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Publisher's version / Version de l'éditeur:

Buildings XIII: Thermal Performance of Exterior Envelopes of Whole Buildings, 2016-12

A Systematic Method of Assessing the Durability of Wall Assemblies: Towards the Limit-States Design Approach

Michael A. Lacasse, PhD, PEng **Martin Morelli, PhD**

ABSTRACT

The long-term performance in respect to moisture management within any wall assembly depends on the hygrothermal response of the wall. Critical factors in estimating the longevity of wood frame structures include limiting the temperature range, wood moisture content and time of exposure to conditions suitable for the onset, growth and propagation of mold and rot to occur. The intent in constructing highly insulted wood frame walls is evidently to reduce energy usage in buildings but the energy savings as might accrue necessarily cannot be achieved if these walls fail prematurely due to the effects of moisture accumulation in wall cavities. Several approaches to assessing the vulnerability of wood frame structures to deterioration have been developed in recent years some of which suggest applying a limits states design approach to the performance assessment of the assembly. In this paper, a Limit-States Design approach is described that forms the basis of a performance assessment method for wood frame wall assemblies. The approach is based on the requirements set out in ISO 13823 "General principles on the design of structures for durability". The approach developed for a project on the Moisture Management of Exterior Wall Systems (MEWS) is described in which the concept referred to as the Relative Humidity Temperature-index (RHT-index) is used as a basis for evaluating the long-term performance of wood frame assemblies. This index captures the duration of the coexistence of moisture and thermal conditions above a set of threshold levels for which the risk to the formation of mold growth and wood rot is unacceptably high. An example is given to illustrate the application of the approach using the RHT-index when assessing the moisture management performance of a North American stucco-clad wood frame wall assembly in relation to wood rot.

INTRODUCTION

Given the importance of moisture to bring about deterioration in building materials over time, very generally, the long-term performance of building components depends on the hygrothermal response of the component when subjected to interior environmental and exterior climatic loads. In respect to the durability of components having a wood frame structure, this depends on whether the wood components remain dry and if not, the time over which they are exposed to conditions that generate temperatures and elevated levels of moisture content suitable for the onset of the formation of wood damaging fungi. Critical factors in estimating the longevity of wood frame structures include assessing conditions suitable for the onset, growth, and propagation of damage to occur, more specifically, the temperature range, wood moisture content and time of exposure.

In ISO 13823 [ISO 2008] recommendations are made on the use of different methods for the design and verification of structures for durability. For example, verifying a component of a structure for durability can be done

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by applying service-life formats such as: (i) the factor method, or; (ii) the limit-states format.

When employing the factor method the design life is specified and the predicted service life is thereafter determined for the component or structure. The predicted service life is based on sets of factors that relate service life as determined from field studies to the expected life of a component for a similar use and subjected to a like environmental load. However, according to Marteinsson [2003a; 2003b] one of the key issues regarding the factor method is the consideration whether it is trustworthy taking the probabilistic of the field service-life planning into account. Another issue is the difficulty in determining the value of factors and the consequences of changing these factors on the service life estimate [Listerud et al. 2011]. In contrast to the service-life format, the limit-states format consists in checking the performance of a component or structure against a performance, or various limit-states.

Different approaches to assessing the vulnerability of wood frame structures to deterioration have been developed in recent years. Some of these approaches suggest applying a limit-states design approach to the performance assessment of the assembly. For example, a generalized limit states method was presented by Bomberg and Allen [2006] as a systematic framework for limit state design in respect to the durability of building envelopes. In addition, the limit states format has been applied to structures containing wooden components regarding moisture durability. Mao et al. [2011] describe an approach based on the "in-cavity evaporation allowance", which is an experimental method to evaluate the moisture load from rain penetrating a wall. However, moisture management in wood frame structures is often investigated by hygrothermal simulations. In these simulations the threshold values for mold growth and wood decay are expressed in terms of relative humidity and moisture content, respectively. However, the influence of temperature and exposure time is often not included. The results from hygrothermal simulations can be transformed into an evaluation of limit states using e.g., mold isopleths [Sedlbauer 2002] or mold growth and wood decay models [Hukka and Viitanen 1999, Viitanen 1997a, Viitanen 1997b]. A performance based model was presented by Isaksen et al. [2010] employing a dose-response function to predict the onset of mold growth, which was used as limit state.

