# Scientific Analysis of Vapor Retarder Recommendations for Wall Systems Constructed in North America

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## ABSTRACT

*The transport of heat and moisture in buildings is complex. Hygrothermal transport is dynamic, multiphase, multidimensional, and interfacial in a porous media. Vapor, liquid, and ice may be present at the same time within an envelope structure. The hygrothermal performance of the envelope component is also directly dependent on the specific interior and exterior loading. These are some of the reasons why simple generalizations with regard to design elements in building envelopes do not work. One of the best examples is the selection of vapor retarders in building envelopes.*

*There has been considerable controversy about what needs to be done to control moisture vapor movement in the walls of US residential homes. Indeed, guidance in the selection of vapor retarders becomes even more critical for the highly insulated walls that are being proposed for the future net zero energy buildings. In 2003, the U.S. Department of Energy investigated research work to provide a series of recommendations to propose changes to the energy codes. Initial proposals were met with some resistance, primarily based on the fact that there was a perceived lack of scientific backing to the proposals. The Oak Ridge National Laboratory, working in close collaboration with Building Science Corporation, developed a plan to perform a series of hygrothermal computer simulations. These simulations validated previous understandings and provided additional insight on some of the complex interactions present in building envelopes. They also included the impact of 1% water penetration on the sheathing membrane as an additional load as well as the impact of air conditioning during the summer months. These results became the basis for the vapor retarder recommendations. This paper summarizes the scientific evidence for the recommended code changes that were submitted to the International Energy Code Council.*

## INTRODUCTION

In many parts of the United States, damage caused by uncontrolled moisture accumulation in building enclosures is of great concern to the construction and energy conservation communities. Concern about moisture accumulation has caused the building industry to be skeptical of new energy-efficient construction methods and has slowed the adoption of new energy-efficient building envelopes. This can hinder the adoption of energy-efficient building envelope systems with high levels of insulation. The U.S. Department of Energy (DOE), through the Building America Program and the Building Emerging Technology, have been working toward the next generation of high-performance envelope systems that are to be included in the 2020 net zero energy buildings.

As designers insulate the envelope walls with higher thermal resistance, parts of the wall will become warmer but, at the same time, other parts will be much colder. Temperature differences in the wall affect the flow and redistribution of moisture in the wall, a dynamic moisture transport process in both vapor and liquid phases. The amount of free energy that is available to assist in the drying transport of moisture stored in the envelope is reduced by increasing the thermal value of the envelope. Special care and attention is required when selecting material and control layers in envelope systems in high thermal performance applications.

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## CURRENT UNDERSTANDING

Past studies on vapor retarders have indicated the positive effects of the use of vapor retarders, such as the work documented in Hutcheon (1963) and Latta (1976). Most of the reported work has used simple steady-state analysis. Additional work by Karagiozis and Kumaran (1993) provided a state-of-the-art analysis (contemporary to his time) of the use of vapor retarders in Canadian residential climates. However, that study did not include the effects of wind-driven rain. Most of the reported work to date has been using the WUFI (Karagiozis et al. 2001) hygrothermal software or by Match (Rode and Desjarlais 1993).

Interior vapor control strategies (vapor barrier/vapor retarders) were introduced to reduce the influx of interior space water vapor moisture into the concealed wall cavity. The intent was to reduce the inflow of moisture due to moisture generation from the interior. In the 1940s, American construction materials and wall systems were much different than the ones used today. Today, there is a lot of speculation and confusion among building envelope practitioners that most moisture-induced problems are due to restrictive building code requirements. One such requirement is the employment of a sheet of polyethylene for interior vapor control. A thorough scientific study on this matter is not yet available to analyze the complex hygrothermal transport that occurs in real buildings. This paper summarizes an extensive scientific analysis that has been performed on the hygrothermal performance of vapor retarders within a series of wall systems. The research presented here is the first to explain the effects of moisture risk-based analysis by basing the results on a hygrothermal load analysis. This research project, conducted by the Building Science Corporation and the Oak Ridge National Laboratory with the support of the DOE and the North American Insulation Manufacturers Association (NAIMA) presents a clear and scientifically documented response to influence vapor retarder selection for a selected number of wall systems and climatic locations in the United States.

This research work was sponsored to develop a better scientific understanding of DOE-sponsored proposed changes for vapor retarder requirements in the International Energy Code Council (IECC). In 2003, as part of its extensive proposal to the IECC, DOE offered vapor retarder recommendations based on the climate zones used to define energy efficiency. A map of these zones is shown in Figure 1. Although this map had been developed to recommend insulation levels, there was a hope that this same map could be used to guide the use of interior vapor control strategies.

The issuance of this map generated some controversy. Specifically, certain industry segments felt that there was little scientific evidence available to justify the hygrothermal recommendations that were being proposed. The initial recommendations were that no vapor control was required for zones 1 through 5 and that a vapor retarder of 1 perm was adequate for zones 6 and 7. There was the consensus among the industry experts regarding the recommendations for zones 1 through 2 and 6 through 7, but the intermediate zones 3 through 5 were questioned because a comprehensive study had not been made available to the industry to support these proposals.

