as the 10%-level years for the location and the envelope components being considered.

The following steps summarize the guiding principle used in the program to identify the MRYs.

1. Define a set of typical building envelope designs (at least five).
2. Select typical interior boundary conditions (e.g., controlled indoor environment as described later).
3. Prescribe the critical construction orientation to maximize the possibility of moisture wetting. If rain data are available in the weather input file, the prevailing wind direction during rain events can be selected as the critical direction.
4. Perform hygrothermal simulations for as many years of hourly weather data as available (at least one decade of weather data) for every construction defined in Step 1.
5. Investigate the existence of a common worst or 10%-level moisture-critical year for all the constructions selected in Step 1. If none exists, proceed by ranking the comparisons of the years simulated and select the common worst year as the MRY for the considered location.

Indoor Environment Analysis Module

With the interior environment analysis module, an indoor boundary condition can be generated that applies, for hygrothermal calculations, the thermal and moisture loads on the interior surface of the envelope component under consideration. The indoor data includes hourly values of temperature and relative humidity. Two approaches are included in *WeatherSmart* to calculate the indoor air humidity. The two approaches make use of the exterior MRY, which is an output file of the exterior weather analysis module.

Controlled Indoor Environment Method to Select Interior MRYs. An option to derive the air humidity of a commercial and institutional building that is equipped to control the indoor temperature and humidity has been included in the program. Constant values of the indoor temperature for both summer and winter have to be fed into the program. Default values corresponding to the ASHRAE thermal comfort standard are included (ASHRAE 1992). The indoor values for winter conditions suggested by ASHRAE are nominally 21ºC and 30% relative humidity; those for summer are 24ºC and 50% relative humidity.

The controlled indoor environment method requires two types of input data: (1) two values for the indoor temperature and two values for the relative humidity corresponding to the indoor environmental conditions during summer and winter and (2) two values for the balance point temperatures for space heating and cooling conditions. The hourly values of indoor temperature and relative humidity are calculated by comparing the hourly values of the outdoor temperature included in the exterior weather data file with the balance point temperatures. The principle of the method is as follows:

- When the daily average outdoor temperature is below the set point temperature for space heating by two degrees, the building is considered to be operating in space-heating conditions and the indoor temperature and relative humidity are equal to the winter values.
- When the daily average outdoor temperature is two degrees above the set point temperature for space cooling input, the building is considered to be operating in space-cooling conditions, and the indoor temperature and relative humidity are equal to the summer values.
- Where the daily average outside temperature is greater than the set point for space heating and lower than the set point temperature for cooling, the building is considered neither cooled nor heated. In this case, the relative humidity is equal to the exterior ones. The indoor temperature is equal to either the winter or the summer value depending of the outdoor daily mean outdoor temperature.

The threshold value of two degrees between the two set points and the outdoor daily mean temperature has been implemented as a default value in *WeatherSmart*. An option to prescribe different threshold values for either the set point for space heating or the set point for space cooling is built in the current version of *WeatherSmart*.

Non-Controlled Indoor Methods To Select Interior MRYs. Two methods to calculate the indoor air humidity in buildings in which the indoor environment is uncontrolled have been implemented in the current version of *WeatherSmart*. Whereas the first makes use of available large-scale field monitoring data, the second predicts the air humidity using a well-validated model.

Method with Large-Scale Monitoring Data. Large-scale field monitoring of the indoor environment of a large number of buildings has been performed lately in Western Europe (Sandberg 1995). Measured data obtained from this study are currently recommended for hygrothermal calculations by a recent ISO standard (ISO 2000) to derive values of the internal air humidity in different climates. The most important feature of this study is that a statistical analysis of the measured data between the indoor and outdoor environments has been performed. The following five classes of humidity are suggested by this study:

1. very low (e.g., storage areas),
2. low (e.g., offices or shops),
3. medium (e.g., dwelling with low occupancy),
4. high (e.g., dwellings with high occupancy, sports halls, kitchens, canteens; buildings heated with gas heaters and no flue), and
5. very high (e.g., laundry, brewery, swimming pool).

The water vapor pressure difference, Δp, between the interior and exterior environments is given for the five classes. Limits between the classes are a function of the monthly mean outdoor air temperature (see Figure 3). For a monthly mean outdoor temperature below 0°C and above 20°C, the Δp is, respectively, the typical winter value and zero.

