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StoGuard®: Demonstration of Hygrothermal Performance through Computer Modelling at Oak Ridge National Laboratory

Temperature variations in a wall affect the flow and redistribution of moisture in the wall. This dynamic moisture transport process, in both vapor and liquid phases, is referred to as ***Hygrothermal Performance***.

Water will move through a wall assembly in a vapor state as a result of a vapor pressure difference, moving from an area of high vapor pressure to an area of low vapor pressure. Often, a temperature gradient in the wall is the cause of such a vapor pressure gradient. A vapor retarder is used in the wall to control vapor diffusion.

Water can also move through a wall system when it is transported with air movement. In fact, the amount of water that is transported through a wall due to air leakage is many more times the amount of water that moves as a result of vapor diffusion. An air barrier is used to limit the amount of air movement (and its associated moisture content) through the building envelope.

Liquid water typically moves through any openings in a wall when there is a force driving the water inwards. Such forces include gravity, momentum of rain, wind pressure and capillarity. Movement of liquid water is primarily controlled by flashing water to the exterior. Water-resistive barriers protect the wall assembly from liquid water penetration should it get through the cladding.

Both temperature gradients and vapor pressure gradients across the wall are affected by exterior climate, by interior conditions, and by the wall composition itself. The movement of moisture through the building envelope can flow in both directions, towards the interior or towards the exterior. It can also flow in both directions simultaneously, depending on the driving forces and the mechanisms of transport. In cold climates, wall assemblies normally need to be protected from water vapor emanating from the inside. In hot climates, the reverse is more often the case. Therefore, similar wall constructions will perform differently in different climates. Typically, deterioration occurs when a wall gets wet, and stays wet for a significant duration. Some walls are better able to cope with moisture, allowing moisture storage and then drying, with no adverse effects. Ideally, building assemblies should be able to dry both towards the exterior and the interior when needed.

While the hygrothermal performance of a wall can be very complicated, fortunately, the moisture dynamics can be illustrated by well-established building physics. Computer programs exist that can accurately model these wall dynamics. The purpose of this research project was to use an advanced computer model to provide a quantitative analysis of the hygrothermal performance of a number of exterior wall assemblies, each employing the StoGuard® Water-Resistive Barrier. StoGuard® is a fluid-applied air barrier and waterproofing for above grade exterior walls.

Proving Performance Through Simulation

To prove the effectiveness of the StoGuard® System, Oak Ridge National Laboratory (ORNL) simulated the performance of four different wall systems – brick, Sto EIFS with 1 inch of exterior insulation, Sto EIFS with 3 inches of exterior insulation, and stucco – each employing the StoGuard® System (Figure 1).

Each wall system consisted of:

- 0.625 in. interior gypsum wall board, taped and painted
- nominal 2 x 4 in. steel studs, at 16 in. o.c. (20 ga, except the brick wall which used 18 ga studs)
- fibreglass batt insulation in the stud space (except for the 3 in. EIFS wall which had no stud insulation)
- 0.625 in. G-P DensGlass Gold® Sheathing (DGG)
- Sto Gold Fill® and StoGuard® Mesh
- Sto GoldCoat®.

The exterior cladding differed, as shown in Figure 1. In addition, in some cases an 8-perm vapor retarder paint was employed on the interior of the gypsum wall board, while in other cases, 4-mil polyethylene was employed between the gypsum and the studs.

The simulations were performed using the advanced hygrothermal model, MOISTURE-EXPERT. Developed by ORNL, this program predicts dynamic 1- and 2-dimensional heat, air and moisture transport in building envelope geometries. This program takes into account:

- vapor diffusion
- gravity driven liquid moisture
- capillary moisture transport
- surface drainage capabilities
- air cavity ventilation (air movement under temperature and wind pressure gradients)
- thermal transport and thermal capacity effects
- moisture sorption isotherms (basically the absorption of water by materials in the wall vs. ambient relative humidity), including temperature dependent sorption isotherms
- phase change mechanisms, such as evaporation/condensation and freezing/thawing
- internal heat and moisture sources
- experimentally determined system and sub-system performance and anomalies of the building envelope.