The intent in this paper is to demonstrate a systematic method for the performance assessment of wood frame wall assemblies that follows a limit-states design (LSD) approach and additionally respects the requirements set out in ISO 13823 "General principles on the design of structures for durability" [ISO 2008]. The use of the method is highlighted by applying it to a project on the Moisture Management of Exterior Wall Systems (MEWS) [Beaulieu et al. 2002; Kumaran et al. 2002; 2003] and in which the concept referred to as the Relative Humidity Temperature-index (RHT-index) was used as a basis for evaluating the response of wood frame assemblies to climate loads and from which, in turn, the long-term performance could be estimated. This index captures the duration of the coexistence of moisture and thermal conditions above a set of threshold levels for which the risk to the formation of mold growth or wood rot is unacceptably high. An example is given to illustrate the application of the RHT-index in assessing the performance in respect to moisture management of a stucco-clad wood frame wall assembly based on the results of simulations. The values for RHT-index given in the results are related to the risk of occurrence of wood rot. The notional concept of the RHT-index and its application to informing on the hygrothermal response of wall assemblies has been previously presented in several other publications [Kumaran et al. 2002; 2003; Mukhopadhyaya et al. 2003a; 2003b; 2003c; 2004; 2006]; This paper is intended to demonstrate that the approach used in the MEWS-project, and in which the RHT-index is applied as a measure of the response of the wall to hygrothermal effects, is consistent with the broad precepts described in ISO 13823 [ISO 2008]. As such, the methodology described in this paper offers a standard and systematic method for assessing the long-term performance (i.e. durability) of wood frame wall assemblies. It is nonetheless relevant to note that in the approach described in this paper, wall configurations are evaluated against a reference wall of known and acceptable performance, as compared to inferring results from a damage function for the wall.

LIMIT STATES DESIGN – ISO 13823

The principle of the limit-states method is for any component or structure to understand the structure environment, the transfer mechanisms, the environmental action leading to action effects that over time results in the failure of the component or structure, as shown in Figure 1.

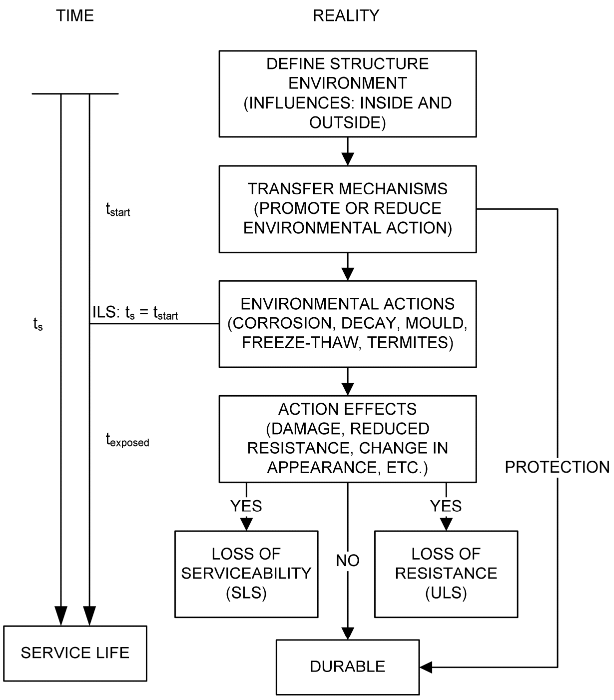

Figure 1 - Limit states method for durability as described in ISO 13823 [ISO 2008]

The durability requirements for structures or components of structures are maintenance of their required minimum level of performance during their design life with sufficient reliability for their intended use. The concept of the limit-states method is to verify the performance against a threshold value (limiting performance state). The effect of exceeding a limit-state may be irreversible or reversible. An irreversible case relates, for example in respect to structural design, to collapse or similar structural failure, whereas a reversible case relates to requirements to maintain the component, assembly or structure serviceable over time. Hence, serviceability limit states are not as severe as those that define an irreversible limit state or what might be referred to as the ultimate limit state. In ISO 13823 [ISO 2008] the Ultimate Limit States (ULS) and Serviceability Limit States (SLS) have been interpreted as:

- Ultimate Limit States (ULS) – is an irreversible process and is typically a condition state associated with collapse; in respect to material deterioration resulting in failure due to loss of resistance, the ultimate limit state is defined when the resistance of the component or structure becomes equal to, or less than, the internal mechanical force; in the context of wood frame structures, material deterioration relates to the onset of wood rot where after intiation of the rot process, loss of wood mass ensues [Viitanen et al. 2010].
- Serviceability Limit States (SLS) – can be either irreversible or reversible process; it is a condition state that corresponds to no longer providing the specified serviceability requirements for a structure or its components; for material degradation, the serviceability limit states are defined by either (i) the relative displacements that affect the function or appearance of either structural or non-structural components; or (ii) local damage or change in appearance that likewise affect the function or appearance of either structural or non-structural components; in respect to wood frame structures, changes in material appearance or local damage due to mold growth would constitute a limiting condition state.