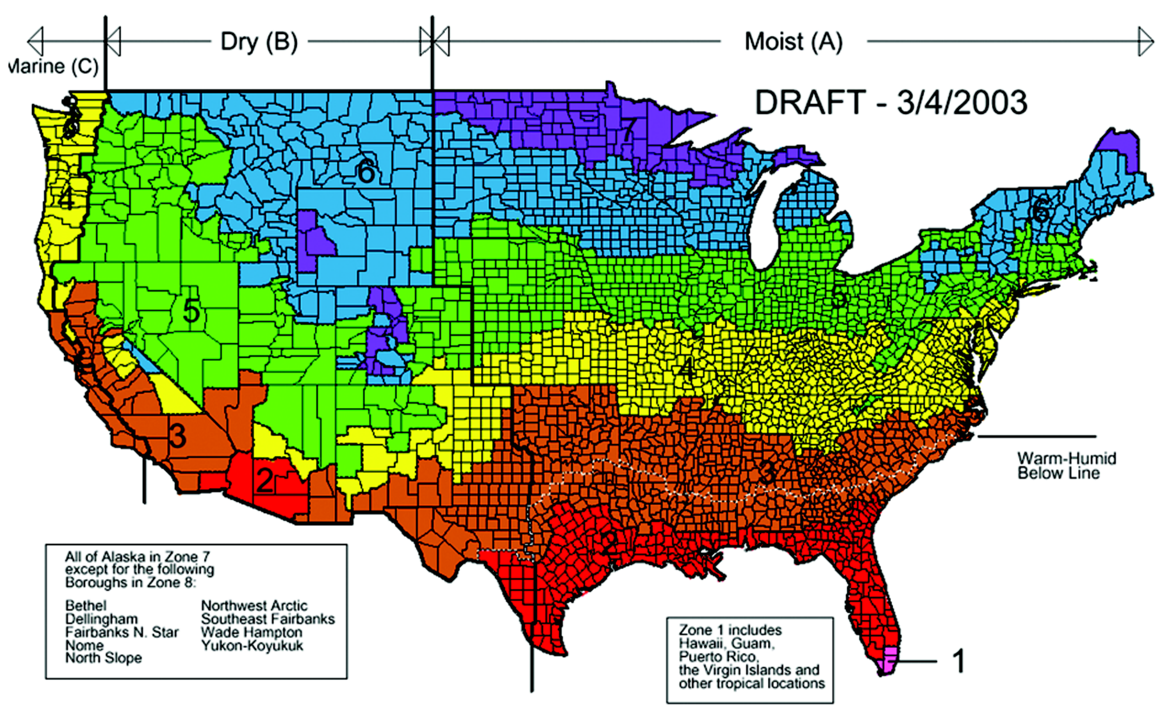



***Figure 1*** *DOE map for thermal and moisture control recommendations.*

## METHODOLOGY

Two different wall systems were selected for analysis. These two wall systems were identified as a brick veneer system and a vinyl siding system and were selected because they represented the extremes of wall cladding hygrothermal performance (brick system represents a sorptive "reservoir" cladding that can absorb and store a copious amount of rain-water, whereas the vinyl siding system has no absorption and is very air permeable).

The construction of these walls from the interior side was comprised of 8 perm interior latex primer and paint, 0.625 in. gypsum board, a 2 by 4 or 2 by 6 stud cavity insulated with R-13 or R-19 batts (as required by the zone), a 0.5 in. oriented strand board (OSB) sheathing, and one layer of 60-minute building paper with the appropriate cladding. With the brick veneer, a 1 in. wide air space was placed between the exterior sheathing and the brick. This air space was evaluated as an unvented and a ventilated airspace. Schematics of these walls are shown in Figure 2.

To examine the role of interior vapor control, four control strategies were evaluated. These strategies were:

- "Smart vapor retarder" (MemBrain™ product as a nylon film)
- 4 mil polyethylene sheet
- Asphalt-coated kraft paper fiberglass batt facer
- No vapor control

Hygrothermal weather data were compiled for the nine geographic locations: Boston, MA; Atlanta, GA; Chicago, IL; Kansas City, MO; New York City, NY; St. Louis, MO; Omaha, NE; Norfolk, VA; and Seattle, WA (see Figure 3). In addition, a selection of simulations was performed for St. Paul, MN. These cities were selected to focus primarily on the DOE climate zones that were of concern. Thirty years' worth of National Climatic Data Center (NCDC) data were collated to provide moisture design years; the two years selected were the 10th percentile hottest and 10th percentile coldest years. Extensive past work conducted by ORNL (Karagiozis 2002) and other researchers at the International Energy Agency (IEA) Annex 24 (IEA 1996) has demonstrated that a strong relationship between exterior temperature and exterior vapor conditions exists, making it a good indicator for selecting moisture design years.

Wind-driven rain is a critical hygrothermal load. Indeed, in most instances, this load is several times greater than all other loads combined. As such, the selection of orientation for the hygrothermal simulations must be assigned based on analysis of the amount of water load each orientation receives. The maximum load must be established for each orientation before a moisture engineering analysis is performed. This requires a better understanding of the prom-inent wind direction and concurrent wind-driven rain occur-rences. In this project, the analysis was performed for both weather files (10th percentile coldest and hottest years) used in the hygrothermal simulations.

Wind-driven rain is also used as an additional load in this analysis. We assume that a portion of the rain that strikes the façade enters the wall system as a leak. Specifically, one percent of the wind-driven rain that strikes the façade is depos-ited into the OSB sheathing as leak water during the hour when the rainfall is recorded in the weather file.