MOISTURE-EXPERT is a highly complex program, typically requiring more than 1000 inputs for the 1-D simulations. Inputs include:

- exterior environmental loads
- interior environmental loads
- material properties
- envelope system and subsystem characteristics.

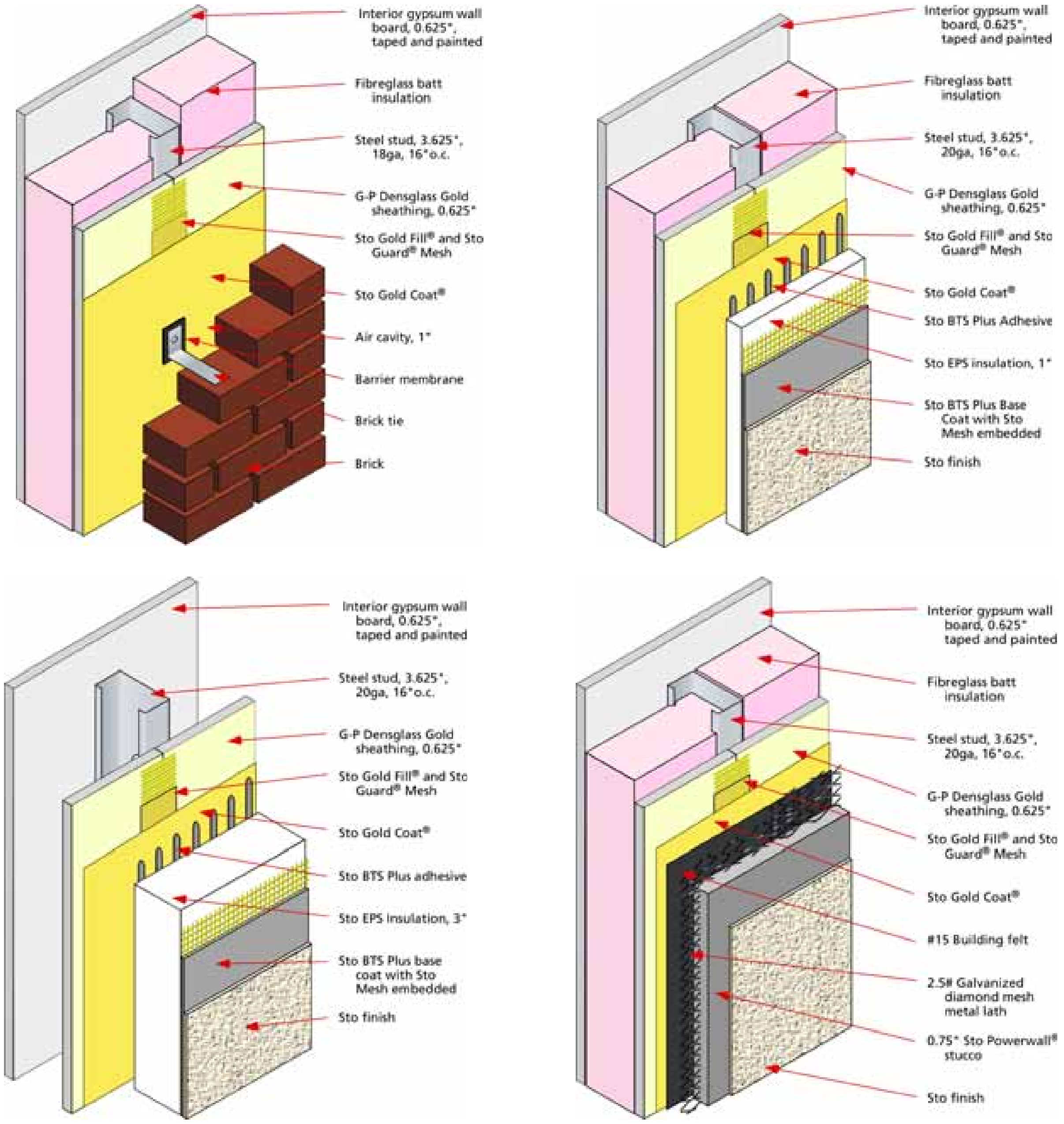


Figure 1. Wall Systems in the Hygrothermal Modeling.