Thus mold growth is understood as a reversible process where mold growth can be initiated under certain conditions and later cease to grow; thus the condition state may temporarily exceed the serviceability limit state until over time, the conditions are altered whereby the condtition state no loneger exceeds the limiting value.

The basic requirement for ULS is defined in Eq. (1) and expresses that the load effect (S(t)) must be smaller than the resistance. Serviceability Limit States is defined in Eq. (2) and expresses that the load effect must be smaller than the limit indicating onset of serviceability failure [ISO 2008]. These two requirements must be satisfied at any time, t, during the design life, t_s, of the component.

$$R(t) \geq S(t) \tag{1}$$

$$S_{lim} > S(t) \tag{2}$$

where, R(t) is the resistance capacity of the structural component at time t; S(t) represent the action effect, e.g., an internal force, stress, deformation, at any time t; and S_{lim} is the serviceability limit state.

In Figure 1, t_{start} is the time to reach the initiation of deterioration of a component, i.e., the Initiation Limit State (ILS). For a component protected against agents, e.g. preservative treatment of wood, the service life, t_s, can be determined as in Eq. (3).

$$t_s = t_{start} + t_{exposed} \tag{3}$$

where, $t_{exposed}$ is the service life after initiation of deterioration.

For example, [Viitanen et al. 2010] has been empirically defned the intiation time for the activation wood rot process for pine sapwood in terms of the sustained temperature and relative humidty conditions.

MEWS PROJECT – AN EXAMPLE OF THE LSD APPROACH FOR PERFORMANCE ASSESSMENT OF WOOD FRAME WALL ASSEMBLIES

Project overview

A limit state design approach has been used for performance assessment of wood frame wall assemblies in the MEWS project. The intent of the MEWS project was to develop guidelines for moisture management strategies for wall assemblies to meet user requirements of long-term performance (durability) for the wide range of climate zones to which the walls could be subjected across North America [Beaulieu et al. 2002; Kumaran et al. 2002; 2003]. The MEWS project was about defining the ability of specific wall systems to manage moisture sources, including construction moisture, humid indoor and outdoor air, precipitation, and moisture derived from indoor human activities. Given that moisture may enter wall assemblies in many ways, including vapor diffusion, air movement, rain penetration, and seepage, the envelope design strategy must therefore address all such processes, and must control moisture accumulation throughout the annual climatic cycle, over many years of service life. The focus of this study was on wood-frame buildings of 4 storeys or less, exposed to a range of outdoor climates found in North America. However, the main emphasis of the MEWS project was to estimate the hygrothermal responses of several different wall assemblies that were exposed to various climate loads as occur in North America, and that engendered a range of rain penetration loads within the wall; such estimates of response were derived from the outputs of a hygrothermal simulation model. The simulation model results were obtained as values of relative humidity (RH) and temperature (T) for each of the discrete elements as configured for the model. In the MEWS project a moisture index (MI) and a Relative Humidity Temperature index (RHT-index) were both developed as a means to assess the performance of wall assemblies.

Moisture index (MI) and climate loads on wall structures

The MI was representative of the climate loads to which a given wall would be subjected in simulation and was based on the potential offered for wetting and drying of wall assemblies for a given climate. As such, and given the broad range of climates as might be found in North America, the climate was categorized into 5 severity classes, from low ($MI < 0.7$) to severe ($MI \geq 1.0$) [Cornick et al. 2003; Cornick and Dalgliesh 2003[a]; 2003[b]]. The MI thus was representative of the climate load to which wall assemblies were subjected and refers to the risk to the onset of moisture problems within a wall assembly; a map of North America showing these different MI classes is given in

Figure 2. The RHT-index was used for evaluating the response of wall assemblies to climate loads and from which could be inferred the long-term performance of wood frame structures. The MI together with the RHT-index revealed the hygrothermal wall response under different climate conditions and differing wall configurations and in relation to the degree of water ingress to the wall assembly due to inadvertent rain penetration of the cladding.

