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By Madeleine Z Rousseau[1], B. Arch, M. Sc. and W. Alan Dalgliesh[2], M. Eng., P. Eng.

Session: T2S1

ABSTRACT

The National Research Council of Canada, with partners from industry, has just completed a four-year project on the wetting and drying performance of exterior walls of low-rise wood-frame buildings exposed to a range of climate loads characteristic of North America. The Moisture Management in Exterior walls (MEWS) project activities included a review of typical construction practices, the characterization of hygrothermal properties for many commonly used building materials, the assessment of moisture loads for different North American locations, laboratory tests of large-scale wall specimens to measure water entry through imperfections, and finally a parametric study using IRC's hygIRC 2D-hygrothermal numerical model to predict moisture and temperature balances at selected locations within virtual wall assemblies.

The MEWS study has produced a method of comparing the risks of deterioration associated with different wall assemblies using different material properties, exposed to different climatic moisture loads. Here are a few of the general findings from the application of this method in the MEWS project:

- To minimize risk of deterioration, moisture ingress directly into the stud cavity needed to be strictly limited. This stresses the importance of proper design and execution of the detailing of wall assemblies to minimize moisture entry into the stud cavity.
- Evaporative drying of the wet stud cavity as a moisture control strategy was only effective when its wetting was kept to a minimum over the full range of climatic conditions.
- Hygrothermal properties of materials affected the evaporative drying potential of the stud cavity, but to varying degrees. Materials with higher vapour and air permeance improved evaporative drying. Outdoor and indoor climatic conditions played a large role in the effectiveness of evaporation as a control strategy. The more humid the indoor or outdoor climates, the less drive for evaporation and drying of the wetted stud cavity.
- A ventilated cavity behind a brick veneer coupled with an exterior sheathing with higher vapour and air permeances gave a substantial increase in the drying potential of the stud cavity for all climates investigated.
- The presence of thermal insulation on the exterior of a wet stud cavity (due to construction deficiencies) tended to increase the duration of warm conditions at the bottom of the wet stud cavity, reinforcing the need to minimize water entry into the stud cavity.

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[1] Researcher, Building Envelope and Structure Program, Institute for Research in Construction, National Research Council Canada, Ottawa, Canada, madeleine.rousseau@nrc-cnrc.gc.ca
[2] Private consultant, 237 Valley Ridge Green NW Calgary, Alberta Canada T3B 5L6

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INTRODUCTION

Based on experience, we know that the moisture that goes into a wall must be able to get out again relatively quickly for a long-service life of the wall elements. We know that the "moisture budget" of the wall will depend on the rate of wetting and the rate of drying of its elements, and this will affect "how wet" the wall elements will stay, and for "how long". Traditional design wisdom has been to select design strategies that promote minimal wetting and maximal drying. The application of this motherhood statement had led to debates as few guidelines are in place to allow designers to adjust effectively the design of wall assemblies so that potential wetting is compensated by sufficient drying for new and innovative wall systems or indeed, for traditional ones exposed to new environments.

The wetting of wall elements relates to the following factors: the magnitude of the moisture loads provided by the local climate, the proportion of this moisture landing on the building facades or accumulating at certain architectural features of the claddings, as well as the means for moisture ingress offered by material properties and assembly characteristics. The drying potential will depend on the climate as well as the properties of the materials, and the makeup of the assembly. Attempts had been made to quantify how much time it takes for a wall assembly to rid itself of incidental water in different

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[1] Researcher, Building Envelope and Structure Program, Institute for Research in Construction, National Research Council Canada, Ottawa, Canada, K1A 0R6 madeleine.rousseau@nrc-cnrc.gc.ca

[2] Private consultant, 237 Valley Ridge Green NW Calgary, Alberta Canada T3B 5L6

climates and the risk of deterioration associated with wet and warm conditions of the wall. Now a method has been devised to show just how sensitive certain components are and how significant the climate is when designing to avoid conditions that can lead to deterioration of wall components. This new method and associated tools can be used to compare the performance of new, innovative walls and products to wall assemblies known to give satisfaction for a given amount of water leakage in a given climate. This method was primarily developed and applied as part of a recently completed study of Moisture management in Exterior Wall Systems (MEWS) by a research consortium of IRC and industry partners (Kumaran et al 2003).