Exterior Environmental Loads

To evaluate the performance of each wall system under a variety of exterior environmental loads, simulations were run for 11 different cities, representing 7 different climate zones throughout the United States and Canada (see Figure 2 for the US Climate Zones).

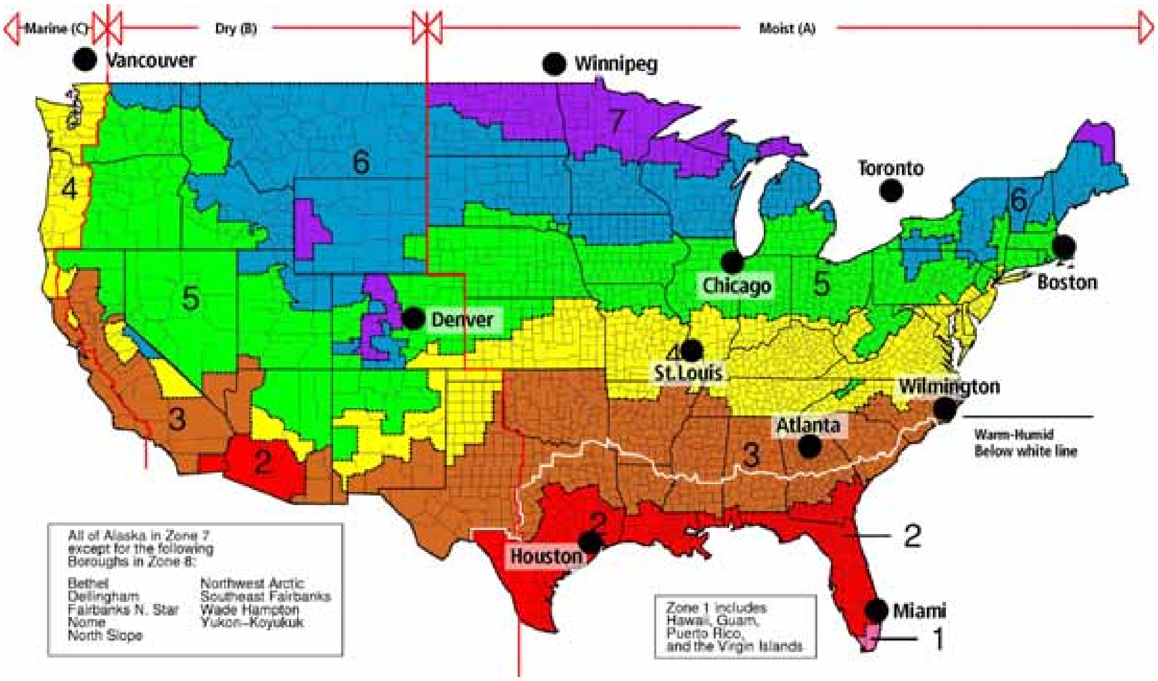


Figure 2. Proposed U. S. Department of Energy Climate Zones for the IECC (International Energy Conservation Code) with 11 Study Cities

An analysis procedure developed by the International Energy Agency (IEA), Annex 24 on Heat, Air and Moisture Transport in Highly Insulated Building Envelopes, was used in this project to develop two "Moisture Design Years" for each city. Based on 30 years of recorded hourly weather data, these two Moisture Design Years represent the 10th percentile coldest and 10th percentile hottest hourly weather data. In addition, the corresponding relative humidity, wind speed and direction, solar radiation, sky radiation, cloud index, and rainfall were input into the simulation. Wind-driven rain is a critical hygric load, typically several times greater than all other loads combined. Therefore, the weather data were analyzed, in accordance with ASHRAE Standard SPC 160P, "Design Criteria for Moisture Control in Buildings", to develop wind-driven rain roses for at least four orientations for each location. A wind-driven rain 'rose' is a graph, flower-like in appearance, mapping the wind direction with the greatest rainfall. The orientation with the highest moisture load was chosen for the simulation (Figure 3).