This method has been built into *WeatherSmart* to calculate directly the indoor relative humidity for the five classes of humidity according to Equation 3. It requires the input of temperature and humidity included in the outdoor boundary conditions file, the output of the exterior weather analysis module. Having determined the hourly values of both the indoor and outdoor temperatures, as well as the outdoor relative humidity, computation of the indoor relative humidity, ϕ_i, is straightforward. The interior temperature is derived in the same way as that described for the controlled indoor environment.

$$\phi_i = \left(\frac{p_i}{p_s}\right) \times 100 = \left(\frac{p_e + \Delta p}{p_s}\right) \times 100 \qquad (\%) \tag{3}$$

where

p_i = the indoor water vapor pressure (Pa),

p_e = the outdoor water vapor pressure (Pa),

p_s = the saturation vapor pressure (Pa); the water vapor pressure differential, Δp, is obtained from Figure 3.

Method Where Air Humidity is Predicted. The second uncontrolled indoor environment method included in *WeatherSmart* is a steady-state model suggested by Jones (1993) to calculate the water vapor conditions in buildings. The model predicts the indoor humidity based on the humidity mass balance that occurs (1) by moisture transfer through bulk air movement between the inside and outside of a building and (2) by the moisture adsorption and desorption from the fabrics and furnishing inside a building to the bulk air inside a room.

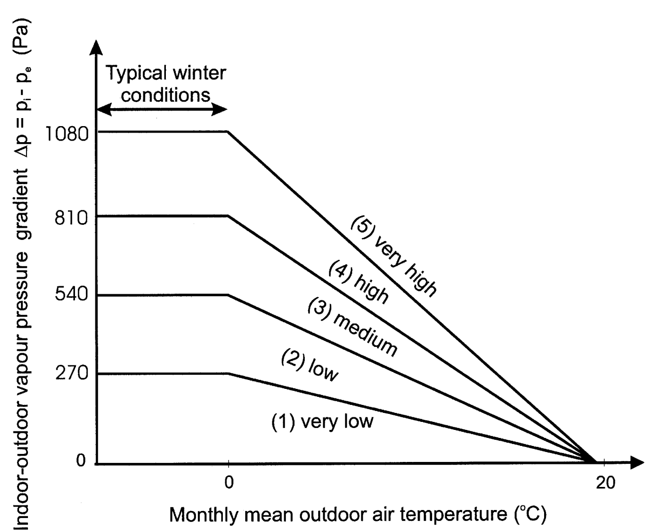

Figure 3 *Variation of internal humidity classes with external temperature for non-controlled indoor humidity buildings, data taken from ISO Standard (2000).*

Jones' formula, the so-called Jones moisture admittance equation, is an upgrade of the earlier Loudon steady-state model (Loudon 1971), which assumes that moisture is carried mainly by ventilation. The main difference is that the moisture admittance model takes into account the moisture absorption-desorption of the inside building surfaces and furnishings. It has been reported that approximately one-third of the moisture generated inside a room may be absorbed by its surfaces (El Diasty et al. 1992). This implies that the hygroscopic behavior of internal surfaces and furnishings should be accounted for in the mass balance of the moisture of the indoor environment. This is particularly true when the ventilation rate inside the building is very low and the dominant process is the moisture transfer to and from the building interior surfaces and furnishings. A recent study (Oreszczyn and Pretlove 1999) involving large-scale field monitoring has demonstrated that Jones' model is more appropriate for transient situations, where changes in relative humidity are determined over short periods of less than a month or a season, e.g., hourly time steps.

The hourly indoor vapor pressures, p_i, are calculated in *WeatherSmart* according to Equation 4 (i.e., the conversion of Jones' formula for humidity ratio, kg/kg, to water vapor pressures, Pa). Use of Jones' steady-state model requires the input of several parameters. It assumes that some features of the building under consideration are already known. This method of calculating the uncontrolled indoor air humidity is useful when a more accurate description of the indoor environment is required. The relative humidity, ϕ_i, is derived simply by dividing indoor vapor pressures by the saturation vapor pressures. The indoor temperature, required to calculate the saturation vapor pressures, is derived in the same way as that described for the controlled indoor environment approach.

$$p_i = \left(\frac{0.0062 I p_e + (Q_g/(28.8v)) + 0.0062\beta p_s}{0.0062(I+\alpha)}\right) \times 1000\ (\mathrm{Pa}) \tag{4}$$

where

I = the ventilation rate (ACH),

Q_g = the rate of the moisture generation (kg/h) (nature and magnitude of the different indoor moisture sources inside buildings could be found in Christian 1994),

v = volume of the room (m^3).

