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A Methodology to Develop Moisture Management Strategies for Wood-Frame Walls in North America: Application to Stucco-Clad Walls

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1. INTRODUCTION

Effective moisture control in the building envelope is essential if acceptable service life is to be achieved for the built environment. Effective moisture control implies both minimizing moisture entry into the system, and maximizing the exit of moisture, which does enter, so that no component in the system stays 'too wet' for 'too long'. But what is "too wet" and "too long"?

At the institute for Research in Construction, National Research Council of Canada, a research project called MEWS[1] (Moisture Management for Exterior Wall Systems) was initiated to answer the above questions. The project has now resulted in a methodology that leads to design considerations for improved moisture management strategies for any wall assembly at any geographic region in North America. The methodology includes the integration of information from a review of field practices (Rousseau et al., 2002), extensive measurements of hygrothermal properties of building materials (Kumaran et al., 2002), definition of environmental loads (Cornick et al., 2002), investigation on damage functions (Nofal and Kumaran 1998), experiments on wind-driven rain penetration (Lacasse et al., 2001) and a detailed parametric analysis using a benchmarked and advanced hygrothermal model called **hygIRC** (Maref et al.2001; Mukhopadhyaya et al. 2001). This paper attempts only to summarize the methodology and lists some of the observations from its application to stucco-clad (Portland cement plaster) wood-frame walls. A full description of each module in the methodology is beyond the scope of this paper [2].

2. THE METHODOLOGY

The long-term performance of any wall assembly of a building is considered as the consequence of the hygrothermal responses of the wall as a whole and localized responses of any of its components and material layers; these responses are specific to each geographic location and to the indoor climate. In MEWS context, the long-term performance of wood and wood-based materials determines the long-term performance of the wall.

The project makes full use of IRC's mathematical model hygIRC, benchmarked against many sets of laboratory experiments (Maref et al. 2001), for predicting the hygrothermal response of the wall as a whole as well as at a localized vulnerable area of the wall. New knowledge was required on the following fronts:

- Climate characterization for North America, in terms of moisture loads imposed on a wall
- Typical practice of design and construction of walls with different cladding systems in place

[1] MEWS is joint research project between IRC- NRC Canada and the following external partners: Louisiana Pacific Corporation, Marriott International Inc., Fortifiber Corporation, EIFS Industry Members Association, EI DuPont de Nemours & Co., Canadian Wood Council, Fiberboard Manufacturers Assn., Canada, Masonry Canada, Canadian Plastic Industry Association, Canada Mortgage and Housing Corp. and Forintek Canada Corporation

[2] Readers interested in further details are welcome to read the collection of Internal Reports from IRC .

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- Estimation of quantity and distribution of water ingress into the wall assembly, in relation with climatic loading
- Characterization of hygrothermal properties of materials
- Selection of indicators of the hygrothermal response of the wall

Many internal reports (See References section) document the outcome of the research activities on the above fronts within MEWS. Only the details on the application of hygIRC are given below.

2.1 Parametric Analyses and Hygrothermal Responses

2.1.1 Using hygIRC model

The computer model hygIRC is used to investigate the hygrothermal responses of wall assemblies. The model predicts (not in absolute terms but on a relative basis) real-time response of the wall to changing environmental conditions and hygrothermal loads. It simulates simultaneous heat, air and moisture transfer. For each combination of the parameters, hygIRC provides the hygrothermal response of the wall assembly, at each hour. These responses at any selected point are quantified in terms of a temperature, a moisture content (or RH) and a pair of airflow velocity vectors.

2.1.2 Input data

MEWS investigations were on various types of wood-frame walls. Based on the review of practice, the vertical cross-section of a full height one-storey wall (2.4 m high) is generated. The cross section includes all the material layers as well as top and bottom plates, at their nominal thickness(see Figure 2 for an example). This 2-dimensional cross-section is defined within hygIRC as a matrix of rectangular sections and grid points. This definition allows for the calculation of the spatial and temporal distribution of various hygrothermal responses.

Seven specific locations are selected to represent the broad spectrum of a quantity called Moisture Index (MI) for North America and in five climatic zones (Cornick et. al. 2002). These are: Phoenix (MI 0.13); Fresno (MI 0.49); San Diego (MI 0.74); Winnipeg (MI 0.86); Ottawa (MI 0.93); Seattle (MI 0.99) and Wilmington (MI 1.13). The moisture index is a combination of a wetting index, which represents the wind-driven rain to which a wall can be exposed, and a drying Index, which represents the drying potential offered by the climate through evaporation (Hagentoft and Haderup, 1996).