The interior environmental conditions in residential buildings are dynamic. Interior conditions change as a func-tion of the operation of the building (mechanical ventilation systems, humidifiers, dehumidifiers, etc.), changes of the

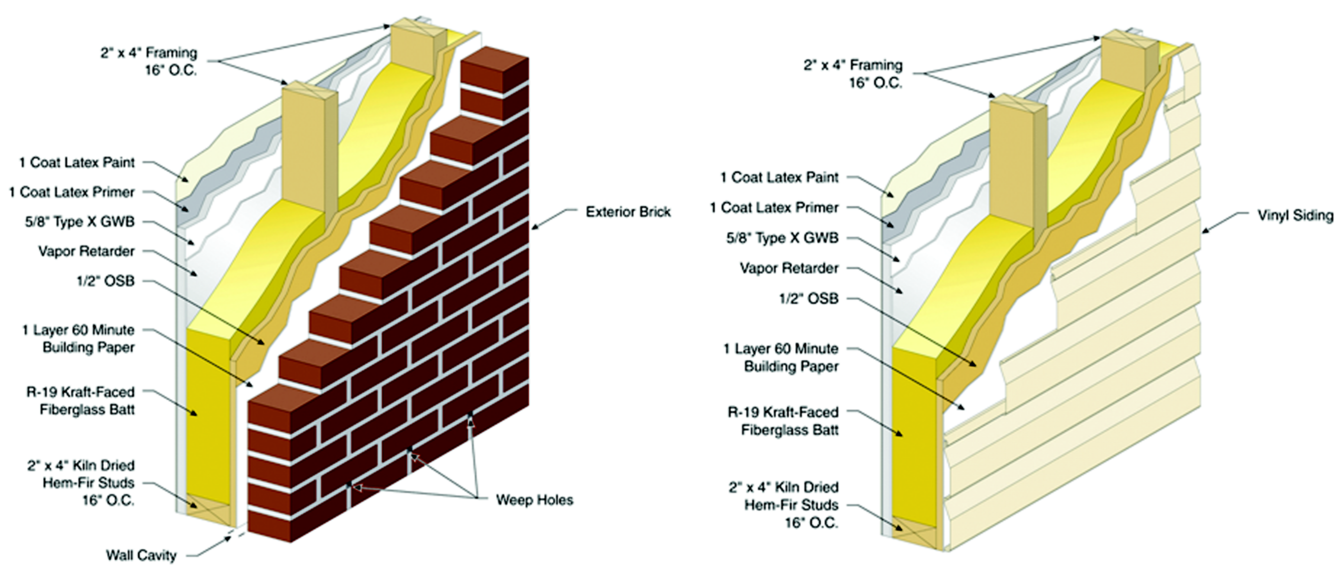



***Figure 2*** *Schematics of the test wall configurations. Note that the material labels are incomplete and do not represent all of the wall sections.*

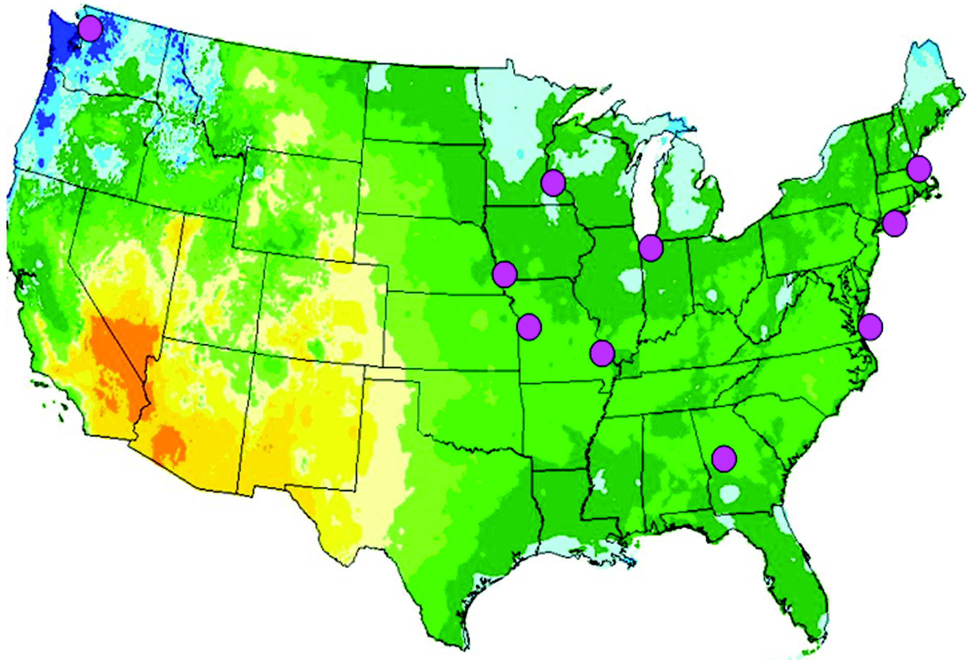
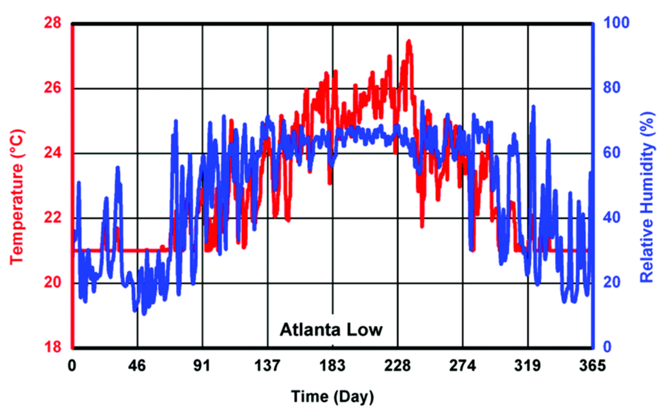