α and β are the moisture admittance factors that reflect the moisture storage behavior of the inside surfaces and furnishings. Typical values for the two admittance factors suggested by Jones (1993) for wood-lined rooms are 0.6 for α and 0.4 for β. A recent study using Jones, moisture admittance factors has confirmed good agreement with large-scale field monitoring data of indoor relative humidity (Oreszczyn and Pretlove 1999).

The ventilation rate inside the building, *I*, is calculated according to Equation 5.

$$I = \frac{Q_{total}}{v} \quad \left(\frac{1}{\mathrm{h}}\right) \tag{5}$$

where

v = volume of the room or building (m^3),

Q_{total} = total volumetric flow rate of air into space (m^3/h). It is a function of the air infiltration from the exterior and, if present, air supply to the mechanical ventilation system. Q_{total} may be prescribed directly as an input in *WeatherSmart* or calculated according to the combined residential infiltration and ventilation method suggested in the *1997 ASHRAE Handbook—Fundamentals*, Chapter 25.

CASE STUDY TO SELECT OUTDOOR MOISTURE REFERENCE YEARS

One example application of the program *WeatherSmart* is presented in this section. The example consists of selecting five outdoor MRYs for five Canadian locations. The MRYs are derived in order to assess the long-term energy efficiency and moisture durability of typical high-rise wall systems in the Canadian type of climate. An hourly-based construction-dependent method implemented in *WeatherSmart* is used for the purpose. This method is described earlier in the present paper.

The five Canadian locations correspond to Halifax (Shearwater), the National Capital Region (Ottawa and Hull), Toronto, Winnipeg, and Vancouver. These locations were selected because of their important stock of commercial and residential high-rise buildings that are of interest in this study.

The envelope components that are used in this study are five wall sections representing typical commercial and residential high-rise building envelope constructions in Canada and are

- brick veneer-with steel stud (Wall 1),
- brick veneer masonry block (Wall 2),
- precast concrete (Wall 3),
- thin stone veneer (Wall 4), and
- load-bearing masonry (Wall 5).

All five walls belong to the heavyweight type and are represented with their different layers in Figures 4-a through 4-e.

One wall orientation was prescribed for each of the five locations. The walls were all oriented to face the prevailing wind direction during rain events obtained from weather data analysis of the considered location. This choice of the wall orientation maximizes the possibility of exterior wetting due to wind-driven rain, which is usually problematic for high-rise buildings.

A systematic approach was undertaken to identify the critical moisture years for each location and high-rise wall system considered. The approach adopted in the present study