MEWS STUDY

The MEWS project's main trust was to examine and compare the effects of changes in climates, material properties and design of wall assemblies on the risk of structural deterioration associated with excessive simultaneous "wet and warm" conditions prevailing in the wall cavity of light frame construction. Thresholds for the "wet and warm" conditions indicative of a risk of structural deterioration were set at 95% relative humidity (RH) and 5ºC.

Wall assemblies investigated included several cladding systems (stucco, masonry, Exterior Insulation and Finish System (EIFS) and wood-based and vinyl siding), sheathing boards, sheathing membranes, thermal insulation and vapour barriers. IRC researchers conducted experimental and computer modelling studies to support the investigation of the moisture and temperature conditions prevailing in the stud cavity when a wall assembly – with or without wall system deficiencies allowing water leakage into the stud cavity- was exposed to two years of climate loading selected from weather records for a series of localities.

An experimental study of water ingress into seventeen large-scale wall specimens provided a relationship between the rate of water ingress into the stud cavity and the environmental loads (water spray and air pressure difference) the wall specimens were subjected to (Lacasse et al 2003). In the complementary computer modeling study (Mukhopadhyaya et al 2003; Beaulieu et al 2002), a series of virtual wall assemblies were subjected to moisture loading at two different locations: on the exterior cladding and at the bottom of the stud cavity (at variable rates based on the results of the experimental study)(Figure 1). Water entered in the stud cavity through a wall system deficiency providing a path for water leakage. This deficiency consisted of a missing length of sealant bead at a junction between the cover plate of a penetrating element (e.g. vent duct) and the wall assembly, combined with a discontinuity of the sheathing membrane at that junction. Hundreds of simulations conducted on a variety of wall assemblies allowed the research team to isolate the effects of certain changes in the wall characteristics or the climate on the moisture and temperature conditions prevailing at the bottom plate of the stud cavity. The trends observed in the results of the modeling study are indicative of the factors that affect the wetting and the drying of wood-frame assemblies.

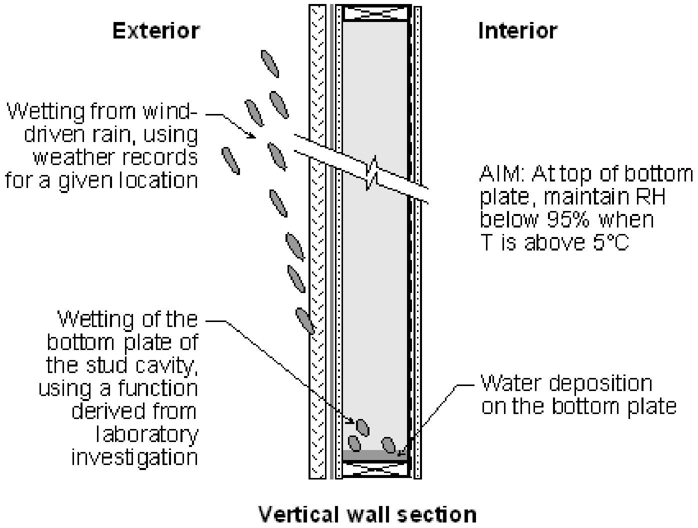


Figure 1. Example of a virtual wall assembly subjected to wetting of the cladding and of the bottom of the stud cavity over a (simulated) two-year period, to examine the effect of this wetting on the drying of the assembly.

OTHER ELEMENTS OF THE MEWS STUDY

Research was also carried out on several other fronts to support the experimental and modelling work. For instance IRC reviewed current building practices, characterized hygrothermal properties for about 80 building materials, and performed a comparative examination of modelling and experimental outputs (known as "benchmarking" the computer model (Maref et al 2002). A new indicator to estimate the severity of the climatic moisture loads, the Moisture Index (MI) was developed and supported by extensive analysis of climate records (Cornick et al 2001). The MI index combines the potential wetting and potential drying of a climate into a single normalized value. The wetting potential is based on the annual rainfall and the drying potential is based on the potential for evaporation in ambient air. The analysis is based on up to 30 years of meteorological records for a given locality. The higher the MI index value, the higher the climatic moisture loads for that locality. Another novel indicator of simultaneous elevated levels of moisture and temperature within the wall assembly was developed, the RHT index, to help compare the risks of deterioration associated with wall designs of interest in given climate settings. The RHT index is a two-year computation of the duration and magnitude of moisture and temperature levels above selected thresholds, extracted from hygrothermal computer modelling outputs for a selected location within a virtual wall assembly.