Wall moisture response indicator - RHT-index

The RHT-index is a moisture response indicator derived from simulation of a selected period of time (e.g. last two years of a 3-year simulation period) for any specified area of a wall cross-section [Beaulieu et al. 2002; Kumaran et al. 2002]. The index captures the duration of the coexistence of moisture and thermal conditions above set threshold levels for which the risk to the formation of e.g. mold growth or wood rot is considered too high, and is given as:

$$\text{RHT (Cumulative value (2}^{\text{nd}}\text{ \& 3}^{\text{rd}}\text{ year of simulation))} = \sum (RH - RH_x) \times (T - T_x) \qquad (4)$$

where, $RH > RH_x$ [%] and $T > T_x$ [°C] are values averaged over 10 day intervals of simulation.

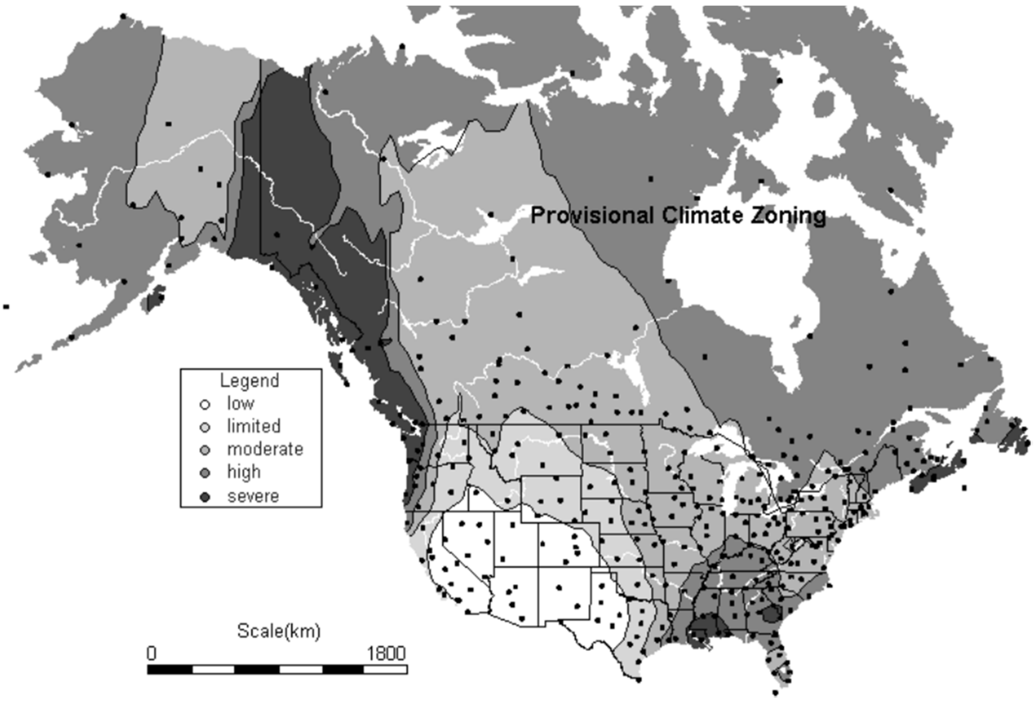

Figure 2 – Moisture index (MI) classification for North America of climate severity to wall assemblies [Beaulieu et al.; 2002]

Hence, a single-numbered indicator RHT is formed by summing only non-zero values over a two year simulation period for a target region in the wall. During any time step when either or both $RH < RH_x$ and $T \leq T_x$, the RHT value for that time step is zero. The user-defined values used in the MEWS project and being nominal conditions for the initiation of damage to wood were: RH_x = 95 % and T_x = 5 °C; whereas the limiting values for the initiation of mold growth were: RH_x = 80 % and T_x = 5 °C. The higher RHT-index values indicate an increased severity of the hygrothermal response; a greater risk to the formation of damage. As such, the RHT-index can be used for a comparison of different wall configurations in specific climates, or the same configuration in various different climates; these elements will be presented in the subsequent section.