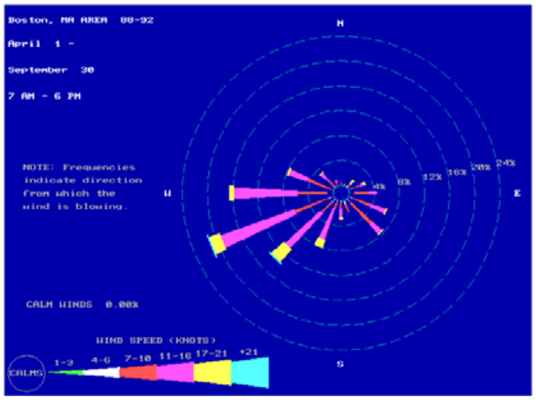


Figure 3. Example of a wind rose, Boston Logan Airport

Moisture Design Years are significantly different than the years used for energy calculations, representing the conditions over a year period that represent hygric (or moisture) loads appropriate for moisture design purposes. This approach for the development of Moisture Design Years has been used extensively in North America. It is proposed for the ASHRAE Standard SPC 160P, and has been examined in detail by IEA Annex 24.

Interior Environmental Loads

Most simulations assume constant interior conditions. In reality, however, interior conditions vary depending on the time of day, exterior conditions, and as a function of operation of the building (mechanical ventilation systems, humidifiers, dehumidifiers, etc.). The relative humidity of indoor air is particularly sensitive, being the result of a balance between moisture gains, moisture removal from the building and moisture storage by materials inside the building and within the walls. For accuracy, computer simulations should reflect this variation in interior conditions.

In these simulations, interior conditions were calculated on an hourly basis and allowed to vary depending on time of day, exterior conditions, and the addition of internal moisture representative of a family of four (two adults and two children) in a one-storey, 2500 sq. ft. house. To capture these variations, a running weekly average of moisture conditions was used in the simulation. This method of simulating interior environment is intended for inclusion in ASHRAE SPC 160P.

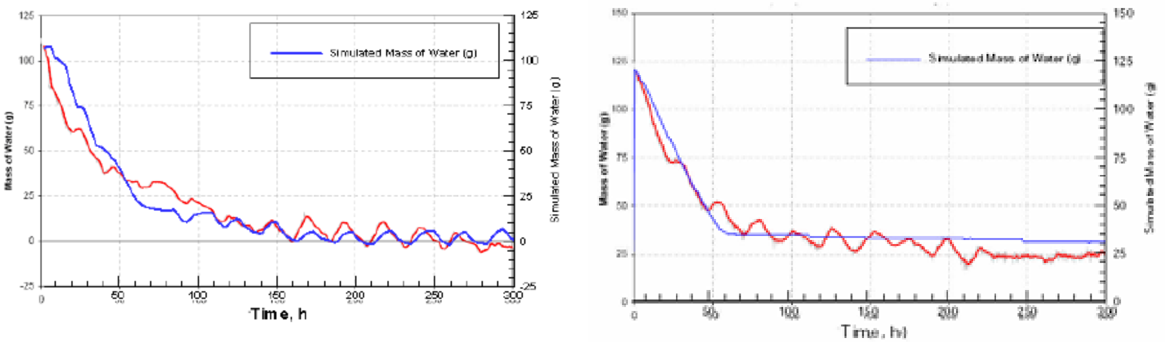
Material Properties

Material properties, such as thermal resistance, water vapor permeance, absorption, etc., are important input parameters. For the most part, previously published material property values were used in the simulation. However, as part of this project, water vapor permeance and sorption measurements were conducted on the StoGuard® products and these results were used as simulation inputs.

Validation of Envelope System and Subsystem Characteristics

Prior to the launch of the simulation activity, the hygrothermal model and the input parameters used were validated through full-scale physical wall drying tests conducted at the University of Waterloo. Two sets of tests, and the corresponding simulations, were undertaken. A wetted wall was dried using a fan to simulate wind fluctuations and a second wetted wall was dried using a lamp to simulate solar radiation. Moisture content was measured at the exterior of the sheathing board.

The correlation between the physical testing and the simulation was excellent, as shown in Figure 4. This validation testing also helped to establish the drainage, drying and air flow characteristics of the walls for input into the computer simulation.