EFFECT OF THE SEVERITY OF THE MOISTURE LOADS IN THE STUD CAVITY (Q)

Of all the factors investigated in the study, the control of water leakage directly into the stud cavity (defined as "Q" in L/m^2 per hour) was the most critical design concern for maintaining moisture conditions below the selected excessive level of 95% RH in air in equilibrium with the bottom plate in the stud cavity. Figure 2 compares the trends in the levels of risk of deterioration (as defined by the "RHT index") that researchers found for virtual wall assemblies with no added deficiencies allowing water leakage directly into the stud cavity. The trends for the same walls with such deficiencies are also shown for exposures to climatic loading of increasing intensity (as defined by the "MI index"). These two curves are a generalization of the trends observed, since each wall assembly investigated responded differently, as a result of its particular wetting and drying mechanisms.

Virtual wall assemblies with no direct water leakage into the stud cavity exhibited RHT values of zero over a wide range of climatic moisture loading, meaning that the cladding assembly - the first line of defense against water ingress - provided a level of water resistance sufficient to maintain the relative humidity of air in equilibrium with the bottom plate of the stud cavity below 95% while its temperature was above 5ºC over a simulated two-year period. An RHT value of zero was considered in this study to represent zero risk of deterioration by wood decay. For the walls without added deficiencies (i.e. no direct water leakage into the stud cavity), the wetting of the cladding systems – even absorptive claddings – was counterbalanced by sufficient drying inherent in the make-up of the assemblies. Only in one case did a wall assembly with no direct water leakage into the stud cavity exhibited a positive level of risk of deterioration at the bottom plate: the assembly included an absorptive cladding (stucco), no vented cavity behind the cladding and was exposed to a very severe climatic environment (very wet and mild, with low drying potential). This suggests that such wall constructions used in locations with such climatic characteristics would require higher levels of design redundancies than when they are built in less demanding climates.

When the wall assemblies included a deficiency allowing direct water ingress into the stud cavity, the risk of deterioration increased rapidly as a function of the severity of the climatic moisture loads i.e. prolonged wetting and shortened drying periods. Not only did the severe climate exposure resulted in larger amounts of water being introduced into the stud cavity but it offered a lower drying potential as well. The level of risk of deterioration in the stud cavity was very much linked to the severity of the climatic moisture loads and to the presence of deficiencies into the wall assembly providing a path for water entry directly into the stud cavity. In dry and hot climates, the wall assemblies with water leakage path into the stud cavity tended to exhibit a lower level of risk of deterioration but the risk would not be totally eliminated unless careful control of direct water leakage into the wall assembly were implemented.

