A New Look at Residential Interior Environmental Loads

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ABSTRACT

When designing exterior wall systems for residential buildings, interior environmental loads are typically considered as constants, if considered at all. More advanced design and modeling tools may incorporate dynamic interior environmental conditions, i.e., scheduled hourly fluctuations in temperature and relative humidity, into the analysis of wall performance. IEA Annex 14 and 24 recommendations are one alternative for specifying daily interior moisture product rates for use in dynamic hygrothermal performance modeling studies. The use of interior environmental moisture production rates from the ASTM Handbook of Moisture Control or the proposed ASHRAE standard 160P on "Design Criteria for Moisture Control in Buildings" may produce substantially higher interior loads than those observed by measurements. There are two issues that must be examined: the use of appropriate interior calculation methods and the use of appropriate interior loads. In other words, are the IEA Annex 24, ASHRAE, or ASTM Handbook assumed rates of moisture production appropriate for all locations or should they vary?

In this paper, the authors report measured interior temperature and relative humidity in several units of multifamily housing and compare the measured moisture production rates to the rates suggested by other design sources. In general, measured moisture production rates in Seattle were found to be lower than the handbook design rates. Using measured interior moisture production rates versus calculated ones may produce distinct differences in hygrothermal performance modeling analysis of exterior wall systems. The modeled performance differences resulted in significantly different wall component recommendations depending on the interior moisture production rate chosen. The authors conclude that using a single handbook design moisture production rate and suggested interior calculation load for hygrothermal performance modeling analysis is not appropriate in all cases but, rather, that the standards should require hygrothermal analysis using at least two of three possible ranges of interior moisture production, i.e., low, medium, or high. The authors suggest that the choice of which range of moisture production rates to use should be based on the designer's investigation of how the building will be occupied and the type of HVAC system used.

INTRODUCTION

Weatherization of older homes or the construction of new, relatively airtight, energy-efficient homes have been anecdotally blamed for high interior moisture conditions during various periods of the year. High interior moisture loads can introduce an array of potential building problems, such as condensation on interior surfaces and windows, mold growth and musty odors, and deterioration of interior furnishings. As a consequence, indoor air quality may be jeopardized by tight home construction if the only method for providing ventilation is passive. As the rate of North Americans diagnosed with asthma increases each year and the awareness of the causes of "sick building syndrome" also grows, control of the interior environment becomes ever more critical.

Moisture control in residential homes depends on the rate of moisture production, the exterior climate, and ventilation system design and operation. Unlike temperature control, direct humidity control is seldom included in residential and some commercial buildings other than as a by-product of mechanically cooling air. Currently, open literature for major North American cities contains limited data regarding interior moisture load characteristics.

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Over the course of 2+ years, portable relative humidity and temperature (RH/T) sensors were deployed in several apartment and condominium units throughout the city of Seattle. The main purpose of collecting these data was to augment the paucity of existing data regarding measured interior relative humidity and temperature conditions within occupied multifamily units. A secondary purpose of this data collection was to compare the measured interior boundary conditions against the recommended interior boundary conditions for use in hygrothermal modeling studies that were being undertaken for a wide variety of wall systems typically used in Seattle.

TenWolde and Walker (2001) recently summarized most of the options available for establishing interior boundary conditions for purposes of moisture design analysis. They outlined a methodology to obtain design values for indoor boundary conditions that has been proposed for use by ASHRAE Standard Committee 160P, "Design Criteria for Moisture Control in Buildings."

The proposed SPC 160P method recommended for determining the interior boundary conditions was initially chosen for purposes of the Seattle Building Enclosure Hygrothermal Performance Study in 2002. In the end, the proposed ASHRAE 160P methodology was not used for the Seattle Hygrothermal Modeling project, and IEA Annex 24 recommendations were also abandoned in favor of using averages from the measured data gathered during the course of the Seattle study.

INDOOR CONDITIONS

ASHRAE recommends that indoor temperatures during the winter months be maintained between 68°F and 75°F and indoor temperatures during the summer months should be between 73°F and 79°F. In practice, complaints may occur with any temperature not maintained at 72°F with some air circulation. Relative humidity (RH) measures the amount of moisture in the air; ASHRAE recommends RH be maintained between 30% and 60% for indoor environments. RH below 30% can cause drying of the mucous membranes and discomfort for many people. RH above 60% for extended time periods promotes indoor microbial growth.

Interior environmental conditions in residential buildings are dynamic, changing as a function of building systems (mechanical ventilation systems, humidifiers, dehumidifiers, etc.), exterior climatic conditions, inhabitant activities, the number of plants within a dwelling, and the kind of objects within the interior environment capable of storing moisture. Indoor conditions that affect the heat, air, and moisture transport in building envelopes include:

- Temperature
- Moisture content of the air (RH must be used carefully)
- Internal pressures
- Thermal sources
- Moisture sources

A significant amount of moisture can be produced within dwellings, and intentional means of removing that moisture do not exist most of the time. Water vapor is typically removed by air change, either by natural air leakage through the building envelope or by mechanical ventilation systems. Another mechanism to remove excess water vapor from the interior of buildings is to use dehumidification equipment designed with the capacity to remove interior moisture production loads. An essential component to maintaining good indoor air quality is controlling the level of moisture vapor in the interior air. The most cost-effective way to control moisture is at the source of its production.