(a)

(b)

Figure 4. Comparison of wall drying results for Simulation and Physical Testing. a) Solar Drying; b) Ventilation Drying.

The MOISTURE-EXPERT Simulations

Initial Equilibrium Moisture Content of 80% relative humidity and 21ºC, as per the requirements of ASHRAE SPC 160P, were imposed. An hour-by-hour analysis was performed starting October 1st of the 10th percentile coldest year followed by the 10th percentile hottest year. The wall systems were assumed to be airtight, with proper water management and flashings. Cladding cavity venting was included in the analysis only in those walls designed to be vented. System imperfections were not included, other than simulating a water penetration rate of 1.0% of the rainfall during the year at the outer plane of the StoGuard® moisture protection. The 1.0% load is the current rainfall infiltration design load value in ASHRAE SPC 160P Standard. This is an assumed value used for simulation purposes only to evaluate the performance of the wall system in the case that it might get wet, and is not indicative of any expectation that the system will allow wetting. The simulation used actual drainage results from the University of Waterloo.

Modelling simulations were run for the four wall assemblies with a vapor retarding interior paint in all eleven of the selected locations, representing 44 simluations. Seven cities in a northern climate were again run with a 4 mil polyethylene vapor barrier bringing the total number of simulations to 72.

Evaluating the Results – Relative Humidity

To evaluate the ability of the StoGuard System to perform satisfactorily, the relative humidity (RH), temperature (T) and Mold Growth Index (MGI) was determined throughout the thickness of each wall over the two-year period. Each simulation plotted the results as a colored graph on a wall section at one-week intervals. The result was 104 plots for each two-year period showing the wall drying or wetting as the simulation progressed. The total of 22,464 plots were generated from the simulations. A random sampling of 8 of the plots is shown in Figures 5 and 6. The plots show a one-week progression of drying in two wall assemblies, brick and EIFS, in Boston, MA, following an April rain event. The blue arrows indicate the location of the 1% rain load that is directed behind the cladding.

Figures 5 and 6 show the difference in the drying rate between walls that have a 4-mil polyethylene vapor barrier as opposed to a vapor retarding interior paint. The reader should be careful not to draw conclusions from the one-week sampling of the simulation; they are presented only to provide an example of the output from the modelling.