From multi-year weather data files (up to 30 years), two years are selected for each location. These two years of climate data define the exterior environmental conditions prevailing at each location for the parametric analyses. One of these is called a "*wet*" year to represent the highest rain load and the other an "*average*" year to represent an average rain load, characteristic of the location. Hourly weather records from these two years are put together to define a three-year weather cycle in the following sequence: *wet-wet-average*.

The interior environmental conditions considered are temperature and relative humidity. A summer and winter setting of RH and T are simulated in accordance with ASHRAE recommendations (ASHRAE Handbook of Fundamentals, Chapter 3).

Out of the database of material properties (Kumaran et. al. 2002), three sets of properties for each generic material are selected; the mean value and the lower and upper limits are used as parameters in the analyses.

2.1.3 Simulation Runs

Before the parametric simulation runs start, a year is used to "condition" a given simulated wall to a *wet* year of local weather and hence to the natural hygrothermal loads only. Each material in that wall starts with equilibrium moisture content that corresponds to an exposure to an environment of 50% RH and the assembly does not include any deficiency that could lead to water leakage into the stud space. Thus, one year into the simulation, the wall assembly attains a state natural to the wettest local weather, however, with no deficiency. The subsequent *wet* year and *average* year of simulation are then used to assess the response of the walls for two years. At this stage of the simulation the walls may include a deficiency that allows water leakage into the stud cavity; the local weather conditions determine the rate of water leakage (Lacasse et. al. 2001). Snap shots of the wall responses from these two years of the weather sequence are recorded every ten days. This yields 73 records of temperature, moisture content (or RH) and airflow velocities throughout the wall for each simulated case.

2.2 Analysis of the Hygrothermal Responses

The wood framing and the sheathing board are looked upon as the critical layers most susceptible to the detrimental effects of undesirable moisture accumulation during the service life of the wall. A sheathing segment, for example 1.4 mm thick and 0.6 m high above the bottom plate of the stud cavity for stucco walls, is identified as the region of interest for the entire sets of the "73 records" of responses obtained from the hygIRC simulations.

A novel concept called RHT Index is used to quantify and compare the localized response at the selected segment mentioned above. This index captures the duration of the coexistence of moisture and thermal conditions above a set of threshold levels, during an exposure period of two years. The threshold levels depend on the physical process that is of interest in regard to the durability of any selected material in the wall. Two sets of threshold levels are considered in MEWS. A combination of 95 % RH and 5 °C temperature (called RHT95) averaged along the segment is selected for its potential relevance to the growth of wood decay fungi. The second combination considered for MEWS is 80 % RH and 5 °C temperature (called RHT80) averaged along the segment for its potential relevance to corrosion processes. The cumulative values of the RHT index, over the two-year period, obtained from all the 73 records are used in all discussions in this paper.

The graphical representation of the RHT response of a wall after two years of exposure to the local weather is presented in Figure 1. The line closer to the X-axis shows the behaviour of a wall

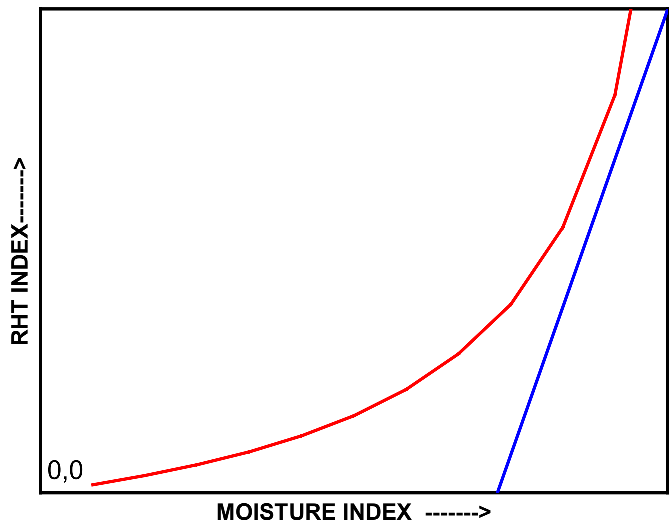

Figure 1: Characteristic curves expressing the relationship between climate loading and moisture response of a wall assembly; the straight line represents an ideal wall construction with no water entry into the stud space whereas the curve represents a wall with deficiency; the deficiency assumed in MEWS is a 1 mm X 45 mm opening on the exterior wall assembly.

with no deficiencies (or zero rainwater entry behind the sheathing), in response to the hygrothermal loads imposed by two years of local weather and indoor conditions. This line is characteristic of a given wall assembly with a given set of material properties. The curve above the line shows the wall's response when an additional moisture load, for example in the form of water leakage into the same wall through a deficiency, is present. This latter curve will vary in shape and location on the RHT-MI plane, depending on the magnitude of that additional load.