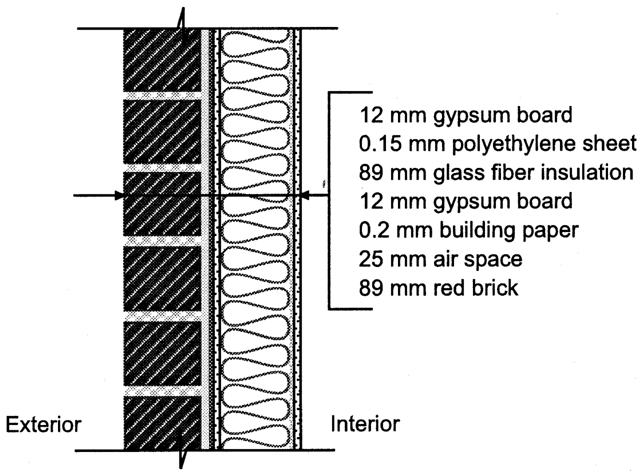

Figure 4-a. *Brick veneer with steel stud backup (*0.22735m*)*

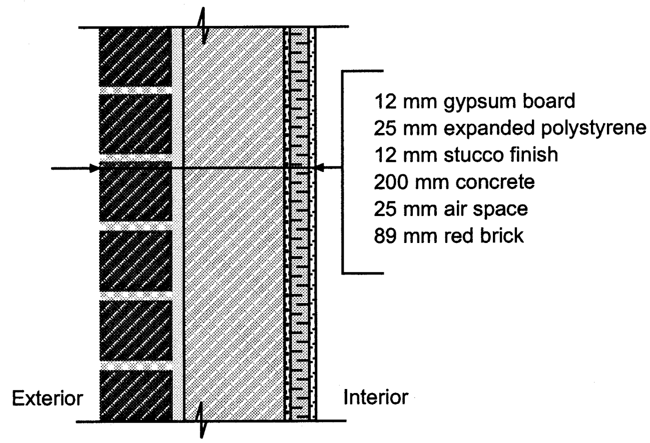

Figure 4-b. *Brick veneer masonry block wall (*0.363m*)*

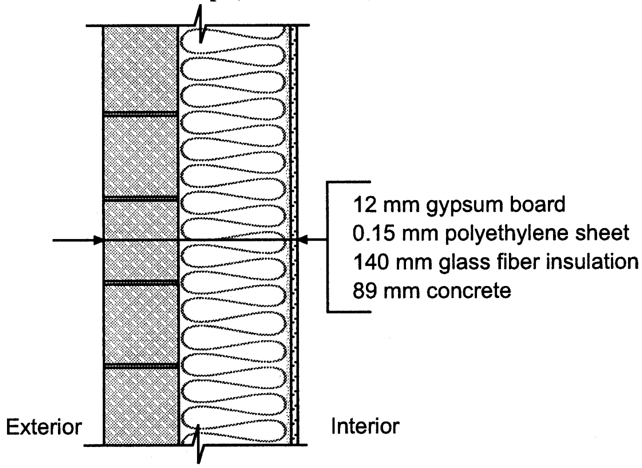

Figure 4-c. *Precast concrete wall (*0.24115m*)*

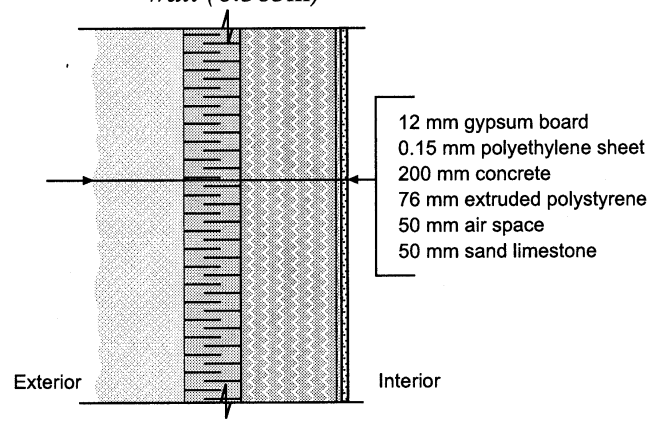

Figure 4-d. *Thin stone veneer wall (*0.38815m*)*

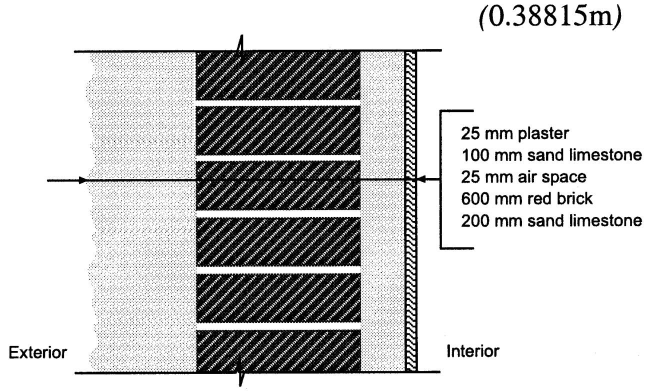

Figure 4-e. *Load-bearing masonry wall (*0.95m*)*

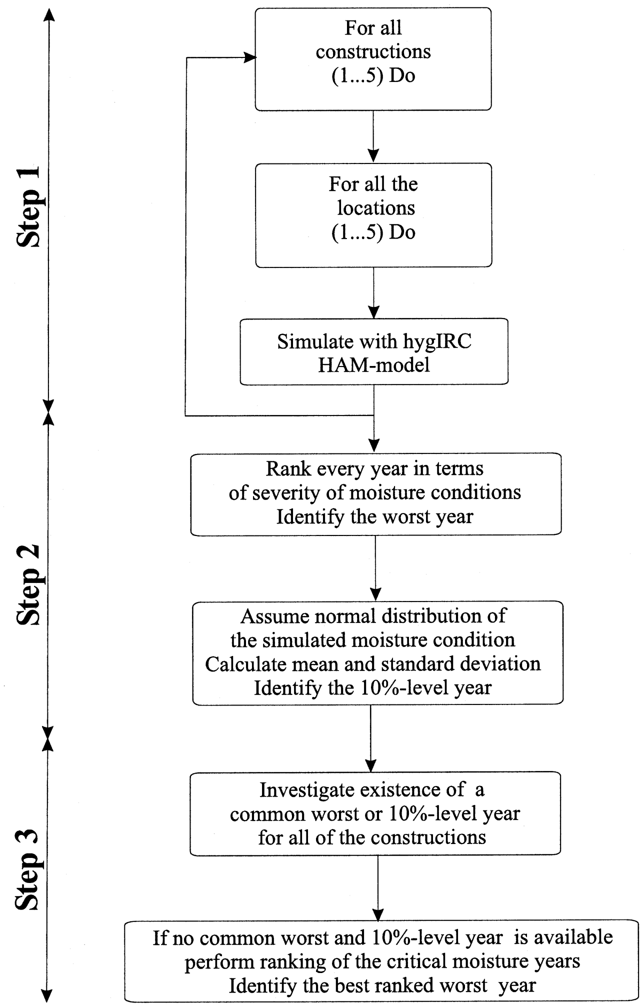

Figure 5 *Schematic of the methodology adopted to select construction-dependent MRYs for five cities.*

is summarized in Figure 5. As depicted in the figure, three main steps are performed to select the reference years.

1. One-dimensional long-term hygrothermal simulations are performed for all of the five walls in each of the five Canadian locations. Five moisture files, corresponding to the simulation results of a particular wall and location, are generated for each city (i.e., a total of 25 moisture files generated).

2. In the second step, the moisture files obtained from the simulations are processed and the yearly average moisture content, MC-Avg, and the maximum daily moisture content, MC-Max, are calculated for each year. Two critical moisture years are generated from each moisture file—the worst and 10%-level years. The worst year is the one characterized by the highest values of MC-Avg or MC-Max and is identified by ranking the years of the data set according to the generated moisture levels during the corresponding years. The 10%-level year has got a 10% chance of reoccurring and is identified from a statistical analysis of the calculated MC-Avg or MC-Max. The 10%-level years are the years with the closest values of MC-Avg or MC-Max to the 10% chance of occurring according to Gaussian statistical distribution.

3. The third and last step consists of performing a series of matches and ranking the critical years to select the moisture reference years. Two tables are generated in this step—the matching years and the ranking years tables, respectively. In the matching years table, all the worst and 10%-level years are identified. A subset of a matching years table is represented in Table 1. The matching years table helps to verify if a *common* worst