***Figure 3*** *Geographic locations of selected simulation cities (yearly rainfall [dark = high, light = low]).*



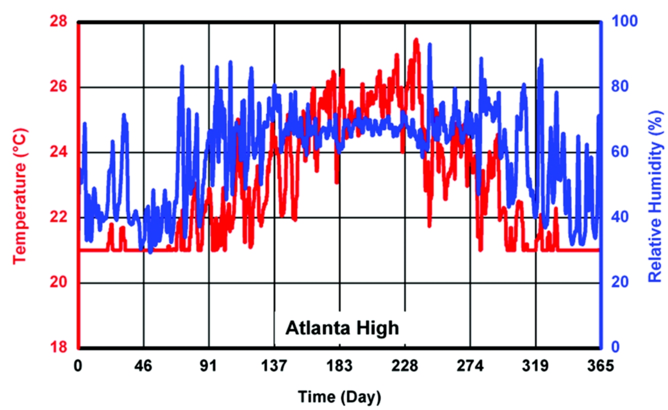




***Figure 4*** *Interior temperatures and relative humidities used as boundary conditions for the hygrothermal simulations.*

exterior climatic conditions, inhabitant activities, plants, and the kind of objects placed in the interior environment (moisture storage). The interior loads generated from this environment are needed to simulate the hygrothermal performance of wall systems.

TenWolde and Walker (2001) described a state-of-the-art methodology to obtain the interior environmental conditions in terms of an analysis approach and design values. This methodology, which is intended for inclusion in the proposed *ASHRAE Standard 160P, Design Criteria for Moisture Control in Buildings* (ASHRAE 2005a), was adopted as the model for determining interior design moisture loads. Yearly indoor relative humidity profiles were developed for each location using either mechanically ventilated homes (as specified by *ANSI/ASHRAE Standard 62.2-2003, Ventilation and Acceptable Indoor Air Quality* (ASHRAE 2003), or naturally ventilated homes (employing loads as specified by the proposed ASHRAE Standard 160P). In the simulated cases, interior moisture generation rates simulating a family of four were used to develop the indoor relative humidity profiles. Examples of these boundary conditions are shown in Figure 4. Specifically, the interior temperature and relative humidity boundary conditions developed using these procedures for the city of Atlanta are shown as "Atlanta Low" and "Atlanta High," respectively. Day 0 represents January 1. These data were generated for each climate to be studied.

The resulting indoor relative humidity profiles show that relative humidity in homes is quite seasonally dependent and depends both on exterior climate and application period of air conditioning. The interior humidity is also governed by the moisture generation rate, the air change rate, and building leakage characteristics. This indoor air relative humidity model was applied to a 2500 $ft^2$ house.

Accurate material property data are required to undertake these hygrothermal studies. Specifically, sorption isotherms (absorption of water vs. ambient relative humidity), vapor permeability (allowance of water vapor transmission through the material), and liquid transport properties were needed for all of the critical components of the test structures. The vapor retarder data were measured by ORNL. Data for all materials not measured by ORNL were taken from the ASHRAE Technical Report TRP-1018 (Kumaran 2006) or from the WUFI material property database (Karagiozis and Kuenzel 2001).

## MOISTURE MODELING

The ORNL MOISTURE-EXPERT V2.0 (Karagiozis 2004) hygrothermal model was employed in developing a parametric analysis of the hygrothermal performance of the selected walls as a function of various climatic conditions, vapor control strategies, and interior conditions.

The model was developed to predict the dynamic one-dimensional and two-dimensional heat, air, and, moisture transport in building envelope geometries. The model treats vapor and liquid transport separately. The moisture transport potentials are vapor pressure and relative humidity, and temperature for energy transport. The model includes the capability of handling temperature-dependent sorption isotherms and liquid transport properties as a function of drying or wetting processes.

The model has been extensively validated for a number of proprietary wall systems, as well as the 40 odd walls in the test facilities in Charleston, SC, and Puyallup, WA. In addition, a comprehensive validation was performed for ASHRAE TRP-1091 project on rainscreen walls and membranes research (Straube et al. 2004).

In this particular vapor retarder application, the heat and moisture transport phenomena, in the presence of solar driven processes in wall systems, is very complex. Many simultaneous transport processes may be present in all climatic conditions. To accurately capture the thermal and moisture movement requires that the software tool to be used in the parametric analysis must have the following qualifications:

- At least two-dimensional analysis capability; includes heat, vapor, liquid, and air transport (for cavity ventilation purposes); includes coupling of thermal flow and airflow to capture natural convection and thermally driven moisture transport; includes wind-driven rain; includes evaporation/condensation and freeze/thaw latent transport, transient model, air ventilation of air spaces, radiative exchange in air cavities, full functional dependencies of material properties, hysteresis, and temperature dependencies (sorption, water vapor permeabilities, and thermal conductivities); demonstrates past ability on extensive evaluation/validation; solutions that are not time-step dependent; and, finally, that solar radiation, night-time radiation exchange, and cloud interference be incorporated in the analysis.

Based on the qualifications required to perform the DOE vapor research investigation, a limited number of computer models can be used. The research model MOISTURE-EXPERT was selected for this modeling activity, as it met the above requirements.

### Description of the Model Proposed for this Project

MOISTURE-EXPERT v.2.0 (Karagiozis 2002) is an advanced hygrothermal simulation model developed at ORNL that has been used extensively to develop design guidelines and guidance for numerous heat, air, and moisture transport problems. The moisture transport potentials used in the model are moisture content, vapor pressure, and relative humidity; for energy transfer, temperature is the driving factor. This model includes functional dependencies of material properties (Karagiozis and Salonvaara 1995). The two-dimensional version of the software will be used in the modeling activity.