2.3 Evaluation of the Wall Response

As indicated by the results from the parametric analyses, any strategy that brings the two curves in Figure 1 closer to zero RHT is a design consideration for better long-term performance of the wall.

These considerations can be any one or a combination of the following:

- Selection of materials with properties resulting in less wetting and/or better drying
- Development and use of innovative materials with even better properties than the ones currently available and used in the simulations
- Use of a drainage plane or drained and ventilated cavity between the cladding and the sheathing
- Implementation of design details that reduce the potential for deficiencies or their impacts
- Sheltering of the wall to reduce the moisture load on it
- Changes in the basic design of the wall system, as a last resort when other alterations are not sufficient

3. APPLICATION TO STUCCO-CLAD WALLS

The basic design for a stucco-clad wood-frame wall, considered in MEWS analyses, is shown in Figure 2.

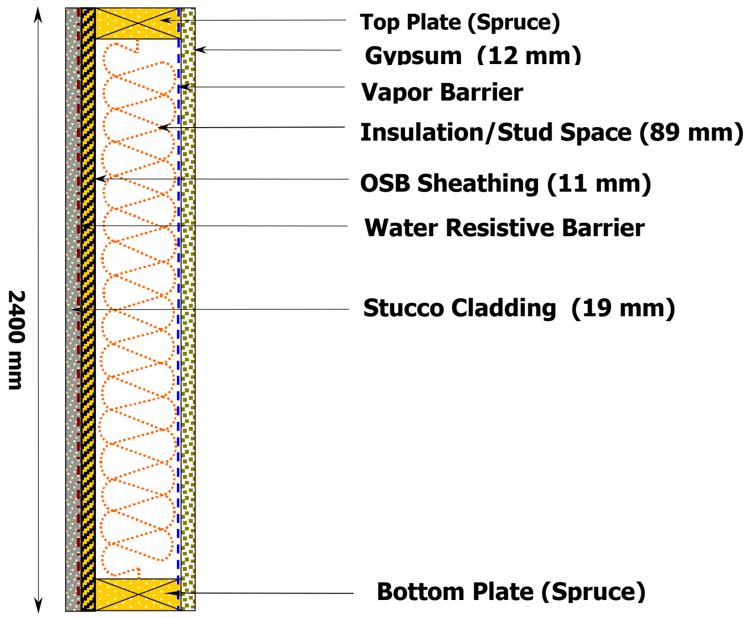

Figure 2. Basic wall design selected for parametric studies of stucco-clad wall assemblies

The parameters considered for hygIRC simulations included the following:

- seven locations in North America
- three types of stucco in terms of water vapour transport property
- three levels of vapour permeance for vapour barrier
- three types of water resistive barrier (WRB or sheathing membrane) in terms of vapour transport property
- three types of OSB in terms of water vapour transport property
- one plywood
- one fiberboard sheathing

– one basic level and location of water ingress (corresponding to a deficiency) into the stud cavity and five other variations of it
– one basic variation of the design with the introduction of a cavity behind the cladding
– the above cavity, vented or non-vented
– one case of air leakage path between the exterior and interior
– two sequences of three year weather exposure
– four levels of interior RH and temperature

A complete examination of all possible combinations of the parameters will amount to more than 200,000 simulations. Though necessary to assess fully the effect of each parameter, they could not all be accommodated within the scope of MEWS project. The decision was to select strategically a subset of the possible combinations. About 150 combinations were chosen for hygIRC simulations. The results from these simulations are discussed in detail in the IRC internal report (Mukhopadhyaya et al., 2001). Only a few salient features are presented here.