LSD approach as applied to a Stucco-clad wood frame wall assembly

In this example, consideration is given to the attack mechanism by decay fungi in a stucco-clad wood frame wall assembly. Two different scenarios were simulated; firstly, without water ingress from rain, and secondly, with a well-defined rain ingress through inadvertent leakage in the wall. The sources of data for this example were obtained from the MEWS project based on laboratory studies [Beaulieu et al. 2002; Mukhopadhyaya et al. 2003]

Defining "structure" and "environment" — Referring to Figure 1, the two primary and initial elements of the LSD method for durability are defining the structure and the environment. In this instance the structure is defined as the stucco-clad wood frame wall assembly, as configured for simulation. Whereas the environment relates to the conditions and loads to which the structure is to be subjected, through which environmental actions (e.g. wood decay, mold growth) arise and from which the effects of these actions manifest themselves (heightened risk to formation of damage, health issues); both of these elements are further described in the subsequent sections.

Stucco-clad wood frame wall assembly — The wall configuration is shown in Figure 3 together with the region of focus that in the simulations was a thin slice (5 mm) of the top surface of the bottom plate, extending 53 mm from the sheathing board. It was understood that the onset of wood damage or mold formation in this particular location would be equal to an insufficient wall configuration.

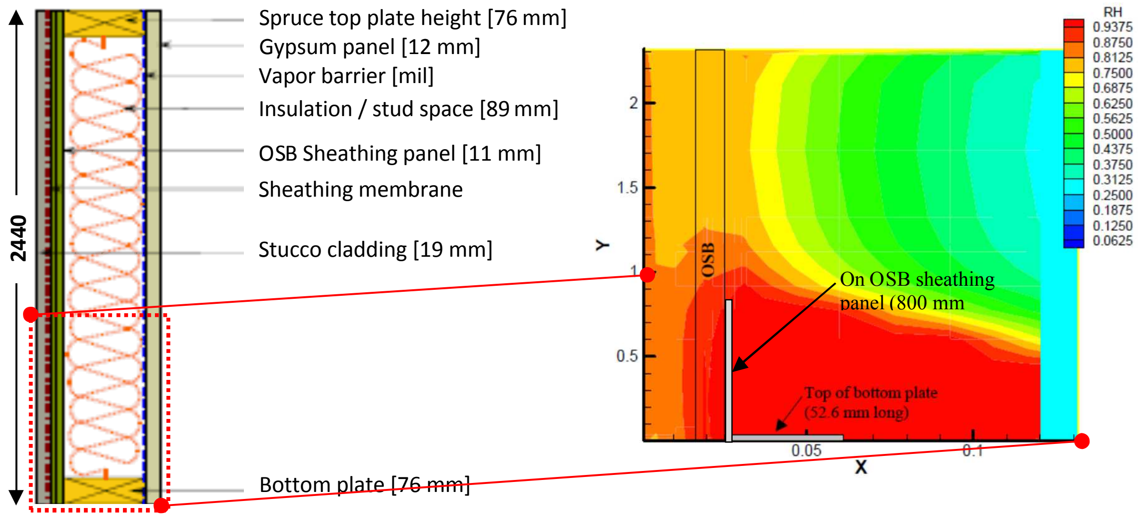

Figure 3 – Stucco-clad wall cross section subjected to Ottawa climate; 2-year simulation; the dark (red) areas were regions for which model predicted RH > 87%; [Beaulieu et al.; 2002]

Boundary conditions — The exterior environment influencing the wall structure was described by hourly values of exterior temperature and relative humidity, solar radiation, cloud index, and wind driven rain (i.e. for WDR: hourly rainfall, wind speed and wind direction) for specified climatic locations of interest in the study; these included, amongst a set of 7 locations: Wilmington, NC, Ottawa, ON, Winnipeg, MB, and Seattle, WA; the respective moisture index (MI) values for each of these locations were: 1.13, 0.99, 0.93, 0.86. From multi-year weather data (> 30 years), two years were selected for each location defining a "wet" and an "average" year. A "wet" year represented the wettest year that also exceeded the average year by at least one standard error of the mean (i.e. 1σ). These two years were combined to define a three-year weather cycle (wet-wet-average) to which the wall assemblies were subjected in the simulation; derived values for RHT-index were however based on the results of the last two years of simulation.