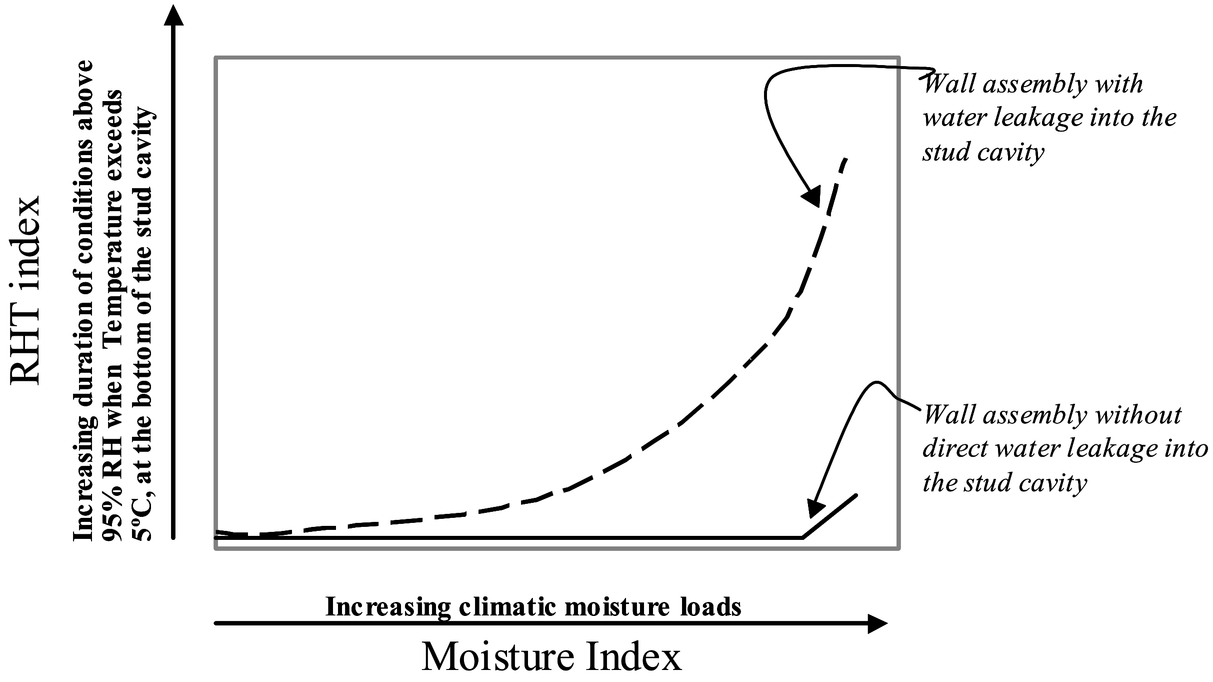


Figure 2 Generic relationship established between the severity of the climate moisture loads, the hygrothermal response of the wall and the water leakage into the stud cavity (defined as 'Q' in the study)

REDUCING WETTING OF THE WALL ASSEMBLY

Obviously designers cannot change the severity of the moisture loads in a given geographical region. Nevertheless, designers can choose to acknowledge those loads and adapt the design and construction of wall assemblies to suit the severity of the climate. Maps of climate severity are available and the MEWS project has generated a map that characterizes climate, dividing North America into five zones according to net drying and wetting potential.

Building envelope design and detailing affect the distribution and magnitude of the water load on the façade. Designers and builders can take action to deflect the loads from claddings and deficiencies usually developing at junctions between the wall and penetrating elements like windows by:

- providing positive slopes to horizontal elements that project from the plane of the façade (e.g. balconies, walkways and window sills), making sure to take the shrinkage of the wood framing after construction into account;
- projecting roof soffits over the façade to shed water and keep it away from low-rise walls. Findings of a large field study commissioned by Canada Mortgage and Housing Corporation (CMHC 1996) showed that the depth of the soffits had some incidence on the frequency of rain penetration problems in walls located below these elements
- projecting rigid flashings above through-the-wall penetrations such as windows, doors and ducts.

The detailing of junctions between penetrating elements and the wall itself is critical to the wetting of the stud cavity, as confirmed by IRC MEWS laboratory investigation. The introduction of flashing membranes and pans to collect and drain water either directly to the outside or to a drained cavity behind the cladding provides a measure of protection against any water leakage that might occur as a result of imperfections between or aging of materials, or leaking components penetrating the walls (e.g. windows frames).

Total avoidance of water ingress cannot be relied upon for all stud cavities all the time. Water leakage into the stud cavity needs to be brought down to a level that can be handled by the drying ability of the wall in its given climate exposure setting. This level is in fact quite specific to each case, and can be the subject of a more detailed analysis, for the development of guidelines on the application of a specific wall design in a given climate. In more general terms, the MEWS study showed that the drying ability of the wall is unlikely to cope with more than a relatively small amount of direct water leakage into the stud cavity. Figure 3 shows the trend observed for all virtual walls investigated for the relationship between the rates of water leakage into the stud cavity and the level of risk of deterioration defined by the RHT index. In area A, the risk of deterioration was not much affected by the increase in water leakage into the stud cavity, which implied that periods of wetting alternated with periods of drying, resulting in a near-zero accumulation of water in the stud cavity over time. When the water leakage increased further (area B), perhaps due to either an increase in the size of the deficiencies providing a leakage path, or an increase in climate-related moisture loads, the risk of deterioration increases rapidly. This indicates that the cumulative periods of excessive wetting were increasingly longer than the drying periods, and that the wall drying potential “could not keep up” with the increasing water loads within. As the water loads increased further (area C), the wall was overloaded with water and the risk eventually reached its maximum level.