The most important features of the response of the wall shown in Figure 2, across North American climatic conditions, are presented in Figure 3 in which the index RHT95 is used. The "triangles" show the characteristic response of a stucco-clad wall to driving rain and other climatic loads acting on the exterior surface of the wall. In this case no deficiencies that would allow water leakage into the stud cavity are present. Moisture is transported only through liquid and vapour diffusion across each material layer in the assembly. Air movement is restricted by the air permeance of each material layer. These transport processes respond only to the local weather and interior conditions. For all locations, except Wilmington, RHT95 is zero. For Wilmington it takes a value equal to 149. This indicates satisfactory service life for wood members in the deficiency free assembly for most of the regions in North America. As the MI approaches the upper limit, as indicated by the result for Wilmington with MI equal to 1.13, additional design considerations to control rain deposit on the exterior surface will improve the service life of wood and wood based members in the assembly.

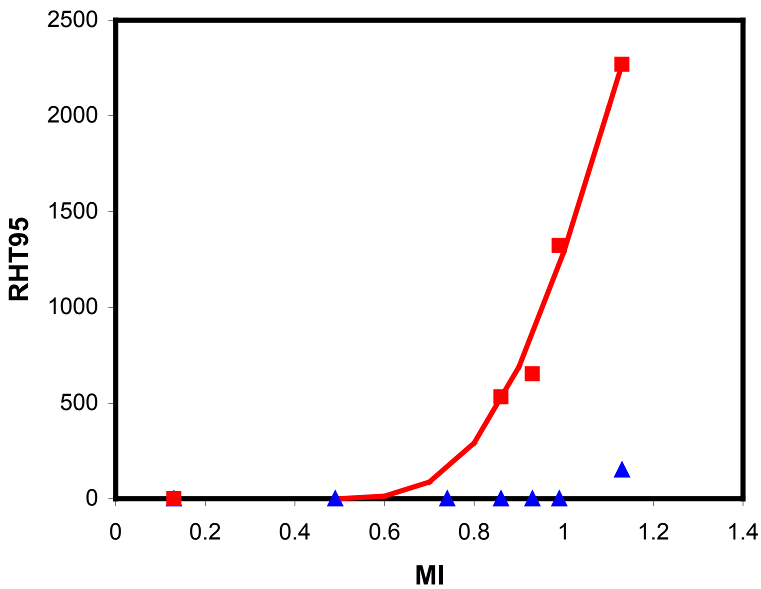

Figure 3. The response of stucco clad walls to moisture loads in various climatic regions in North America; the "triangles" are for a deficiency free wall and the curve for the same wall with the nominal deficiency assumed in MEWS.

The upper curve and "squares" in Figure 3 show the characteristic response of the same wall, except with the deficiency present in the cladding. This deficiency effectively increases the moisture load into the wall, i.e. this opening in the cladding allows exterior water to enter into the stud cavity. Depending on the intensity of the wind and simultaneous rainfall, on an hourly basis, water enters in varying amounts through the opening. During the two-year simulations, for the most severe combination of high wind-speed and high rainfall that is found in the seven geographic locations selected, this additional load allows about a litre of water into the wall section (arbitrarily chosen as 1 m in the third dimension) in that severest hour.

The higher the RHT index, the longer is the exposure of the critical segment (1.4 mm x 600 mm of sheathing facing the insulated stud space, just above the bottom plate) to elevated moisture content and temperature. Figure 3 shows that this exposure increases exponentially with MI – and particularly so for MI higher than approximately 0.8. Information currently available in the literature associates certain levels of elevated thermal and moisture conditions with potential problems for wood-based products. Studies are underway to shed light on a correlation between RHT95 and the long-term performance of such products. In the meantime, only a comparative analysis of the results is possible.

4. ANALYSIS OF RESULTS

Results from the parametric study lead to observations similar to the following. These may lead to several design considerations for better moisture management.

4.1 Effect of Climate Severity

The magnitude of the response in terms of the RHT95 of the evaluated segment increases exponentially with MI. For the same combination of parameters (and deficiency), the RHT95s for Wilmington (warm and humid), Ottawa (cold and wet) and Phoenix (hot and dry) are approximately 2300, 650 and 0, respectively. Similarly for a given combination of parameters, for an ideal construction with no deficiencies, the above numbers are approximately 150, 0 and 0. This suggests that the design strategy for Wilmington should include enhanced protection of the walls from direct exposure to driving rain; simulations show that the RHT95 can be reduced to 9 from 150, with total shielding from rain, for a deficiency free wall in Wilmington. A wall with nearly zero deficiency may perform well in Ottawa even with direct exposure to rain; of course addition of shelters to deflect rain away from penetrations will lead to better moisture management.