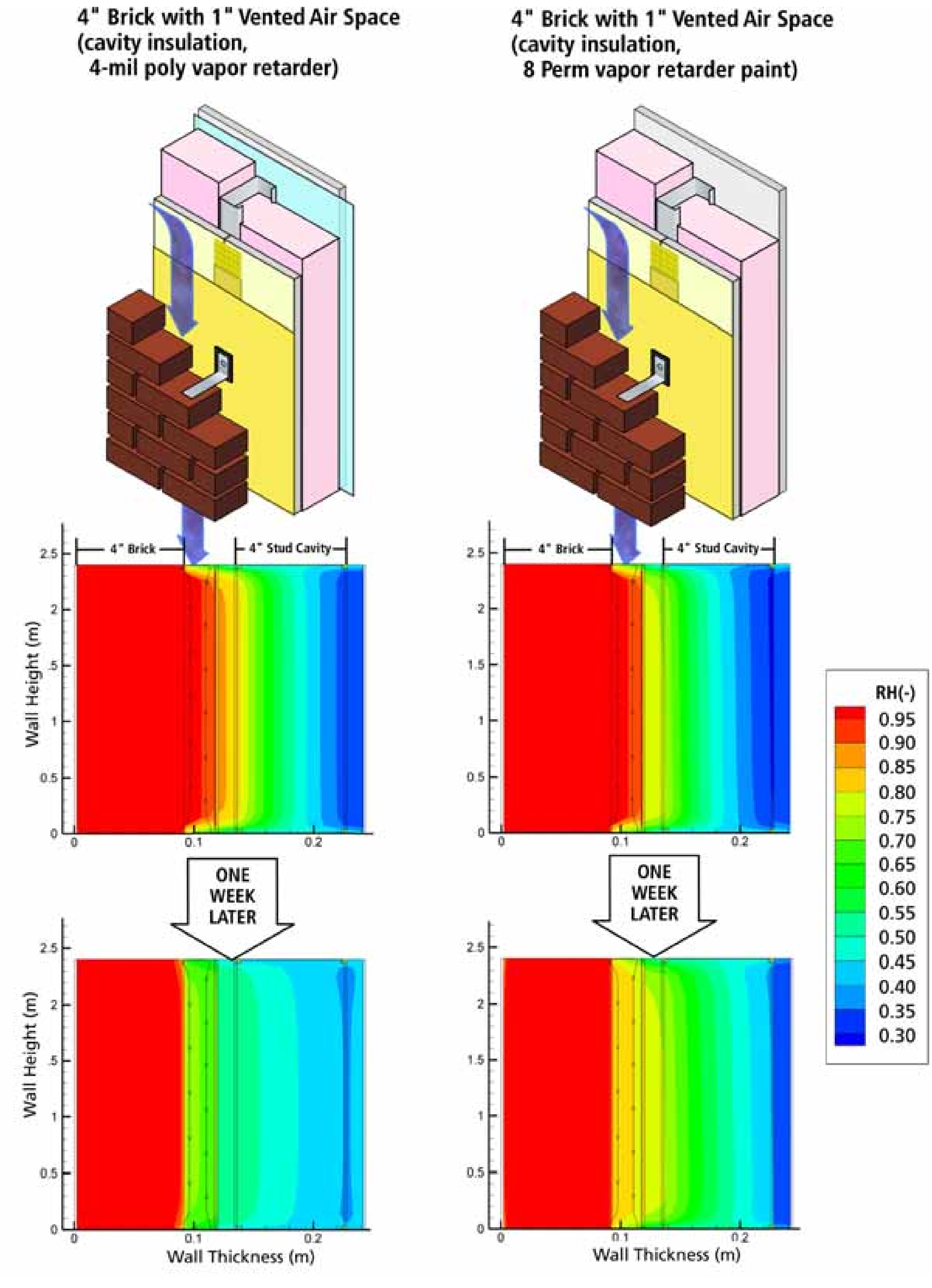
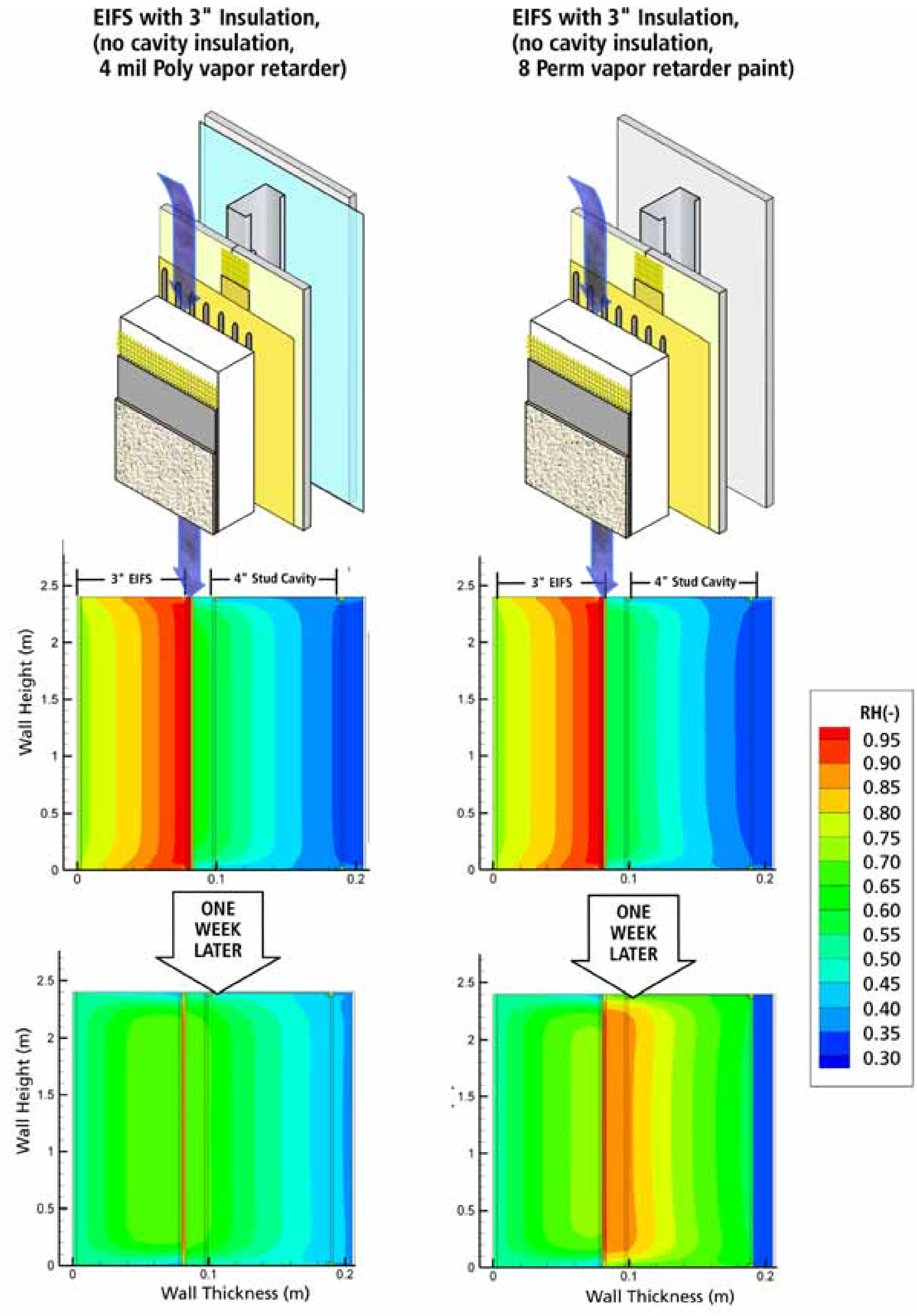