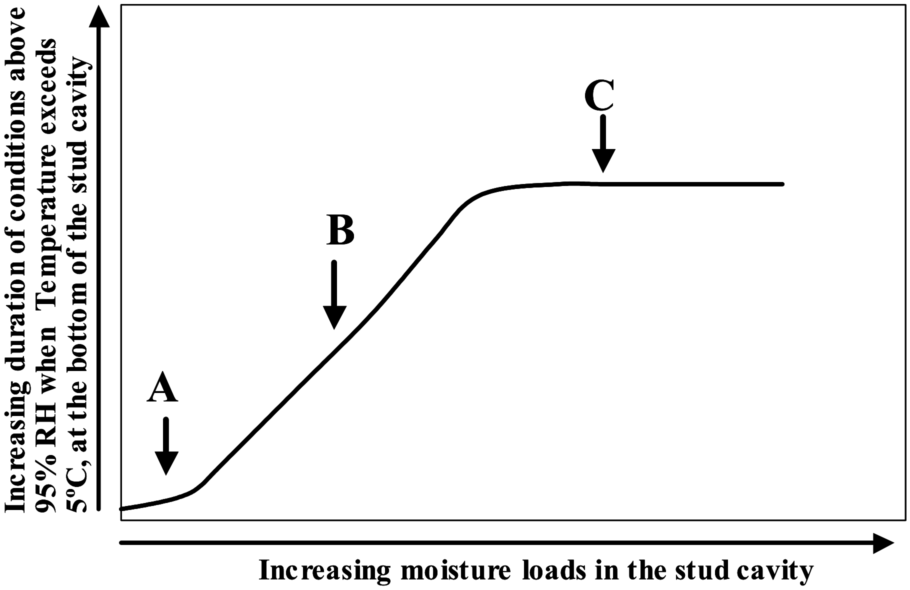


Figure 3 Generic relationship established between the severity of the moisture loads (due to climatic moisture loading and/or magnitude of wall deficiencies) getting into the stud cavity and the hygrothermal response at the bottom of the stud cavity.

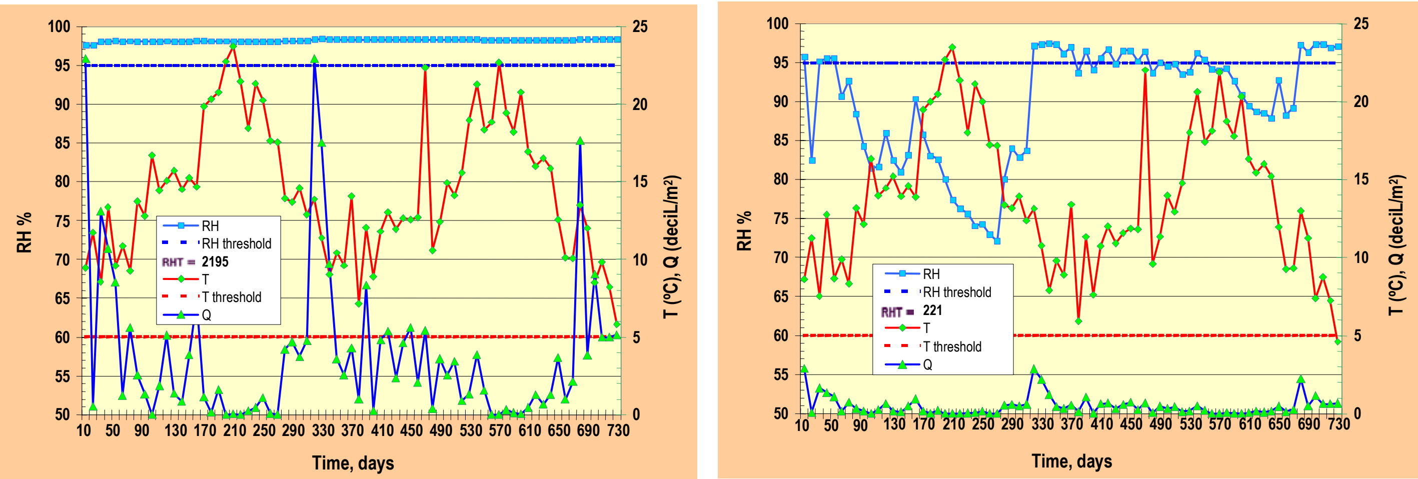
As the wetting mechanisms were more potent than the drying mechanisms investigated in the modelling study (most virtual walls investigated did not include a clear vented air space behind the exterior cladding), it became evident that the drying potential offered by the makeup of such assemblies could dry out the bottom plate of the stud cavity below 95%RH only when the wetting rate was low. For the designers and builders, this finding validates the critical importance of minimizing moisture ingress into the stud cavity, and the potential benefits of spending the time and effort to accomplish this during the construction process. It also indicates that evaporative drying through several layers of materials of several common constructions sandwiched together can be very limited, and should not be counted on as a primary defence against moisture ingress, but rather as a secondary level of protection in the moisture management strategies available to designers and builders.