or 10%-level year exists. The eventual common year will be declared as the moisture reference year for the location considered for all the base-case walls. The ranking years table ranks all the years simulated in terms of moisture severity. An example of a ranking years table is reproduced in Table 2. When no common worst or 10%-level is found, the best-ranked year in terms of moisture severity becomes the moisture reference year. Definition of the best-ranked year will be defined in a later part of this section. Two main criteria have to be fulfilled by any of the considered years in order to be eligible as a critical moisture year in the time period of the whole data set. A high moisture content in the whole assembly of the selected envelopes should be induced during that year, relative to the other years in the study. A high yearly average total moisture content in the assembly is the actual calculated parameter, MC-Avg. A high daily level of moisture content in the whole assembly should also be induced by the same critical year, relative to the other years, MC-Max.

For the first step of this study (see Figure 5), one-dimensional hygrothermal simulations with hourly time steps over three decades were performed using IRC's hygrothermal package HAM solver, hygIRC, which solves for simultaneous heat and mass transfer within porous building envelope materials. hygIRC is an enhanced version of LATENITE, developed jointly between IRC/NRC and VTT Finland (see Karagiozis and Kumaran [1993], Salonvaara and Karagiozis [1994], and Karagiozis et al. [1995]). The three decades of hygIRC weather files used for all hygrothermal simulations are hourly recorded values covering a period from 1:00 a.m. January 1, 1960, to 1:00 a.m. January 1, 1991. The weather files were generated using weather data obtained from the Atmospheric Environment Services (AES) of Environment Canada. The material properties used in the hygrothermal simulations are taken from an IRC/NRC database. A detailed database on hygrothermal properties of a variety of building materials was developed at IRC during the past decade. The grid mesh in each of the layers of the wall systems simulated was optimized intentionally coarse to reduce the computational time but fine enough to not lose the required numerical