SOURCES OF MOISTURE

There are many sources of moisture that can increase the amount of water vapor in the building interior. Some sources have nothing to do with the operation of the building, such as the construction moisture content of the building materials, water table level/water and vapor ingress from the ground, and basement and crawlspace walls storing and transporting large quantities of water vapor to the interior. Penetration of wind-driven rain and exterior water into building envelope elements also creates seasonal moisture storage effects. Most of the time, each source of moisture is independent of the other, but combined together, they may account for significant amounts of available water to affect interior environmental conditions and building enclosure performance.

PEOPLE AS MOISTURE SOURCES

In Denmark, research work grouped the different sources of moisture production in dwellings as follows:

- Transpiration from the human body
- Evaporation from plants
- Personal hygiene activities
- Cleaning of dwellings
- Washing up
- Laundering and subsequent drying
- Cooking

Inhabitants and their use of the building may generate a significant amount of water vapor that is released to the interior environment, though they may not necessarily be the largest source at all times. Table 1, from a publication by LBNL, shows the distribution of moisture loads for various activities in terms of pints of water per day.

In general, open literature data for a family of four gives the following moisture production values:

- 3.5 kg/day (7.7 lb/day) of moisture release from our body;
- plants contribute 0.46 kg/day (1.0 lb/day);
- personal hygiene contributes about 0.5 kg/day (1.1 lb/day; family of four about 1.3 kg/day or 2.9 lb/day);
- house cleaning contributes about 0.2 kg/day (0.4 lb/

Table 1. Household Moisture Sources

Moisture Source	Estimated Amount of Moisture (Pints)
Aquariums	Replacement of evaporative loss
Tub bath (excludes towels and spillage)	0.1/standard size bath
Shower (excludes towels and spillage)	0.5/5-min shower
Combustion (unvented kerosene space heater)	7.6/gal of kerosene burned
Clothes drying (dryer not vented outdoors, or indoor drying line)	4.7-6.2/load
Cooking dinner (family of four, average)	1.2 (plus 1.6 in gas oven/range)
Dishwashing by hand (dinner, family of four)	0.68
Firewood stored indoors	400-800/6 months
Gas range pilot light (each)	0.37/day
House plants (five to seven plants)	0.86-0.96/day
Humidifier	2.08/hour
Respiration and perspiration (family of four)	0.44/hour
Refrigerator defrost	1.03/day
Saunas, steam baths, and whirlpools	2.7/hour
Combustion exhaust gas backdrafting or spillage	0-6,720/year
Desorption of building materials and furnishings (seasonal)	6.33-16.91/average day
Desorption of building materials and furnishings (new construction)	10/average day
Ground moisture migration	0-105/day
Seasonal high outdoor absolute humidity	64-249/day

Source: *Moisture Sources Associated with Potential Damage in Cold Climate Housing* (1988)

day);

- washing up contributes approximately 0.4 kg/day (0.9 lb/day);
- laundry and drying contribute anywhere from 0.1 kg/day to 1.8 kg/day (0.2-4.0 lb/day); and
- cooking contributes approximately 0.897 kg/day (2 lb/day).

Summing up these values, a typical family of four may produce 4 to 14 kg/day (9-31 lb/day) of moisture. This value can be compared to values given by NRCan, which states that a typical household of four people release up to 160 L (42 gal) of water into the air within their dwelling each month. Add to that other common sources of moisture—from gas appliances, saunas, long showers, leaky plumbing, etc.—and it's easy to see how homes can suffer from poor air quality, property damage, and, in severe cases, major structural problems due to excessive interior moisture. In addition, health experts know that fungi, mold, and dust mites flourish in damp areas and can cause health problems such as allergies and asthma.

APPROACHES TO ESTABLISHING INTERIOR ENVIRONMENTAL BOUNDARIES

Ten Wolde and Walker (2001) report that no standardized methodology for moisture design exists as yet, but ASHRAE Standard Committee 160P (2002), Design Criteria for Moisture Control in Buildings, is attempting to formulate appropriate design assumptions for moisture design analysis and criteria for acceptable performance. The standard will include interior design loads (temperature, humidity, and air pressure) as well as exterior design loads (temperature, humidity, and rain).Ten Wolde and Walker (2001) assert that the question of whether design features such as vapor retarders or ventilation systems are necessary cannot be answered unless there is a consensus definition of interior and exterior moisture boundary conditions that the building is expected to sustain without negative consequences to itself or its inhabitants. TenWolde and Walker report that the SPC 160P standard will include interior design loads (temperature, humidity, and air pressure) as well as exterior design loads (temperature, humidity, and rain). Although it is common to impose very stringent criteria for structural design because of safety concerns, moisture damage usually occurs over a long period of time and usually has less disastrous, although sometimes costly, consequences. Ten Wolde and Walker note that a consensus is beginning to emerge that a 10% likelihood of failure is an appropriate level in building moisture design analysis and that the definition of failure will also be addressed in ASHRAE Standard 160P.