FACTORS AFFECTING THE DRYING OF WALLS

The dissipation of water that accidentally enters a wall assembly can be achieved by drainage of water (in liquid form) or by evaporation (in vapour phase) either through the series of layers of materials alone or that combined with a vented or ventilated air space(s). The MEWS modelling study examined the factors contributing to the potential benefits of evaporative drying of the stud cavity, as a function of the climates (indoor and outdoor), the material properties and the make-up of the assembly, once water was allowed to bypass the first and second lines of protection of the wall assembly due to construction deficiencies and enter the stud cavity.

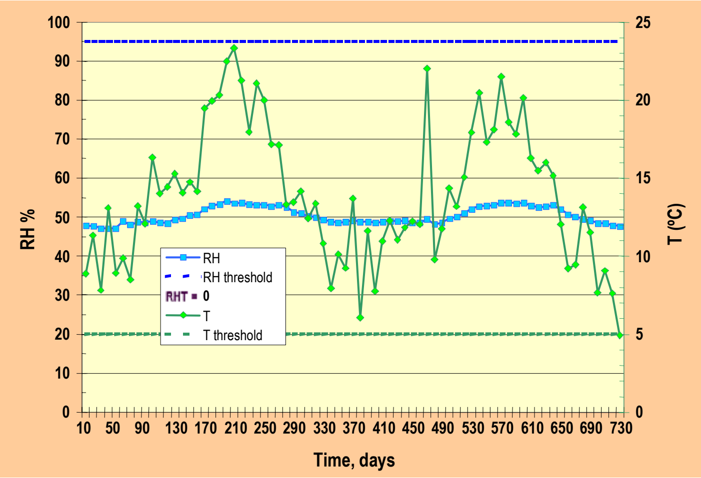
First, Control the Wetting of the Stud Cavity

The foremost finding of the study was that the evaporative drying potential of a given wall assembly without a vented air space behind the cladding is generally too small to keep up with significant amounts of water leakage into the stud cavity. In general when the stud cavity was in the areas B or C of the curve in figure 3, the drying rates offered by the materials studied could not dissipate this excess moisture rapidly enough over the course of the simulated two-year period. Figure 4a and b show the hygrothermal response of a given wall assembly to different moisture loads in the stud cavity.



(4A) WALL A with large moisture load in the stud cavity (Q)

(4B) Wall A with 1/8 of that moisture load (Q)



(4C) Wall A with NO moisture loading in the stud cavity

Figure 4. A given wall assembly with given hygrothermal properties responded differently as a function of the magnitude of the moisture loads introduced in the stud cavity due to construction deficiencies providing a direct path for water ingress. Graph (A) shows the wall subjected to a high moisture loads into the stud cavity, while in graph (B) the wall was subjected to one eighth of that loading. Wall A in scenario (B) is predicted to experience prolonged periods of drying of the bottom of the stud cavity below 95% RH. Graph (C) shows that a wall without accidental moisture loading of the stud cavity was predicted to maintain RH conditions well below the threshold of 95% at the bottom of the stud cavity.