The interior climate was represented by two parameters: temperature (T) and relative humidity (RH). Interior room T and RH were switched from winter values of 22°C, 25% RH (when mean monthly outdoor temperature was less than 11°C) to summer values of 25°C, 55% RH for the warmer months, following the criterion given in the ASHRAE handbook [ASHRAE 1999].

Defining transfer mechanisms — These are mechanisms by which loads (e.g. structural, environmental) are transferred to the structure. In respect to a wood-frame wall assembly, the hygrothermal simulation model, a description of which is given by Nofal [2001], is capable of transferring moisture loads to the structure provided these are compatible with the basic variables that affect heat, air, and moisture transfer across the wall. As such, and given that the hygrothermal model used in these studies could manage the transfer of heat air and moisture through the usual mechanisms, there were nonetheless a number of elements that required specific mechanisms to be developed, and included: (i) Wind-driven rain (WDR) to be converted to a rain load on the vertical surface of the wall; (ii) Proportion of water at the surface of the wall that might enter the wall assembly; (iii) Location of water deposition in the wall.

In regard to the a rain load on the wall due to WDR (i), Straube's method [Cornick et al. 2002] for calculating the amount of wind driven rain impinging on a wall was selected for use; it was chosen because it generally provided the most conservative values of the several different methods considered in the MEWS study; it took the following form:

$$WDR = RAF * DRF(r_h) * \cos(\theta) * V(h) * r_h \quad (5)$$

where: WDR is the wind driven load (l/m^2-h); RAF is the rain admittance factor; r_h is the horizontal rainfall intensity (mm/m^2-h); V(h) is the wind speed at the height of interest (m/s); θ is the angle of the wind to the wall normal; derived values for the RAF, and DRF, the driving rain factor can be found in Cornick et al. [2002].

The proportion of water at the surface of the wall that might enter the wall assembly (ii) was based on the results of water penetration tests of a series of stucco clad wall assemblies [Lacasse et al. 2002] and from which an empirical function was derived for water entry to the wall that considered both the quantity of water being deposited on the wall and the pressure difference across the assembly; this function was given as:

$$Q\ (L/h) = R_w * f(\Delta P) = R_w * \{0.0314 + 7.74 * 10^{-5}\,\Delta P - 8.14 * 10^{-8}\,\Delta P^2\} \quad (6)$$

Where Q is the rate of water entry to the wall; R_w the rate of water striking the wall; ΔP pressure difference across the wall assembly.

The third derived mechanism for the transfer of moisture to the assembly is the location of water deposition in the wall proper (iii). For the study being used as example of the LSD approach, the water was placed in two different locations on the interior surface of the wood-based wall assembly; based on observations of experiments of water entry conducted during this study, water was observed to accumulate along the lower portion (ca. 5 mm x 0.8 m height) of the sheathing panel (OSB) in proximity to the bottom plate and as well, on the horizontal surface of the bottom plate over a length of 2-inches (5mm x 56.4 mm); both these surfaces were wood-based and are depicted in the relative humidity (RH) contour plot provided in Figure 3. In this figure the different levels of RH in the respective elements of the wall configuration are shown following a simulation. As is perhaps evident, those locations having the highest RH formed regions of focus and for which the results of T and RH were compiled to provide the hygrothermal response of the most vulnerable points in the wall assembly given the assumptions made in respect to the deposition of water on wall components. Evidently, these locations were also those where water tended to accumulate.

Defining environmental actions — Environmental actions arise as a result of the response of a wall to the effects of climate loads and interior environmental conditions based on, as was previously described, the different transfer mechanisms that affect moisture transfer to the structure. Actions such as damage to wood-based components or the formation of mold result from specific conditions of T and RH in the wood-based component for a sufficiently long period to increase the risk to the formation of rot or mold. The RHT-index is a moisture response indicator derived from the result of simulation that captures the degree of risk over time; in this study threshold values for the initiation of mold growth were: RH_x = 80 % and T_x = 5 °C, and for damage of wood: RH_x = 95 % and T_x = 5 °C. Using the values of RHT-index derived from simulation results, one can readily compare the performance of different wall assemblies for a given climate, or the effect of different climates on a specific assembly.