Ten Wolde and Walker state that in a moisture analysis for building envelope design, the choice of indoor environmental conditions is extremely important, especially for buildings in cold climates. They note that several European countries have defined Indoor Climate Classes. For instance, Tammes and Vos (1980) describe four climate classes for use in the Netherlands based on interior vapor pressure ranges. This approach requires a different definition for each climate and does not account for large seasonal changes. They also note that Sanders (1996) and the IEA Annex 24 take a different approach and define four climate classes on the basis of three critical indoor vapor pressures or "pivot points." These pivot points are related to the occurrence of condensation in a north-facing wall, net annual moisture accumulation in a north-facing wall, or net annual moisture accumulation in a flat roof. These pivot points depend on construction and climate.

The approach to establishing indoor environmental boundary conditions favored by TenWolde and Walker is independent of construction type but includes the influences of ventilation and air-conditioning equipment, as well as controls that may or may not be part of the building design. In Seattle residential buildings, indoor humidity is rarely controlled, and summer air conditioning is rarely employed. Thus, during winter conditions, as Ten Wolde and Walker note, the indoor humidity depends on a combination of sources (such as people, humidification, and foundation moisture) and building ventilation. For summer conditions in Seattle, considerations of interior boundary conditions can be somewhat simplified and often equated with outdoor conditions as windows are typically left open.

DESIGN INDOOR HUMIDITY FOR HEATING

Ten Wolde and Walker (2001) state that humidity of indoor air is the result of a balance between moisture gains, moisture removal from the building, and net moisture exchange with hygroscopic materials inside the building. TenWolde (1994a, 1994b) showed that moisture storage in residences stabilizes the indoor humidity and that daily or even weekly averages can be used for the purpose of building moisture analysis. Ignoring storage and using time-averaged values for the other parameters allows the determination of the indoor vapor pressure:

$$P_i = P_o + \frac{P_{atm} m_s}{0.62198 m_v} \quad (1)$$

where

P_i = indoor vapor pressure, in. Hg (Pa),

P_o = outdoor vapor pressure, in. Hg (Pa),

P_{atm} = atmospheric pressure, in. Hg (Pa),

m_s = moisture source rate, lb/h (kg/s),

m_v = ventilation rate, lb/h (kg/s).

The ventilation rate for residential buildings is often expressed in terms of air changes per hour, rather than as a mass flow rate. The mass flow rate can be obtained from the air change rate using Equation 2:

$$m_v = \frac{\rho V I}{n} \quad (2)$$

where

ρ = air density, lb/ft^3 (kg/m^3);

V = building volume, ft^3 (m^3);

I = air exchange rate, 1/h;

n = 1 in IP units, 3600 s/h in SI units.

Combining Equations 1 and 2 with the assumption of a standard atmospheric pressure of 29.9 in. Hg (101.3 kPa) and air density of 0.075 lb/ft^3 (1.2 kg/m^3) yields a simple equation:

$$p_i = p_o + \frac{c m_s}{VI} \quad (3)$$

where

c = 641 in. Hg ft^3/lb (4.89 × 10^5 m^2/s^2).

Ten Wolde and Walker report that the moisture source term in Equation 1 includes both generation (e.g., people) and dehumidification. If dehumidification exceeds the rate at which moisture is added, this term becomes negative.

In the Seattle project, we adopted the equations above but also accounted for the transient moisture capacity of the air. The air was allowed to be influenced by the condition of air in the previous hour. In addition, humidification was allowed to bring the relative humidity to either 15% or until surface condensation appeared on a window with a U-factor of 0.35 (IP). While it is well understood that windows have a multidimensional distinct distribution of heat flow, this uniform U-factor approach of 0.35 allowed more sophistication than that proposed in ASHRAE Standard 160P and is expected to give values that are a closer representation of typical conditions. Table 2 shows measured and established data from the International Energy Agency (1991) and Christian (1993) and TenWolde (1988, 1994).

Figures 1 and 2 show the indoor boundary conditions as predicted by the proposed ASHRAE 160P method for two different daily moisture production rates of 5 kg/day and 10 kg/day, respectively. Two years of exterior data were employed, starting from January 1. It is evident that by using the above-described method, substantial fluctuations result in the hourly relative humidities. No damping is taken into account due to the moisture absorption or desorption of building furnishings, though Virtanen et al. (2000) reported that such damping can have a significant role in reducing humidity peaks during short load periods.