Then, Consider the Vapour and Air Permeance of External Layers

When materials with higher air and vapour permeance were coupled with a ventilated air space located behind the exterior cladding, the wall assembly showed considerably better drying ability, even when the water leakage into the stud cavity was in the high range (for this study). The results of a single set of modelling simulations for a masonry-clad wall assembly with a air and vapour permeable sheathing board for a variety of climate loads consistently showed the larger drying potential. Further investigation into the benefits of such an approach to wall design is warranted.

A smaller portion of the computer modelling study investigated the level of risk of deterioration (i.e. the RHT index) and the drying potential offered by certain wall assemblies when the stud cavity leakage was much reduced. In this case, the wall assemblies with a non-impervious cladding (i.e. stucco) and a sheathing board of much higher vapour permeance and air permeance on the exterior of the stud cavity exhibited a much higher drying ability to the exterior than the same wall with lower permeance sheathing boards. Materials with higher air and vapour permeance placed on the exterior of the wet stud cavity were more conducive to evaporative drying, and provided benefits to handle relatively low rates of moisture ingress into the stud space.

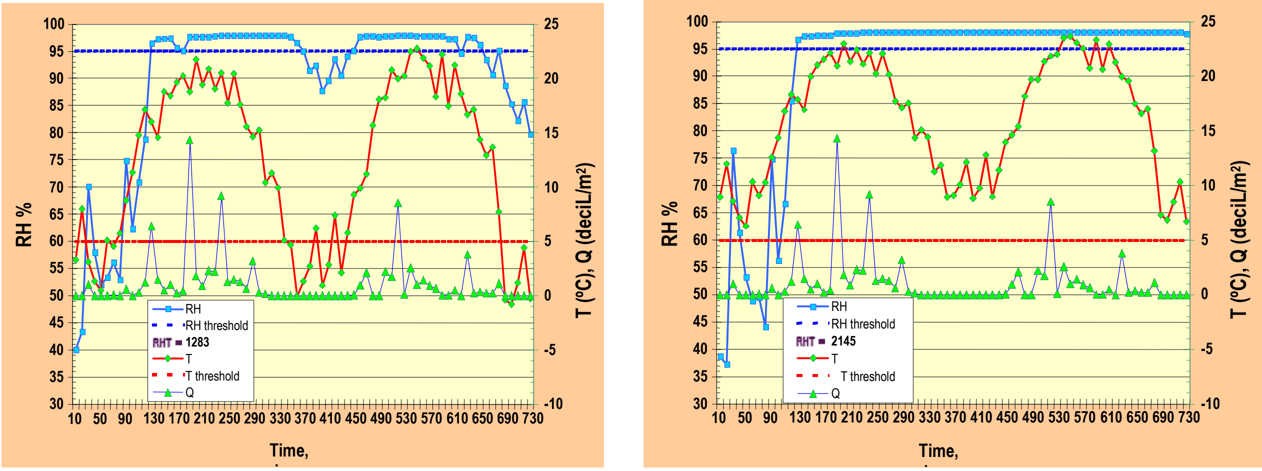
The properties of the sheathing membranes investigated did not make much difference in the hygrothermal response of the virtual wall assemblies. One could have assumed that, as a sheathing membrane acts as the second line of protection against rain penetration, its hygric properties should make some difference. However, construction deficiencies in the wall specimens were such that a path to bypass the sheathing membrane was present and allowed rainwater to infiltrate into the stud cavity, regardless of the properties of the sheathing membrane. In the experimental work, it was observed that water could enter through a deficient seal at the junction between a ventilation duct cover plate and the exterior cladding, and then move inwards and enter the stud cavity through an unsealed gap between the sheathing membrane and the duct itself.