TABLE 1
Critical Moisture Years for the Five Canadian Cities

		10%-level year		Drying out worst	Temp worst	RH worst	HorRad worst	DifRad worst
		MC-Avg	MC-Max					
Halifax (Shearwater)	Wall 1	1984	1973	1967	1972	1967	1973	1990
	Wall 2	1979	1967					
	Wall 3	1979	1984					
	Wall 4	1966	1966					
	Wall 5	1968	1967					
National Capital Region	Wall 1	1979	1983	1979	1972	1990	1973	1990
	Wall 2	1968	1982					
	Wall 3	1986	1990					
	Wall 4	1967	1962					
	Wall 5	1981	1982					
Toronto	Wall 1	1973	1966	1972	1972	1972	1973	1964
	Wall 2	1968	1966					
	Wall 3	1968	1972					
	Wall 4	1967	1964					
	Wall 5	1972	1983					
Winnipeg	Wall 1	1962	1987	1980	1979	1969	1968	1971
	Wall 2	1968	1966					
	Wall 3	1985	1985					
	Wall 4	1965	1966					
	Wall 5	1968	1984					
Vancouver	Wall 1	1961	1962	1968	1985	1967	1980	1989
	Wall 2	1962	1985					
	Wall 3	1966	1981					
	Wall 4	1966	1963					
	Wall 5	1967	1980					

precision or to capture the effect of the weather on the considered wall system.

Results obtained from the second step (see Figure 5) of the study are summarized in the matching years table (Table 1). The critical moisture years for the five Canadian locations are summarized using different criteria for moisture severity. The criteria used in the different columns of Table 1 are

- the 10%-level year generating the high yearly average moisture content in a particular wall system when subjected to a particular weather climate, MC-Avg;
- the 10%-level year generating a high daily maximum moisture content in a particular wall system when subjected to a particular weather climate (i.e., the year that causes a day of a maximum moisture content in the wall assembly, MC-Max);
- the year with the lowest drying out potential for the location (Drying-out);
- the coldest year for the location (Temp);
- the most humid year for the location (RH);
- the year with a low total horizontal radiation for the location (HorRad); and
- the year with a low total diffuse radiation for the location (DifRad).

TABLE 2
Worst Moisture Years for Five Canadian Cities

	Worst Year	Walls	MC-Max Rank	MC-Avg Rank	Total Rank
Halifax (Shearwater)	1967	Wall 1	3	1	27
		Wall 2	6	1	
		Wall 3	8	1	
		Wall 4	1	1	
		Wall 5	4	1	
National Capital Region	1984	Wall 1	1	1	27
		Wall 2	1	5	
		Wall 3	1	3	
		Wall 4	1	11	
		Wall 5	1	2	
Toronto	1972	Wall 1	1	1	22
		Wall 2	1	1	
		Wall 3	1	1	
		Wall 4	1	10	
		Wall 5	3	2	
Winnipeg	1983	Wall 1	3	1	63
		Wall 2	1	14	
		Wall 3	1	4	
		Wall 4	9	18	
		Wall 5	6	6	
Vancouver	1963	Wall 1	2	3	21
		Wall 2	2	2	
		Wall 3	3	1	
		Wall 4	4	2	
		Wall 5	1	1	

One can see from Table 1 that each criterion for selecting the critical moisture years gives a different result. This was expected because moisture conditions in building envelopes are a *combination* of all the processes considered in each criterion mentioned above.

The 10%-level years are also quite different for each of the walls and locations, if one has to consider both high yearly moisture content (MC-Avg) and yearly high daily moisture content (MC-Max). Indeed, the results show that the two processes rarely occur in the same year. The 10%-level years approach (i.e., critical moisture conditions occurring in wall structure once every 10-year period) was generally unsuccessful in predicting a common 10%-level year for all the cities.

The same observations were made and documented in previously published results (Sanders 1996; Geving 1997). At the same time, these results justify the use of hygrothermal models to help make a final decision for selecting reference years for any location and in proceeding with the final stage of step 3 described earlier to identify the critical moisture year.