Figure 3 shows the seasonal humidity ratio as a function of temperature for each month of the year for Seattle, which is shown to be humid not only during the summer periods but also during the fall season (September and October) concurrent with the rainy season. Information on the seasonal humidity ratio is critical for building envelope designers for better understanding of the interior loads. It is important to identify the different periods and seasons so that the importance of the shoulder seasons (seasons that the interior space is not air-conditioned) be identified and appropriately taken into consideration.

The above method of predicting the indoor humidity of a building, known as the Loudon method, is based on the mass balance between the humidity generation and loss due to ventilation. No account is taken of the moisture absorption and desorption by the interior surfaces, furnishings, and envelope contributions. As much as a third of the water vapor generated in a room can be absorbed by its surfaces so that ventilation rates necessary to control humidity levels can be considerably overestimated (Kusuda 1983). A simplified but robust method to accommodate the complex heat and mass transfer on interior surfaces of a building is the revised moisture admittance model as described by Jones (1995).

Table 2. Daily Residential Moisture Production (TenWolde and Walker 2001)

	Daily Moisture Release (kg/day) Per Household Type			
Source	**1-2 Adults**	**1 Child**	**2 Children**	**3 Children**
International Energy Agency (IEA 1991) and Christian (1993)*		10		
			5-10	
				14.4
	7	20		
			14.6	
	13.2	19.9	23.1	
		11.5		
		5-12		
		6-10.5		
	4.3			
TenWolde (1988), home 1	7.2			
TenWolde (1988), home 2	6.8			
TenWolde (1988), home 3	8.5			
TenWolde (1994b), home 1	6.6			
TenWolde (1994b), home 2	5.5			
TenWolde (1994b), home 3	6.6			
TenWolde (1994b), home 4	6.6			
Average	7.2	11.9	13.3	14.4

* Data in IEA (1991) are in Table 6.2, p. 6.5.

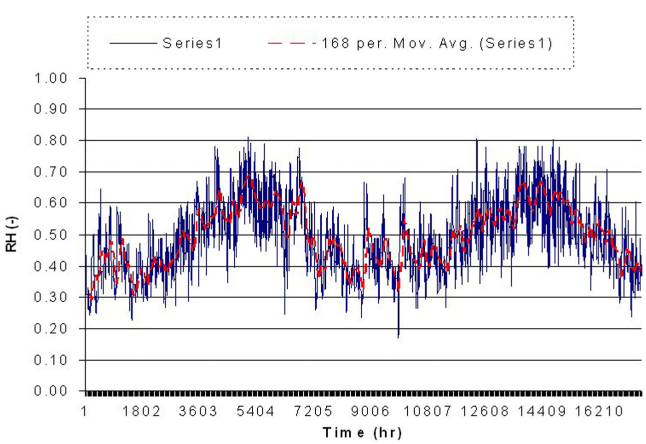

Figure 1 *Seattle interior RH as a function of time (Md = 5 kg/day, ACH = 0.5, A = 200 m²).*

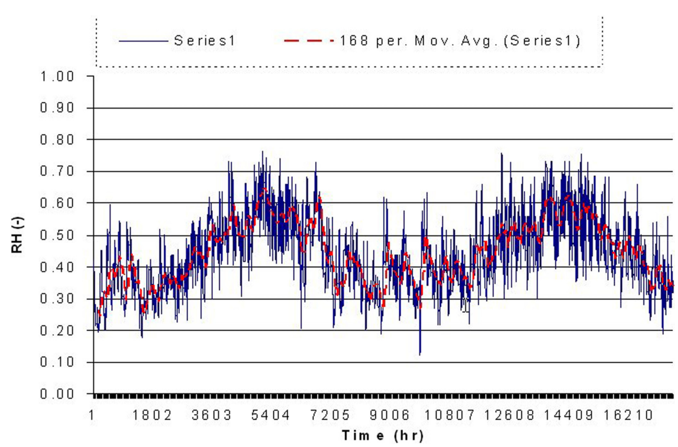

Figure 2 *Seattle interior RH as a function of time (Md = 10 kg/day, ACH = 0.5, A = 200 m²).*