Figure 5. One week of Moisture Expert simulation for a brick clad wall. Simulation shows an April rain event in the study city of Boston. 1% of rain striking wall is assumed to enter the brick cavity (blue arrows).



EIFS with 3" Insulation, (no cavity insulation, 4 mil Poly vapor retarder)

EIFS with 3" Insulation, (no cavity insulation, 8 Perm vapor retarder paint)

Figure 6. One week of Moisture Expert simulation for an EIFS clad wall. Simulation shows an April rain event in the study city of Boston. 1% of rain striking wall is assumed to enter the EIFS cavity (blue arrows).

Evaluating the Results - Mold Growth Index

Deterioration occurs when a wall gets wet and stays wet for a significant duration; the mere presence of moisture does not indicate a problem. To evaluate the potential for material deterioration and mold growth, the moisture content, relative humidity and temperature data were fed into a risk assessment model that calculates a "Mold Growth Index" at the exterior sheathing.

The Mold Growth Index (MGI) was developed by Finnish researchers in 1998. Based on experiments involving visual inspection for mold growth on wood under a variety of environmental conditions, mathematical relationships for the growth rate of mold were developed. These mathematical relationships correlate the expected extent of mold growth based on moisture exposure time, temperature, relative humidity and dry periods. The resulting model provides a numerical Mold Growth Index from 0 to 6, as shown in Figure 7. In essence, the Mold Growth Index represents the existence of conditions conducive to mold growth. The higher the Mold Growth Index, the more conducive the conditions for mold growth activity. These mathematical mold growth relationships were incorporated into this research to provide an indication of the performance of the wall systems.

Mold Growth Index	Descriptive Meaning
0	No growth
1	Some growth detected with microscope
2	Moderate growth detected with microscope
3	Visually detected some growth
4	Visually detected coverage more than 10%
5	Visually detected coverage more than 50%
6	Visually detected 100% coverage

Figure 7. Mold Growth Index Values and Their Meaning.

Figure 8 summarizes the maximum Mold Growth Index values experienced for each of the tested wall systems over the two year period. The maximum MGI for the cladding assemblies in Figures 5 and 6 was extremely low (0.3 or less) In general, the results show good to excellent results (MGI values of less than 2.0) for all locations, with the following exceptions:

Boston: all walls performed well except the stucco wall with the 4-mil vapor retarder which showed a MGI value just over 2.