## GOVERNING EQUATIONS

### Moisture Balance

The moisture transport balance is given as

$$\frac{\partial(\rho_m u)}{\partial t} = \nabla(-D_\phi \nabla\phi - \delta_p \nabla P_v + \rho_v V_a) , \qquad (1)$$

where

$\rho_m$ = dry density of porous material, $kg/m^3$;
$D_\phi$ = liquid moisture transport coefficient, kg/s;
$u$ = moisture content, $kg_{wet}/kg_{dry}$;
$T$ = temperature, $^oC$;
$\phi$ = relative humidity;
$\delta_p$ = vapor permeability, kg/s·m·Pa;
$P_v$ = vapor pressure, Pa;
$V_a$ = velocity of air, m/s;
$\rho_v$ = density of vapor in the air, $kg/m^3$; and
$t$ = time, s.

### Air Balance

The air mass balance is given as

$$\frac{\partial\rho_a}{\partial t} + \nabla(\rho_a V_a) = 0 , \qquad (2)$$

where $\rho_a$ is the dry density of air, $kg/m^3$.

### Momentum Balance

The momentum balance (Navier Stokes equation) is given as

$$\frac{\partial(\rho_a V_a)}{\partial t} + \nabla(\rho_a V_a \cdot V_a) = -\nabla P_a + \nabla^2 \frac{\mu_a}{K_a} V_a + \rho_a g\,, \qquad (3)$$

where

$P_a$ = air pressure, Pa;
$K_a$ = air permeability, s/m;
$\mu_a$ = dynamic viscosity, m/s$^2$; and
$g$ = gravity, m/s$^2$.

## Energy Balance

Heat transfer in a porous media is complex. Present in the material are conduction, convection, evaporation/condensation sources, and radiation heat transfer. The equation governing this scalar quantity is given below as

$$\rho_m C_p \frac{\partial T}{\partial t} = -\nabla(\rho_a C_p V_a T) + \nabla(k \nabla T) + \nabla[L_v(\delta_p \nabla P_v)] - L_{ice} \rho_m u \frac{\partial f_1}{\partial t}\,, \qquad (4)$$

where

$C_p$ = heat capacity, J/kg·K;
$k$ = thermal conductivity, W/m·K;
$L_v$ = enthalpy of evaporation, J/kg;
$L_{ice}$ = enthalpy of freezing, J/kg; and
$f_1$ = liquid fraction.

## Boundary Conditions

**Vapor mass flow at the faces of the geometry**

$$m_v = \beta(P_{va} - P_{vsurf}) + V_a \rho_v \qquad (5)$$

where

$m_v$ = vapor mass flow, kg/m$^2$s
$\beta$ = convective mass transfer coefficient, s/m

**Liquid flow at the faces of the geometry**

$$m_{liquid} = m_{driving\ rain} \qquad (6)$$

where $m_{liquid}$ is the liquid flow, kg/m$^2$·s, with a maximum moisture content equal to capillary moisture content of the exterior surface. The maximum flow rate is given by the predetermined wind-driven rain flux. The wind-driven rain mass flow $m_{driving\ rain}$ available at the face of the geometry is predicted using the proposed ASHRAE Standard 160P. The method takes into account various exposure factors, height, wind speed, and orientations.

**Heat flux at surface including solar radiation**

$$q_{surf} = h(T_{eq} - T_{surf}) + V_a \rho_a T + m_{liquid} C_{p,w} T_a + m_v L_v \qquad (7)$$

$$h_{eff} = h_r + h_c \qquad (8)$$

where

$T_{eq}$ = equivalent temperature (including shortwave solar and longwave radiation with environment)
$C_{p,w}$ = heat capacity of liquid water, J/kg·K
$h_c$ = convective heat transfer coefficient, W/m$^2$·K
$h_r$ = radiative heat transfer coefficient, W/m$^2$·K

In the formulation of the above equation, a thermodynamic equilibrium was assumed. A water penetration source as per the proposed ASHRAE Standard 160P was used in the analysis. One percent of the mass of water that hit the exterior surface was injected at the air cavity and building paper interface.

The model accounts for the coupling between heat and moisture transport via diffusion and natural and forced convective air transport. Phase-change mechanisms, such as evaporation/condensation and freezing/thawing, are incorporated in the model. The model includes the capability of handling internal heat and moisture sources, gravity-driven liquid moisture, and surface drainage capabilities. The model also captures experimentally determined system and subsystem performances and anomalies of the building envelope. One of the model's unique features is its capability to handle temperature-dependent sorption isotherms, water penetration, and directional and process-dependent liquid diffusivity. A few of the assumptions made are as follows:

- Walls are airtight.
- Material properties used in the simulations are representative of material used in each climatic location. Some of the material properties used may not have been measured from one sample, but rather a "pick and match" of several batches of different manufacturers. However, these were the best available at the present time.
- Weather data were developed from 30 years of hourly data by choosing the 10th percentile coldest and hottest years. This approach has been developed at IEA Annex 24 and has been used extensively in North America (ASHRAE is proposing this approach for proposed ASHRAE Standard 160P).
- System imperfections other than water penetration at the sheathing paper interface were not included.
- Cladding cavity ventilation was included in the analysis only in those cases designated as ventilation cases.
- In this project, the effect of aging of materials was not included due to the lack of any data. Therefore, durability changes and influences were not included in this project.

With any engineering analysis, the loads used are assumed substantially higher than average loads. While this statement is not absolute, and exceptions may exist, imposing higher-than-normal hygrothermal loads and tracking the performance of the walls is one way to design systems with an added safety factor.