As for the third step (see Figure 5), several ranking calculations were performed to identify the best ranked years in terms of moisture severity for each wall and location. Table 2 summarizes the best ranked years for the five Canadian cities. The ranking of the years is based on the summation of the ranking for each wall and each location. The fourth column of Table 2 ranks the considered years (column 2) in terms of a higher daily moisture content in the structure (MC-Max).

Ranking of the years in terms of the yearly average moisture content in the wall system (MC-Avg) is given in the fifth column. The last column contains the total ranking of all the walls for the year and location considered (i.e., for each location and all the walls of all the rankings according to columns four and five). Each year is characterized by a value corresponding to the total ranking. The year with the lowest total rank is called the best-ranked year and is the moisture reference year for the location considered.

The resulting moisture reference years (i.e., the best ranked worst years) for the five locations are:

1. 1967 in Halifax (Shearwater);
2. 1984 in the National Capital Region (Ottawa-Hull);
3. 1972 in Toronto;
4. 1983 in Winnipeg; and
5. 1963 in Vancouver.

Comparison of these moisture reference years obtained by the construction-dependent method and the critical years obtained with the previous methods (Table 1) indicates that the construction-independent approaches gave different results for the critical moisture years other than in Halifax (Shearwater) and Toronto. Toronto's best-ranked year (1972) was predicted by the drying-out factor, most humid year (RH), and coldest year. Halifax's moisture reference year (1967) coincides with the worst period predicted using the Π'-factor and the most humid year in that city. The MRYs of the National Capital Region (1984) and Winnipeg (1983) are identified by the ranking approach. None of the other methods gave the same critical moisture years.

This result shows that selecting moisture reference years based only on the lowest yearly mean temperature, solar radiation, or maximum relative humidity is not an accurate methodology. Simple approaches, such as the construction-independent method, were relatively successful for only two of the five cities, Halifax and Toronto. The results also demonstrate that extreme moisture conditions rarely occur once every 10 years—at least for the period and locations considered in this study.

Another point highlighted by these results is the fact that the moisture designer still has to decide between two choices—either to design wall systems for the worst moisture year that occurred once in the particular location in case it happens again or to design for the 10%-level year considering that these severe moisture conditions are not extreme but recur most probably every 10 years.

SUMMARY

A survey of the literature shows that there is not yet an internationally accepted method or unique approach for selecting both exterior and interior MRYs. In view of this, several approaches have been implemented in the indoor and outdoor weather analysis computer program, *WeatherSmart 1.0*, developed at IRC/NRC. With this program, users can obtain representative indoor and outdoor MRYs for long-term HAM calculations.

One construction-dependent and three construction-independent methods for selecting MRY have been incorporated in *WeatherSmart*. The construction-independent methods include

- a modified Π-factor method to identify the critical year in terms of drying-out potential,
- a method to derive the critical year in terms of exterior wetting due to wind-driven rain, and
- a method to obtain the critical year that has both a bad drying-out and exterior-wetting potential.

The approach used to obtain construction-dependent MRY implemented in *WeatherSmart* is analogous to the one suggested at the conclusion of the IEA Annex 24. The concept is to use the moisture conditions within some typical constructions as the criteria for selecting a critical common MRY.

Considering that there are mostly two types of indoor environments in buildings—controlled and uncontrolled—one method for controlled and two methods for uncontrolled indoor environments are included in the program. The approach for a controlled indoor environment assumes that the building is equipped to ensure the desired and known levels of interior temperature and relative humidity. The two methods for uncontrolled indoor environments assume that the level of the indoor air humidity is a balance between the moisture gains and losses. The first method for an uncontrolled indoor environment predicts the indoor humidity by correlating the indoor environment with the outdoor weather using statistical data obtained from large-scale field monitoring. The second method for uncontrolled indoor environment correlates the indoor environment with the outdoor weather, ventilation-infiltration, moisture generation rate, stack effect, and the airtightness of the envelope components.

A case study where weather data analysis was performed for five Canadian cities is presented. The case study represents one example of how the weather analysis tool, *WeatherSmart*, is used to obtain an outdoor moisture reference year. The results of this case show that different criteria for moisture severity may imply different reference years depending on the nature of the building envelope considered. The results demonstrate the need for a higher level approach when the combination effects of the different weather parameters on the response of a particular envelope component are to be taken into account. A construction-dependent method to capture all of the weather effects and the building envelope response to the weather is suggested by the authors and is presented in this paper.