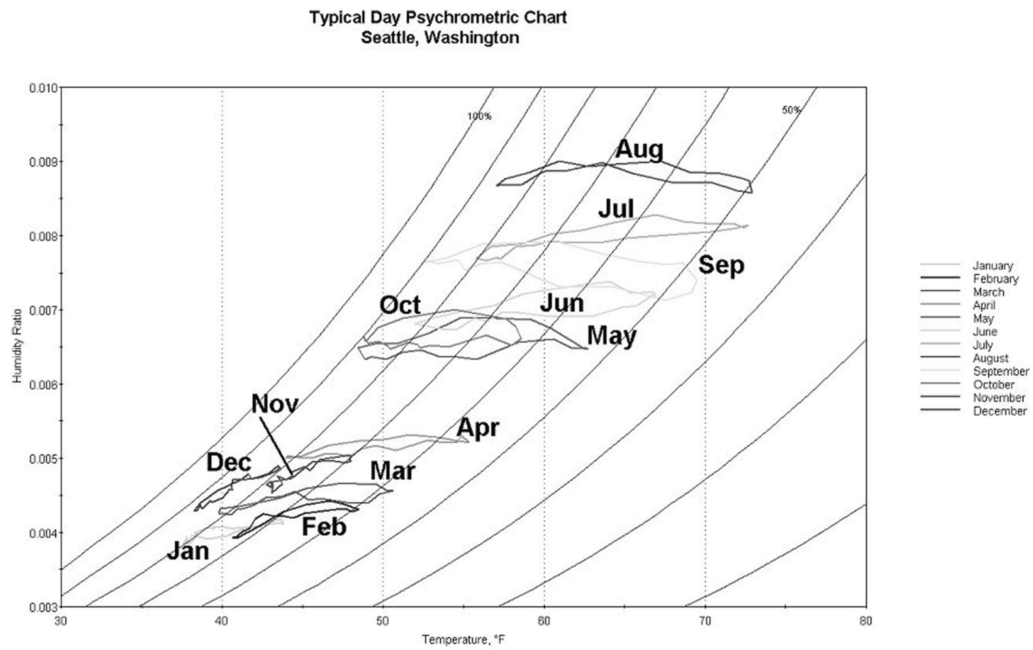

Figure 3 *Seasonal humidity ratio in Seattle.*

$$\frac{\partial(VP_{in})}{\partial t} = \frac{G}{\rho V} - n(VP_{in} - VP_{out}) - \frac{kA}{\rho V}(VP_{in} - VP_{in-mean}) \quad (4)$$

where $VP_{in-average}$ can be calculated by assuming a moisture material storage time constant τ using a weighting factor for an event at time n, as defined by TenWolde (1987) as

$$VP_{in-average} = \frac{\sum_{n=t-4\tau}^{n=t-1} e^{-\frac{n}{\tau}} VP_{in-average}}{\sum_{n=t-4\tau}^{n=t-1} e^{-\frac{n}{\tau}}} . \quad (5)$$

Good agreement was found using the moisture admittance model by Plathner (1999). More than 80% of the calculated values matched measured values within 5%. When the model did not include the approximation for absorption/desorption effects, only 60% of the simulated measured data fell within 5% of the measured data.

Figure 4 illustrates interior relative humidity conditions that were calculated using the 10% percentile cold and hot years. The histogram show that nearly 60% of the interior relative humidity results range between 40% and 50% RH. However, close to 30% of the results show excessively high interior conditions greater than 60% RH. These results illustrate the need for additional research for better understanding of the interior moisture loads.

In Figure 5, histograms for both calculated and measured data are shown for one Seattle apartment. In the calculations, it was assumed that the building interior had an air change rate of 0.5 and a moisture production rate of 5 kg/day. The 10% cold year exterior weather file was used. The agreement

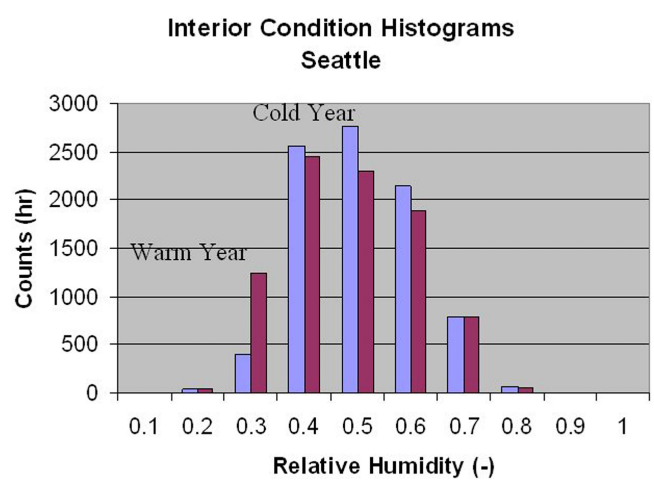

Figure 4 *Numerically generated interior condition for 10% percentile cold and hot years.*

between calculated and measured could be improved if actual measured weather data was used and if the air change per hour value is accordingly adjusted. The results clearly show the need to define the interior conditions more accurately than simply entering inputs into the equations sets. The results can also be interpreted as providing a margin of safety for hygrothermal modeling, but, as will be discussed below, this margin may be too great in certain climatic regions and lead to design decisions that may negatively influence exterior wall hygrothermal performance.