The analysis was conducted while subjecting the exterior boundary of the wall to real weather data (including temperature, vapor pressure, wind speed and orientation, solar radiation, wind-driven rain, sky radiation, and cloud indexes) for the climates selected. Wind-driven rainwater was included in the analysis, and the exterior surface was exposed to the amount of rainwater that hits a vertical wall under existing wind conditions. Two consecutive years of simulations were performed that included the 10th percentile coldest and hottest years from 30 years of data (NCDC). All simulations start on October 1 to allow for the maximum amount of accumulation to occur at the beginning of the simulation. The hourly solar radiation and longwave radiation from the outer surfaces of the wall are also included in the analysis.

The walls were oriented in the direction with the greatest rain loads. Wind-driven rain was found most prominently in the hygrothermal performance of the wall systems. The heat and mass transfer coefficients for external surfaces were dynamic, varying hourly based on exterior weather wind speed and orientation conditions. ASHRAE (2005b) correlations were used to compute these coefficients. Finally, the initial moisture content of the components in the test wall were assumed to be at either 80% equilibrium moisture content or twice the 80% equilibrium moisture content. A schematic of the parametric study is shown in Figure 5.

## SIMULATION RESULTS

Complete details with results of the wall's moisture content and relative humidity as a function of the climatic conditions are given in two reports: one sponsored by NAIMA and the Department of Energy (Karagiozis et al. 2005) and the other one co-authored by ORNL and Building America (Lstiburek 2006) for NAHB. In this paper, only overall results are presented. The transient heat and moisture transfer computer simulations were performed in all nine climatic locations with a vinyl clad wall system or a brick clad wall system. System performance was evaluated using the amount of moisture stored in the exterior OSB sheathing. The threshold for potential mold growth was considered to be 16% moisture content by weight or 80% relative humidity at the interior surface of the OSB. Based on the simulation results, a series of zone-by-zone recommendations were made. The following three figures summarize the simulation work in a general manner.

The hygrothermal performance data for the nine locations were lumped into zones 3 through 6. The lumping criteria were developed such that if one of the exterior climates within a zone allowed moisture to accumulate in the OSB sheathing or be retained for more than 30 days, then the whole zone was either given a warning (yellow—above 18% but lower than 25% moisture content) or a failure (red—higher than 25% moisture content). In Figures 6 through 8, the effects of initial conditions (dry or wet) and the impact of dry (low) or normal (high) interior conditions are shown on the moisture performance of the OSB sheathing.

In Figure 6, results are presented for the unvented brick wall system. From the results, the no vapor control case (8 perm latex primer and paint) shows potential for moisture problems in zones 5 and 6. Similarly, for zones 3, 4, and 5, the potential for moisture problems may occur when poly is used. Smart vapor retarders and kraft paper perform reasonably well when used in this type of wall system.

In Figure 7, the same brick wall system is employed, but it is ventilated (open top and bottom allow air to flow behind the façade). It is obvious that ventilating the exterior cladding produces a very beneficial drying effect on the brick clad wall system.

Figure 8 shows the hygrothermal performance of the vinyl wall system. Here, the effects of the non-absorptive cladding and ventilation effectiveness are demonstrated. With the exceptions of zones 5 and 6 with just the latex primer and paint (high interior conditions), almost any vapor retarder may be used independent of climate zone.

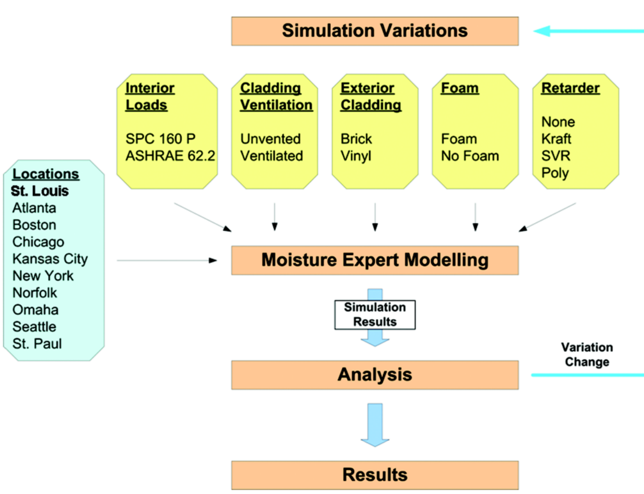



*Figure 5* *Summary of parametric analyses performed. Note that this paper does not report on any of the foam exterior sheathing analyses undertaken in this project.*