Hygrothermal simulation of wall response

The results of hygrothermal simulation of the stucco wall assembly are provided in terms of values for temperature (T) and relative humidity (RH) for each of the discrete elements of which the wall is configured. (or moisture content if desired). Examples of plots of RH and T from which were subsequently derived values for the RHT-index are provided in Figure 4 and Figure 5. In Figure 4 is the RH and T profiles predicted for the stucco wall assembly (Fig. 2) for Winnipeg, MB (Cumulative RHT(95) = 1337) and in Figure 5 for Ottawa, ON (Cumulative RHT(95) = 1536). The plots show average values of RH and T over the 2 year simulation period (730 days) in the region of focus as depicted in Figure 3, in this instance the 5 x 56 mm portion of the bottom plate. The threshold RH values in both these plots represent RHT(95); a solid line is evident at that the 95% RH threshold value and likewise for the T threshold value, a line at 5°C has been traced. The amount of water (Q) dosed to the bottom plate is provided in decilitres•m^{-2}; values ranges from 0 to 20 decilitres•m^{-2} for the Winnipeg climate and to 13 decilitres•m^{-2} for Ottawa.

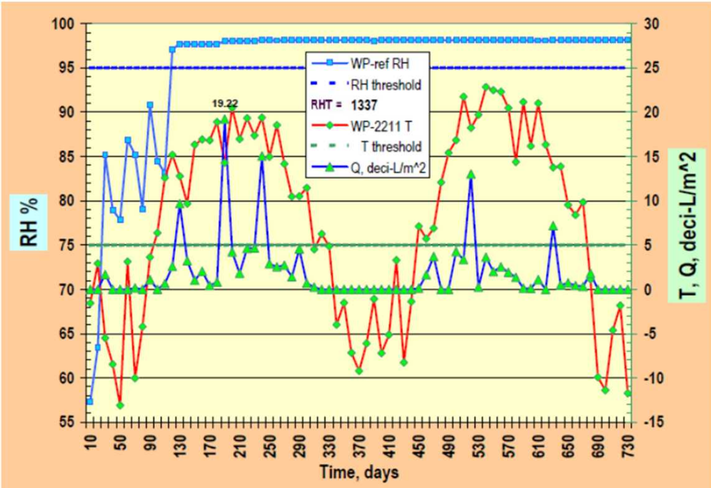

Figure 4 – RH and T profiles predicted for the wall described in Fig. 3 for Winnipeg. Cumulative RHT(95) = 1337; WP refers to Winnipeg and WP-ref RH is the average RH at 10 day intervals in the region of focus for the reference wall; WP-2211 T refers to the average T at 10 day intervals in the region of focus for the reference wall (i.e. wall 2211).

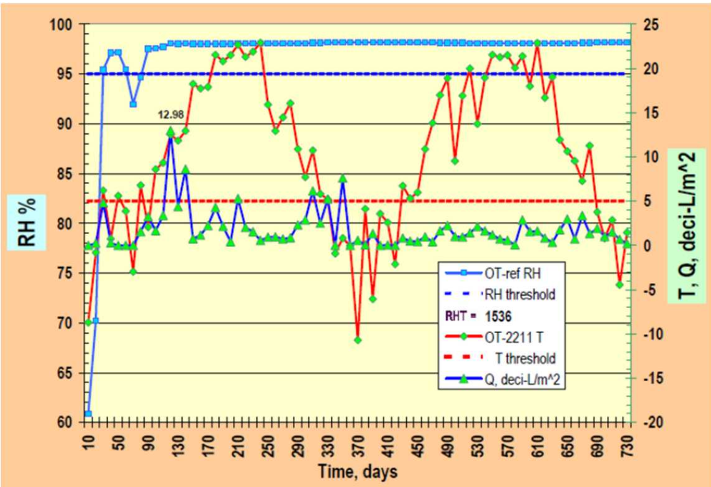

Figure 5 - Predicted RH and T profile for the wall described in Fig. 3 for Ottawa climate. Cumulative RHT(95)=1536; OT refers to Ottawa; OT-ref RH & OT-2211 T respectively, are the average RH and average T at 10 day intervals in the region of focus for the reference wall (i.e. wall 2211).

Results for RHT(95) for 4 locations in North America and having different values for MI are given in Table 1.