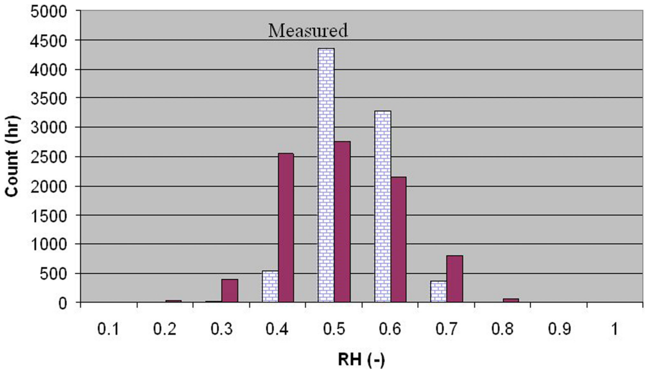

Figure 5 *Comparison of generated interior conditions and measured values (estimated ACH = 0.5, moisture production at 5 kg/day).*

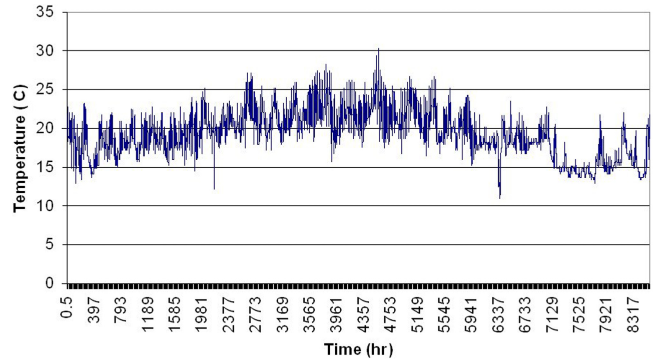

Figure 6 *Measured interior temperature conditions for an apartment in Seattle.*

While we have primarily focused on measuring and comparing the interior relative humidity, equally important is the interior temperature in the building. Usually, most modeling activities assume fixed interior temperatures. Figure 6 tracks the interior temperature in one apartment for one year starting on January 1. Temperatures as low as 11.5°C and as high as 31°C were recorded. Daily amplitudes as high as 2.5°C to 3°C are observed. It is evident that during hygrothermal modeling, it is necessary to include the effects of seasonally adjusted temperatures. These small seasonal and daily changes have a considerable effect on the resulting interior relative humidity.

Figure 7 shows measured relative humidity histograms for six different interior homes (series 1 to 6). The results depicted here are a subset of all the data measured and may not be representative of all interior environmental conditions in Seattle dwellings. The results indicate that critical relative humidity exceeding 60% is present in these dwellings only a small fraction of the time. Relative humidity below 60% typically translates into lower interior vapor pressures than may be present within a wall assembly, though this may not always be the case. The critical observation is that the potential exists for a wall system to dry toward the interior when needed due to the vapor pressure difference.

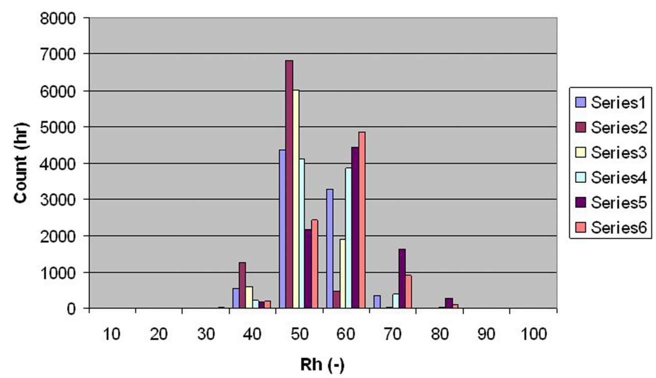

Figure 7 *Measured relative humidity histograms for six different interior homes (series 1 to 6).*

EFFECT ON HYGROTHERMAL MODELING ACTIVITY AND DESIGN DECISIONS

In the absence of a standardized method for defining interior boundary conditions, the Seattle Building Enclosure Hygrothermal Performance Modeling Study was initially carried out using interior moisture production rates and temperature regimes based on IEA Annex 24. Exterior boundary conditions were chosen using the ASHRAE 160P recommended method of using hot and cold reference years, one year representing 10% of the coldest years and one year representing 10% of the warmest years.

The hygrothermal modeling of the Seattle wall systems was carried out using the state-of-the-art modeling tool MOISTURE-EXPERT, developed by Karagiozis (2002). MOISTURE-EXPERT allows use of dynamic hourly weather data and hourly interior conditions to predict the two-dimensional flow of heat, air, and moisture through an exterior wall system based upon the hygrothermal properties of each component in the wall. In addition, a leakage rate can be introduced into the model to simulate a defect or crack in the wall, thus allowing wind-driven rain to penetrate the exterior cladding and weather-resistive barrier to be deposited on the sheathing layer. For the Seattle study, a 2% leakage rate was used, which means that 2% of the wind-driven rain striking the surface of the exterior cladding was allowed to penetrate to the sheathing layer of the walls modeled.