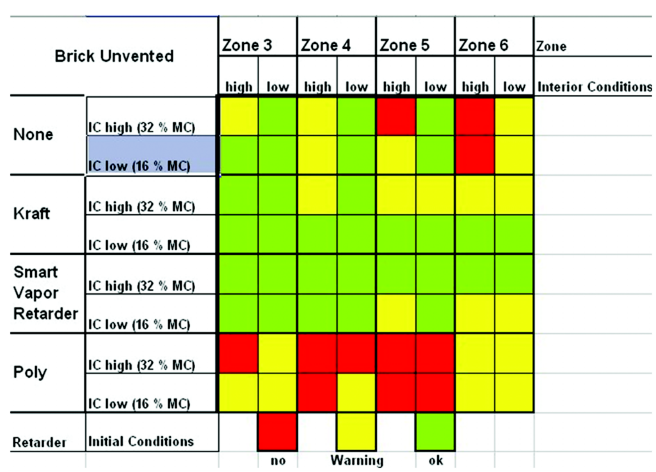



*Figure 6* *Results for unvented brick cladding systems.*

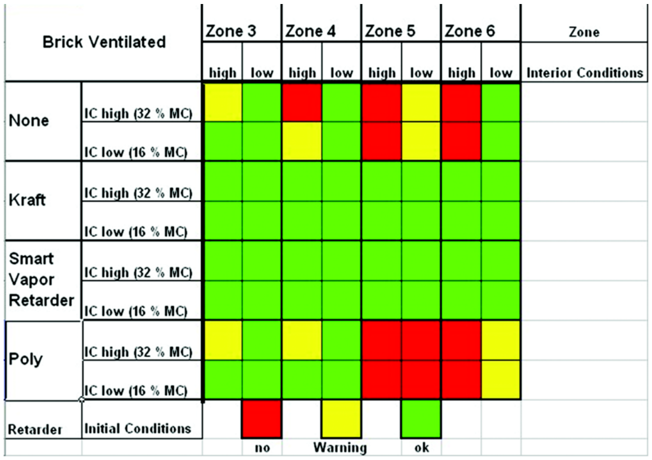



*Figure 7* *Results for ventilated brick cladding systems.*

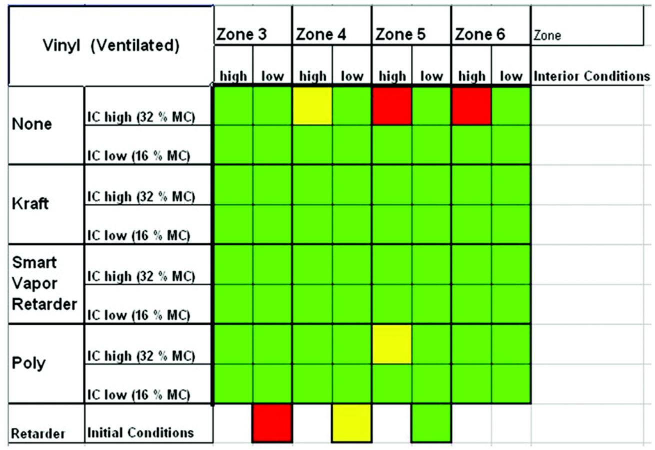



*Figure 8* *Results for non-absorptive vinyl cladding system.*

In Figure 9, the number of hours above the given moisture content is shown for the city of Chicago for the four cases of vapor retarder strategies. The four strategies are: (1) 8 perm vapor retarding paint on the gypsum board, (2) asphalt kraft paper, (3) smart vapor retarder and (4) 6 mil poly sheet. The original conditions were that the sheathing moisture content was at 32%, so a strong drying condition was present. The simulations summarize the results for a three-year analysis. The benefit of the smart vapor retarder (WVP permeance of less than 1 perm at low relative humidities [below 50%] and approximately 50 perm at high relative humidities), followed by the paint coating, then the kraft paper and finally the 6 mil poly case is obvious.

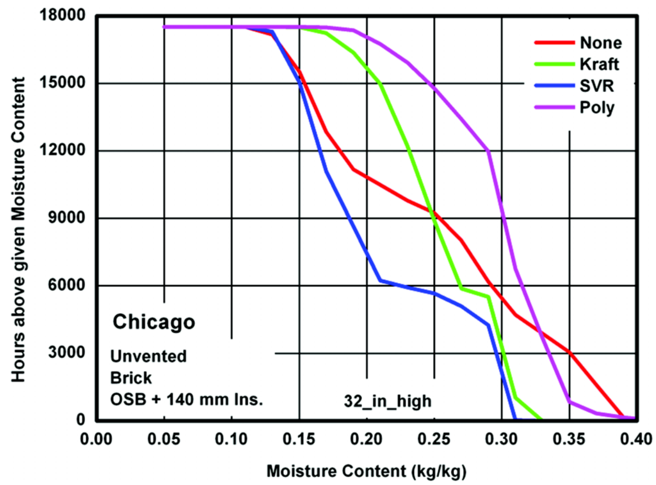



*Figure 9* *Unvented brick wall initially OSB at 32% moisture content.*

### For Zone 6 (St. Paul, MN)

- All absorptive (brick) claddings should be ventilated. The 8 perm coating is not recommended.
- Vinyl walls perform the best with nylon vapor retarder, followed by an asphalt coated kraft paper, and 4 -mil poly. The 8 perm coating did not perform satisfactorily.

### For Zone 5 (Boston MA, Chicago IL, and Omaha, NE)

- In general, the application of exterior foam sheathing (1 in.) reduced the amount of moisture accumulation for the walls investigated in the simulation parametric. Walls with higher water vapor permeance (less resistance to vapor flow), i.e. 8 perm and SVR performed the best. Optimal fine tuning of the exterior foam insulation (higher R-values) can allow the application of kraft paper or equivalent.
- Brick veneer wall systems (as employed in this parametric investigation) require a asphalt-coated kraft paper as a minimum. The smart vapor retarder was found to have a strong positive effect on the moisture performance of the walls in zone 5.
- When high interior loads exist (ASHRAE 2005a) for both vinyl and brick wall systems, these walls require a kraft paper or equivalent vapor retarder.
- For initial high construction moisture, better performance in the short term is achieved by using high permeance vapor retarders, i.e., 8 perm coating or smart vapor retarder but worst in the long term.
- When low interior loads are present, the 8 perm coating case or smart vapor retarder performs adequately for non-absorptive cladding (vinyl). For high interior loads, some diurnal accumulation is noticed in the fiberglass layer and OSB layers which are dissipated during the summer periods.
- Slightly higher moisture accumulation (2% moisture content in the OSB sheathing) is observed with increased R-value of the interior insulation.