4.2 Effect of Material Properties

Different climatic zones may benefit from use of different moisture management strategies through the selection of materials with certain properties. Various details can be found in IRC internal reports. Two examples from the simulations are given below.

Liquid diffusivity and water vapour permeability are two properties of the stucco that are of great importance in controlling moisture loads of the wall. Simulations with a “theoretical” stucco material with higher water vapour permeance (comparable to that of mortar mix) coupled with much lower liquid diffusivity (in the range of that for wood in the longitudinal direction) than the stucco products characterized in the study can reduce the RHT95 of a deficiency free wall that is fully exposed to rain, even in regions of severe moisture loads like Wilmington (RHT95 dropped from 150 to 8). This represents an opportunity for the development and application of innovative products.

The properties of four materials, viz. stucco, OSB, WRB and vapour barrier were used as parameters in the present investigation. The best combination of these materials has noticeable effect on the RHT95 values at various locations. For example, in Ottawa the worst combination of the above four materials gave RHT95 equal to 770 and the best combination 110. In these simulations the deficiency was present. In Wilmington the corresponding change in RHT95 is from 2300 to 960. These results indicate the potential for proper selection of material combinations to improve the service life of the assembly.

4.3 Effects of Cavity Behind Stucco

A cavity behind the stucco cladding offers several benefits to lower the RHT95 of the wall.

- Large-scale water ingress testing in IRC's dynamic wall testing facility indicates that even small drainage channels (approximately 2 mm thick) can capture a large portion of the free water that reaches beyond the cladding, and bring it to a location for its evacuation to the outside. Such a drained cavity behind the stucco can result in a much lower moisture load in the stud space.

- A total separation of the cladding from the sheathing with a fully drained cavity (10 mm wide) does not admit water into the stud cavity. This was confirmed from the results in the dynamic wall testing facility; no water entered the stud cavity from the deficiency at the electrical outlet. For such a wall in Seattle, the simulation gave RHT95 = 0 in comparison with 1200 for the same combination of materials but without a cavity. This emphasises the advantages offered by fully drained cavities behind the cladding, in places like Seattle and Wilmington.

- Simulations indicate that ventilating any cavity (not necessarily fully drained and separated as above) between the cladding and the sheathing, using openings at top and bottom promotes evaporative drying. In Ottawa, for one combination of materials and with the deficiency, RHT95 was reduced from 390 to 4 in this case. In Seattle, the corresponding reduction is from 1200 to 150. Though these cavities can help, detailing of penetrations must still be made to prevent ingress of rainwater beyond the WRB.

4.4 Water Leakage into the Wall through Deficiencies

For the parametric analyses the deficiency that allows rainwater into the wall is a 1 mm X 45 mm opening in one stud space. In the worst combination of rain and wind this may admit about one litre of water (for the simulation, 1 m in the third dimension) in one hour. In a cold climate, reduction of the effect of this deficiency to a quarter of its size has significant influence on the RHT. For example, in Winnipeg, for a given combination of parameters, the RHT95 was reduced from 530 to zero. This is true for Ottawa also where the RHT95 was reduced from 650 to nearly zero. For any locations with MI higher than both Winnipeg and Ottawa, such reductions in the size of the deficiency alone will not help to improve the performance. In Seattle the change for one wall is from 1300 to 320 and for Wilmington from 2270 to 1456. These indicate that for a concealed barrier wall, any level of rainwater penetration beyond the WRB should be avoided in locations such as Seattle and Wilmington.

5. CONCLUDING REMARKS

MEWS has resulted in an integrated methodology for assessing and predicting the long-term performance of any wall assembly at any location in North America. The methodology has been applied to stucco-clad wood-frame construction and several design considerations followed. The technical details that led to these considerations are given in the document "MEWS Methodology and Summary of Findings – Report T8-03".

Though the effect of unintentional air leakage through the wall has been simulated, the information is not enough to make any general observation yet. The same is true with the level of vapour diffusion control needed in different climatic zones and for different indoor climates. We hope to follow up these issues at the Institute in future research projects.

In the remainder of MEWS project the approach presented here has been applied to Exterior Insulation Finish Systems, Masonry walls and walls with hardboard and vinyl sidings (MEWS Methodology and Summary of Findings, 2001).

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