Figure 8 shows how indoor boundary conditions can affect hygrothermal modeling results of a typical wall in Seattle. The ASHRAE 160P method recommended for calculating

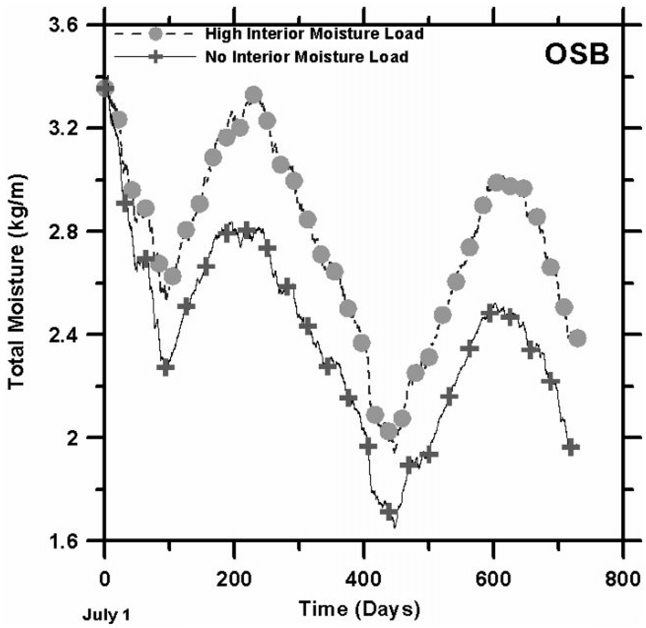

Figure 8 Hygrothermal effect of interior moisture conditions.

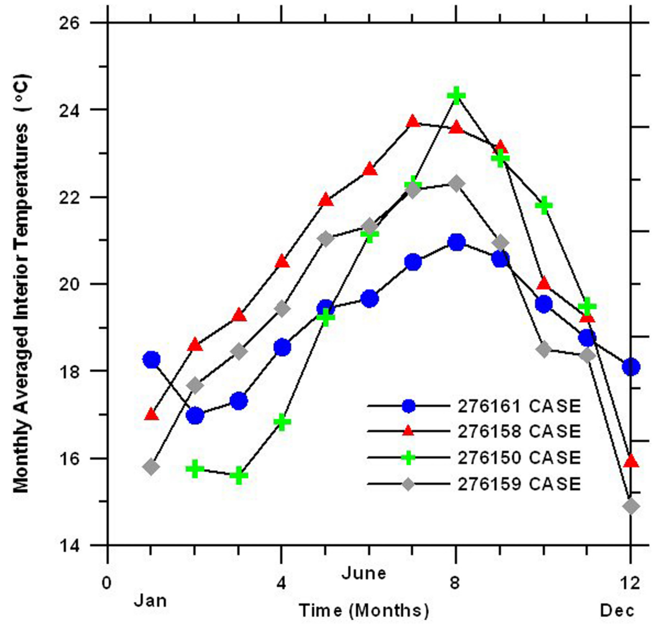

Figure 9 Monthly averaged interior temperatures (°C).

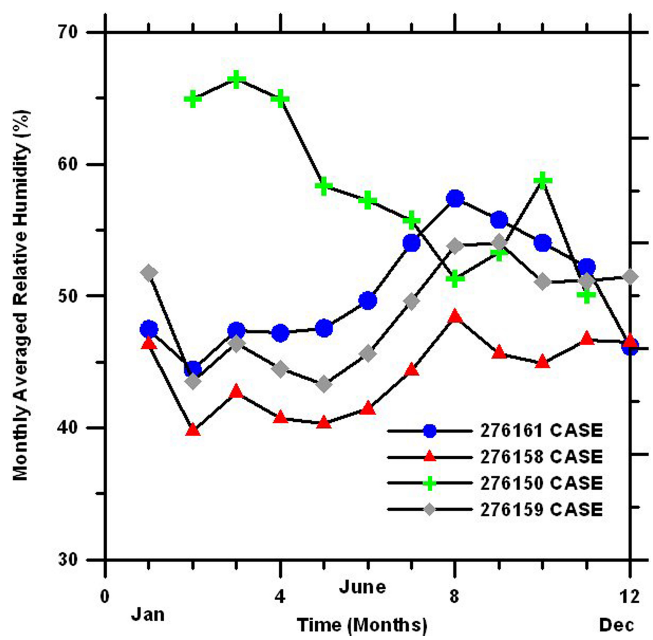

Figure 10 Monthly averaged interior relative humidities (%).

indoor boundary conditions was used to create two moisture production rates, one high and the other low. Figure 8 shows the total predicted moisture accumulation in the oriented strand board sheathing layer, typically the most vulnerable layer of a wall system. The walls modeled are identical, and a vapor open interior system was employed, i.e., absence of a poly vapor barrier. The results show the importance of interior loads on the performance of this stucco-clad wall.