### For Zone 4C: (Seattle, WA)

- Vinyl cladding wall systems were found to perform satisfactorily in Seattle with all vapor retarder strategies, i.e., 4 mil poly, asphalt-coated paper, smart vapor retarder and 8 perm permeance (coating) for low interior conditions (ASHRAE 2003, 2005a). The minimum requirement for zone 4c is 8 perm, as this wall type has demonstrated good hygrothermal performance for zone 4c when the vinyl cladding is well ventilated and low initial moisture conditions exist. For high interior loads, vinyl walls with vapor permeable vapor retarder (8 perm coatings) may accumulate more moisture under these conditions than the smart vapor retarder, asphalt-coated kraft paper, and/or 4 mil poly.
- Brick cladding (absorptive cladding), when exposed to low initial conditions and low interior loads, does not require a vapor retarder 8 perm or less.
- Brick claddings require the application of asphalt kraft paper for both ventilated and unvented wall systems with high interior loads. For low interior loads, the application of an 8 perm interior vapor retarder provided unsatisfactory performance and can induce moisture problems in this region.

### For Climate Zones 4a and 4b (Kansas City, MO; New York City, NY; Norfolk, VA; and St. Louis, MO)

- In all wall-simulated wall cases for zones 4a and 4b, the climatically tuned vapor retarder characteristics of the smart vapor retarder provided the best performance.
- Brick veneer wall systems (absorptive cladding properties) that were not intentionally vented or ventilated and that were found to require a asphalt-coated kraft paper (1 perm rating) as a minimum requirement for satisfactory moisture control performance for high interior load conditions (ASHRAE 2005a).
- For low interior loads (ASHRAE 2005a, 2005b), this condition reduces the minimum requirement to an 8 perm coating for absorptive claddings;
- A 19 mm ventilation cavity with top and bottom openings that effectively ventilates the exterior cladding allows adequate wall drying capabilities to require a minimum vapor retarder of 8 perm. In this scenario, the differences between various vapor retarder strategies has also diminished.
- The 4 mil poly retarder was found not to perform satisfactorily for both low interior and high interior loads for absorptive brick claddings if unvented. Ventilated brick absorptive claddings with high interior loads allowed moisture accumulation peaks with the use of an 8 perm coating.

### For Zone 3 (Atlanta, GA)

- Unvented brick veneer wall systems employing either 4 mil poly or 8 perm coating similar performance for high loads and low initial conditions.
- No problems were observed for the non-absorptive vinyl case for the high loads and low initial conditions.

## CONCLUSIONS

From the numerous simulations performed with different interior climate classes, different initial conditions, different exterior sheathings, different sheathing membranes, different levels of interior cavity insulations and exterior insulations, different exterior climate locations within the IECC climate zones, variations of the hygric materials within the three main classes and different water penetration loadings (0 and 1% were used for all simulations; however, additional variations were employed for some locations), a necessary grouping of the results were needed. Detailed results are available in the reports to DOE (Karagiozis et al. 2005) and NAHB (Karagiozis and Lstiburek 2006). To simplify the above findings, the following definitions were assembled.

### Vapor Retarder Class

A vapor retarder class is a measure of a material's or an assembly's ability to limit the amount of moisture that passes through that material or assembly. Vapor retarder classes shall be defined using the desiccant method with Procedure A of ASTM E-96 (ASTM 2005) as follows:

Class I: 0.1 perm or less
Class II: 0.1 < perm ≤ 1.0 perm
Class III: 1.0 < perm ≤ 10 perm

**Vapor Retarders.** Class I or II vapor retarders are required on the interior side of frame walls in zones 5, 6, 7, and 8 and Marine 4.

**Class III Vapor Retarders.** Class III vapor retarders shall be permitted where any one of the conditions in Table 2 are met.

**Example Material Vapor Retarder Class.** The vapor retarder class shall be based on the manufacturer's certified testing or a tested assembly. The following shall be deemed to meet the class specified:

- Class I: Sheet polyethylene, nonperforated aluminum foil
- Class II: Kraft-faced fiberglass batts
- Class III: Latex or enamel paint

**Minimum Clear Air Spaces and Vented Openings for Vented Cladding.** For the purposes of this section, vented cladding shall include the following minimum clear air spaces. Other openings with the equivalent vent area shall be permitted.

1. Vinyl lap or horizontal aluminum siding applied over a weather resistive barrier as specified in IRC Table R703.4.
2. Brick veneer with a clear airspace as specified in IRC Section 703.7.4.2.
3. Other approved vented claddings.

Table 2 Class III Vapor Retarders Permitted for:

**Marine 4**
Vented cladding over OSB
Vented cladding over plywood
Vented cladding over fiberboard
Vented cladding over gypsum
Insulated sheathing with R-value ≥ 2.5 in 2 × 4 wall
Insulated sheathing with R-value ≥ 3.75 in 2 × 6 wall

**Zone 5**
Vented cladding over OSB
Vented cladding over plywood
Vented cladding over fiberboard
Vented cladding over gypsum
Insulated sheathing with R-value ≥ 5 in 2 × 4 wall
Insulated sheathing with R-value ≥ 7.5 in 2 × 6 wall

**Zone 6**
Vented cladding over fiberboard
Vented cladding over gypsum
Insulated sheathing with R-value ≥ 7.5 in 2 × 4 wall
Insulated sheathing with R-value ≥ 11.25 in 2 × 6 wall

**Zones 7 and 8**
Insulated sheathing with R-value ≥ 10 in 2 × 4 wall
Insulated sheathing with R-value ≥ 15 in 2 × 6 wall

## Recommendations

The impact of the interaction of airflow coupled with water vapor diffusion to include the effects of air infiltration/exfiltration due to the stack and wind pressure should be investigated as a function of climate to allow even more realistic guidelines for vapor retarders.

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