Chicago: all walls performed well except the stucco walls with an MGI value of 2.0 when the 8-perm vapor retarding paint was used and 2.3 MGI when the 4-mil vapor barrier was used.

Vancouver: The walls using the 8-perm vapour retarder paint all had MGI values exceeding 5, indicating an unsatisfactory performance. The exception was the EIFS wall with 3 in. of insulation, which had a maximum MGI of 2.2, indicating moderate, microscopic growth, in the first year of the simulation only; thereafter, the MGI dropped to negligible values. The walls with the 4-mil polyethylene vapor retarder also showed high MGI values. The results for Vancouver are indicative of its generally wet climate, a climate conducive to deterioration and mold growth.

Houston: While all walls performed well during the first year of the simulation, in the second year, the brick and stucco walls showed marked increases in the MGI values to just over 2.

Toronto: The MGI for the brick and stucco walls using the 8-perm vapour retarder paint exceeded 2.0 during the first year of the simulation, but fell to levels less than 0.5 in the second year of the simulation.

However, when 4-mil polyethelene is used on the inside face of the wall the mold growth index drops to less than 1.0.

A “smart” vapor retarder (one that responds with increasing vapor permeability to increasing RH levels) used in lieu of the 4-mil vapor retarder should improve the MGI values. In extreme climates like Vancouver, the “smart” vapor retarder along with ventilation of the cladding cavity is a design approach that should be considered.

			Maximum Mold Growth Index over Two Year Simulation Period			
Location	IECC Zone	Vapor Retarder	Brick	1 in. EIFS	3 in. EIFS	Stucco
Atlanta	**3**	8-perms	0.6	0.3	0.2	1.0
Boston	**5**	8-perms	0.3	0.1	0.1	0.4
Boston	**5**	4-mil	0.1	0.4	0.2	2.1
Chicago	**5**	8-perms	1.5	0.7	0.2	2.0
Chicago	**5**	4-mil	0.6	1.2	1.6	2.3
Denver	**5**	8-perms	0.1	0.1	0.1	0.1
Denver	**5**	4-mil	Neg**	Neg**	Neg**	Neg**
Houston	**3**	8-perms	2.0	0.7	0.9	2.0
Miami	**2**	8-perms	0.5	0.9	1.8	0.6
St. Louis	**4**	8-perms	1.0	0.4	0.1	0.9
St. Louis	**4**	4-mil	Neg**	0.9	1.3	1.5
Toronto	**6***	8-perms	2.4	0.8	0.3	2.2
Toronto	**6***	4-mil	0.6	0.3	0.4	0.7
Vancouver	**4***	8-perms	5.5	5.2	2.2	6.0
Vancouver	**4***	4-mil	3.8	5.8	5.7	5.9
Wilmington	**3**	8-perms	0.4	0.2	0.1	0.4
Winnipeg	**7***	8-perms	0.9	0.6	0.2	0.8
Winnipeg	**7***	4-mil	0.2	0.4	0.41	0.6

* Climate zones extrapolated for Canada ** Negligible

Figure 8. Maximum Mold Growth Index Values for Simulated Wall Systems.

Conclusion

This research clearly indicates the effectiveness of the StoGuard® system in preventing moisture conditions conducive to material deterioration and mold growth. In most cases, the Mold Growth Index, representative of the existence of conditions conducive to material deterioration and mold growth, was less than 2, meaning that at most, moderate microscopic growth may occur. The research also determined that, in general, for IECC Zones 5 and higher, including all cities in Canada, vapour retarders are recommended if high interior relative humidity (i.e., greater than 35%) is expected. In Vancouver, great care must be taken in the design and construction of all buildings, particularly to minimize the interior relative humidity, to ensure a tight air barrier and a vapor retarder inboard of the insulation, and to provide sufficient ventilation behind the cladding.

Elsewhere, and particularly in humid climates, the use of interior vapour retarders should be carefully evaluated since they can inhibit drying of wall assemblies. For very difficult climates like Vancouver ventilated wall designs should be considered. Careful detailing and execution of work, while always important, becomes increasingly more important in assemblies where the MGI is above 2.0. The selection of inorganic materials within the wall assembly that do not provide a food source for mold should also be considered.