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REFERENCES

ASHRAE. 1992. *ANSI/ASHRAE Standard 55-1992, Thermal environmental conditions for human occupancy.* Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASHRAE. 1997. *1997 ASHRAE Handbook—Fundamentals*, Chapter 25. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Christian, J.E. 1994. *Moisture sources*. Moisture control in Buildings, ASTM Manual Series: MNL 18, pp. 176-182.

El Diasty, R., P. Fazio, and I. Budaiwi. 1992. Modeling of indoor air humidity: The dynamic behaviour within an enclosure. *Energy and Buildings* 19: 61-73.

Geving, S. 1997. Moisture design of building constructions: hygrothermal analysis using simulation models. Thesis, Part I and II, Norwegian University of Science and Technology.

Hagentoft, C.-E., and E. Harderup. 1996. *Climatic influences on the envelope using the* Π *factor*. International Energy Agency, Energy Conservation in Buildings and Community Systems Program, Annex 24 Heat-Air and Moisture Transfer in Insulated Envelope Parts (HAMTIE).

Hens, H. 1996. Final Report, Volume 1, Task 1: Modeling. International Energy Agency, Energy Conservation in Buildings and Community Systems Program, Annex 24 Heat, Air and Moisture Transfer in Insulated Envelope Parts (HAMTIE). Belgium: K.U. Leuven, Laboratorium Bouwfysica.

ISO. 2000. Final Draft International Standard ISO/FDIS 13788:2000 (E), Hygrothermal performance of building components and building elements—Internal surface temperature to avoid critical surface humidity and interstitial condensation— Calculation method.

Jones, R. 1993. Modeling water vapour conditions in buildings. *Building Services Engineering Research and Technology* 14 (3): 99-106.

Jones, R. 1995. Indoor humidity calculation procedures. Building Services Engineering Research and Technology 16 (3): 119-126.

Karagiozis, A.N., and M.K. Kumaran. 1993. Computer models for hygrothermal analysis of buildings materials and components. Conference of the CFD Society of Canada, Montreal, Quebec, Canada.

Karagiozis, A.N., M.H. Salonvaara, and M.K. Kumaran. 1995. The effect of waterproof coating on hygrothermal performance of high-rise wall structure. *Thermal Performance of the Exterior Envelopes of Buildings VI*. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Lacy, R.C. 1965. Driving rain maps and the onslaught of rain on buildings. *Proceedings of RILEM/CIB Symposium on Moisture Problems in Buildings*, Helsinki.

Loudon, A.G. 1971. The effects of ventilation and building design factors on the risk of condensation and mould growth in dwellings. Building Research Station Current Paper.

Ojanen, T., R. Kohonen, and M.K. Kumaran. 1994. Modelling heat, air, and moisture transport through building materials and components. *Moisture Control in Buildings*, ASTM Manual Series: MNL 18, pp-18-33.

Oreszczyn, T., and S.E.C. Pretlove. 1999. Condensation targeter II: Modeling surface relative humidity to predict mould growth in dwellings. Proceedings of the Chartered Institution of Building Services Engineers. *Building Services Engineering Research and Technology* 20 (3).

Rode, C. 1993. *Reference years for moisture calculations*. Denmark. Report T2-DK-93/02, International Energy Agency, Energy Conservation in Buildings and Community Systems Program, Annex 24 Heat, Air and Moisture Transfer in Insulated Envelope Parts (HAMTIE).

Salonvaara, M.H., and A.N. Karagiozis. 1994. *Moisture transport in building envelopes using an approximate factorisation solution method*. Toronto: CFD Society of Canada.

Sandberg, P.I. 1995. Building components and building elements—calculation of surface temperature to avoid critical surface humidity and calculation of interstitial condensation. Draft European Standard CEN/TC 89/W 10 N 107.

Sanders, C. 1996. Environmental conditions: Final Report Task 2. International Energy Agency, Energy Conservation in Buildings and Community Systems Program, Annex 24 Heat, Air and Moisture Transfer in Insulated Envelope Parts (HAMTIE). Belgium: K.U. Leuven, Laboratorium Bouwfysica.