As measured RH/T data were not available for interior conditions in Seattle, 20 apartment and residential buildings were instrumented to measure temperature and relative humidity on either a 15-minute or ½-hour basis. These measurements provided additional confidence in the simulated results, as interior moisture loads have an important impact on the overall performance of exterior walls. Data gathered from the installed RH/T sensors were used to develop interior moisture schedules for the large-scale parametric investigation for the city of Seattle. From this rather large set of data, only a small fraction will be presented here.

In Figure 9, measured monthly averaged interior temperatures are plotted for four different dwellings. It is evident that in Seattle, the interior temperature is strongly influenced by yearly seasonal cycles. While temperature is controllable through the use of a thermostat, Figure 9 shows that temperature is not a constant value throughout the year. The monthly averaged interior temperature was found to peak during either July or August and was coldest during the month of December.

In Figure 10 the monthly averaged relative humidity is shown for the same four apartments. With the exception of apartment 276150, none of the other apartments exhibits monthly relative humidities higher than 60%. For apartment 276150 only 10 monthly values were available. All sensors were recalibrated after the monitoring period and did not show drift problems and were within the measurement uncertainty of the manufactured sensors. The highest monthly relative humidities were recorded during the summer, followed by the fall and winter seasons and picking up moisture later in the spring season.

CONCLUSIONS AND DISCUSSION

The purpose of this paper is to provide measured interior data and to show the significance of the needed inputs to define the interior conditions analytically for Seattle's mixed humid/marine climate. Granted, the number of variables affecting wall performance is staggering, but analyzing wall designs based solely on standard analytical procedures that do not include a method to account for leaks or unique local conditions can unnecessarily exclude consideration of potentially beneficial design options. By assigning a value to a potential water leakage rate and by tailoring indoor boundary conditions as much as possible to local conditions, we can begin to grasp the dynamic forces that affect the ability of a wall to dry and begin to develop wall systems appropriate for local conditions.

In Seattle's mixed humid/marine climate, exterior vapor pressure is typically greater than interior vapor pressure five to six months of the year, which limits an exterior wall's ability to dry to the outside. When drying to the exterior is limited, building enclosures either need to have the ability to safely store moisture within the wall system until exterior environmental conditions allow drying to the outside or the walls need to be designed to dry to the interior as conditions warrant. Thus, the choice of indoor boundary conditions is a critical variable in analyzing the ability of a wall to dry in Seattle. Conservative design decisions with respect to the hygrothermal performance of exterior wall systems may lead to material choices that can ultimately be more harmful to the long-term performance of the building enclosure.

For the Seattle Building Envelope Hygrothermal Performance Study (Karagiozia 2002), the hygrothermal analysis showed that a Class I vapor barrier (Lstiburek 2002) prevented the relatively high interior moisture loads, which were initially based on the IEA Annex 24 recommended indoor boundary conditions, from collecting in the exterior wall system. Thus, using these results, a designer would most likely eliminate consideration of wall systems that did not employ some type of robust vapor control strategy. While this result is entirely defensible and logical, the IEA Annex 24 indoor boundary conditions did not correlate well with relative humidity and temperature values subsequently measured in Seattle. Using the measured data as the basis for indoor boundary conditions, the hygrothermal modeling results showed that walls with Class I vapor control provided by a polyethylene sheet were not able to dry as much as the same wall with Class III vapor control (Lstiburek 2002) provided by two coats of latex paint, similar to the results plotted in Figure 8.

To be sure, standards are necessary to promote the adoption and implementation of design practices deemed necessary or otherwise beneficial. Consensus standards are established to address boundary conditions also established through a consensus process. Boundary conditions defined by field measurements can be limited in their usefulness, especially if there is a wide variation in measurements that can call into question the reliability of averages derived from the measured conditions. One must also consider whether the time frame over which data are collected is long enough to signal an accurate trend or an anomaly. Thus, the benefit of standardizing boundary conditions is that direct comparison of outcomes can be made between different systems subjected to the same conditions. With regard to standardizing hygrothermal design considerations and modeling, the differences between hygrothermal regions suggests that standard boundary conditions should be developed based on the unique boundary conditions found within each region.

The reason for our departure from the proposed standards for establishing interior boundary conditions lies mainly in the consistent magnitude of the difference between the measured and predicted values and the fact that this difference was an important variable in deciding which wall components are appropriate for the Pacific Northwest's mixed humid/marine hygrothermal region. The following approach to using standard indoor boundary conditions is suggested for use in moisture design analysis:

1. Don't rule out the possible benefits of different vapor-retarding strategies based solely on results from computer models using standard design conditions.
2. Hygrothermal performance models should be employed using at least two of three indoor boundary conditions, e.g., low, medium, and high moisture conditions (such as that used in the WUFI program), based on the designer's investigation of the likely interior loads and HVAC system operation.
3. Standards in development should consider requiring analysis based on relatively high and low ranges of interior moisture production in order to assess how the choice of envelope components may affect overall exterior wall performance.

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