Effect of the Hygrothermal Characteristics on the Interior Side of the Stud Cavity

The modelling study also examined the effect on drying potential to the interior space of changing the properties of the two interior layers, i.e. the vapour barrier and the interior gypsum wallboard, or by changing the interior relative humidity levels. The results showed that drying to the interior depended upon the vapour permeance of the interior layers and the levels of interior RH conditions. Even with highly vapour permeable interior layers and low indoor RH conditions, however, a stud cavity wetted by external system deficiencies could not be dried below 95% RH for the duration of the two simulated years of climate exposure.

Effect of the Thermal Characteristics on the Exterior of the Stud Cavity

The temperature and relative humidity prevailing at the bottom of the stud cavity for wall assemblies with and without thermal insulation on the exterior side of the stud cavity (with water leakage into the stud cavity) were compared. Particularly in cold climates, thermal insulation to the exterior of the stud cavity tended to increase the duration of warm conditions at the bottom of the wet stud cavity, conditions more conducive to the onset of deterioration. Figure 5 shows the modelling results of the hygrothermal response at the bottom of the stud cavity for two similar wall assemblies, except for the properties of the exterior sheathing boards: assembly A has a wood-based sheathing board and assembly B has exterior insulating sheathing. The walls were exposed to Winnipeg climate (MI =0.86 Heating Degree Days (18ºC)= 5900). The stud cavity of Wall B was maintained above 5ºC for the whole two years, increasing the duration of simultaneous conditions of elevated temperature and moisture, while Wall A experienced a period of temperature conditions below 5ºC, resulting in a lower cumulative RHT value.



Wall Assembly A, with a wood-based sheathing board Assembly B with an insulating sheathing board

Figure 5. Hygrothermal response of two similar wall assemblies with sheathing boards with different hygrothermal properties, exposed to water leakage into the stud cavity in Winnipeg (Cold Canadian climate). RHT value for wall A is lower than RHT value for Wall B.

If condensation control were the only concern, an insulating sheathing would be considered desirable because the increased cavity temperature shortens the period during which it is below the dew point temperature of indoor air, hence reducing the potential for interstitial condensation. In other words, a cautious and comprehensive approach is advisable when different moisture control strategies may be in conflict. This observation comes to support the importance for proper control of all moisture sources as a design prerequisite for other wall elements to perform as intended.

Effect of a Ventilated Cavity Behind the Exterior Cladding

One might assume that adding a clear cavity behind two types of claddings (i.e. stucco and hardboard siding) would significantly raise the evaporative drying potential of a wetted stud cavity. When the wetting of the stud cavity was in the high range of the study, however, the drying benefits of the additional ventilated cavity (open at top and bottom) were marginal. This supports the earlier observation that evaporative drying benefits are contingent on a fairly rigorous control of wetting in the stud cavity. The drying benefits generally increased when the stud cavity wetting was much reduced.

As said previously, all masonry wall assemblies included a clear cavity behind the cladding, and when this was coupled with higher air and vapour permeance sheathings, the wall response showed a dramatic increase in drying potential for all climates investigated.

The potential benefit of introducing additional capacity for drainage of liquid moisture and reducing the moisture load into the stud cavity by means of this cavity was not considered in the modelling work, but was rather studied in the large-scale laboratory experimentation. The result of this experimental work indicated that a drained cavity behind the cladding system greatly reduced the moisture loads into the stud cavity, when a water leakage path was in place. However some small amount of water could still find its way into the stud cavity, hence the need for a second line of protection particularly at junctions between the wall assembly and a penetrating component such as a window or a ventilation duct.

CONCLUSION

The drying of wet stud cavities was a function of four factors: the materials used in the assembly; the ways they were put together; the magnitude of the driving forces for thermal and hygric movements; and last but not least, the amounts of water entering the stud cavity through imperfections in the wall assembly. Unless the wetting of the stud cavity was held to relatively low levels, designing the walls to optimize drying offered little or no appreciable benefits.

The study also confirmed the following good practices: *ACCEPT* the climate loads present in the geographical region of interest; *DEFLECT* the moisture loads away from the façade; *COLLECT* any water that finds its way into the wall assembly by using flashing membranes and pans at penetrations like windows and vent ducts; *DIRECT* the water outside by means of an effective drainage path; *DO NOT*

NEGLECT the maintenance of the wall system's components and interfaces; maintenance is critical to achieving long-term performance and service life.

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