Table 1 – Cumulative values of RHT(95) for 4 locations and having varying moisture loads to the stud cavity

Q dose fraction	Wilmington, NC *MI = 1.13	Seattle, WA MI = 0.99	Ottawa, ON MI =0.93	Winnipeg, MB MI = 0.86
	RHT(95)	RHT(95)	RHT(95)	RHT(95)
0	9	0	0	0
¼ Q	2841	1979	864	697
½ Q	3008	2177	1434	1190
1 Q (VB1)	3213	2290	1536	1337
1 Q (VB2)	3261	2245	1517	1321
1 Q (VB3)	3080	2148	1482	1295

***MI** – moisture index; VB1-3 – are difference vapor barrier as shown in Fig. 6

As is perhaps evident from the values provided in Table 1, there is little or no hygrothermal response when no water is admitted to the stud cavity, with the exception of the Wilmington, NC location where there is nonetheless a small response (RHT(95)=9) at the base of the wall. When the full dose of water is admitted to the stud cavity (i.e. 1 Q), the increases in values of RHT(95) are all evident; increases in values of RHT(95) correspond to increases in values of Moisture Index; e.g. for a MI = 0.86, RHT(95) = 1337 and for MI = 1.13 RHT(95) = 3213. Thus the use of this approach offers a measure of the relative hygrothermal response of the stucco-clad wall for different climate locations in respect to the risk to the formation of wood damage at the bottom plate.

A comparison of values for RHT(95) for walls incorporating different types of vapor barrier membranes can be found across the lower three lines of Table 1 (i.e. 1 Q (VB1); 1 Q (VB2); 1 Q (VB3)). The relationship between the vapour permeability and relative humidity of these 3 types of membrane is provided in Figure 6. Type 1 and type 2 vapor barrier membrane are polymer-based products and where their permeability to vapor is invariable to changes in RH, whereas the Type 3 membrane is a paper-based product shows a marked change in vapor permeability with an increase in RH. These results simply serve to illustrate that one can differentiate between the relative performance of walls having different components in a given climate.

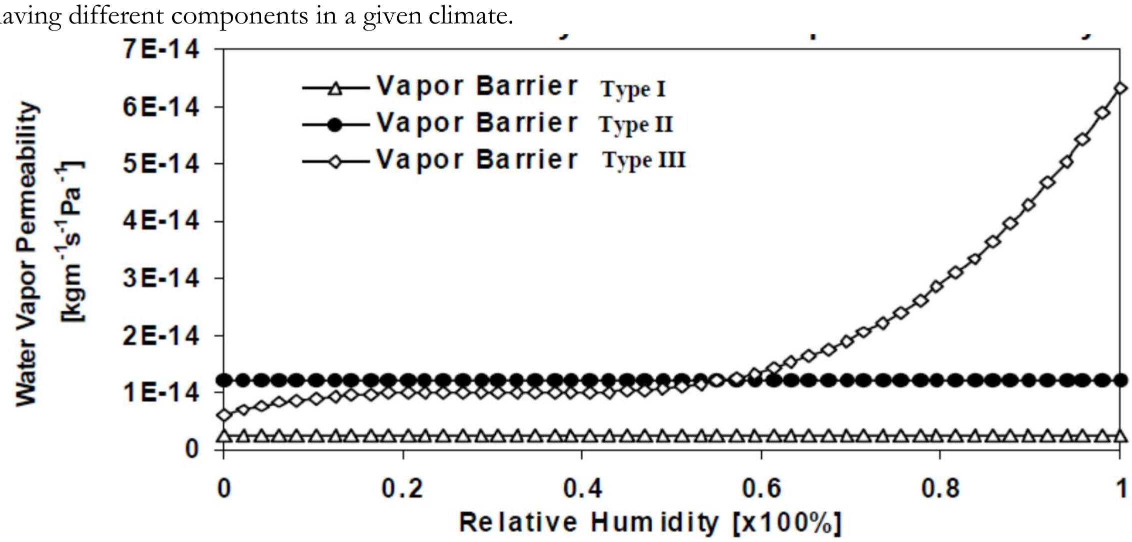

Figure 6 - Relationship between vapour permeability and relative humidity of 3 types of vapor barrier membranes

CONCLUDING REMARKS

There are several other examples of how the RHT-index of wall response can be used to assess the relative performance of wall assemblies; these can be found in e.g. reports by Beaulieu et al. [2002] and Mukhopadhyaya et al. [2003] and the several additional papers previously cited that have been published on these results. The intent in this paper was not to delve into an in-depth explanation of the results but to demonstrate that the proposed approach is consistent with the broad precepts described in ISO 13823 [ISO 2008] and as such, offers a systematic method of assessing the long-term performance (i.e. durability) of wall assemblies. As the limit-states method is probabilistic, i.e. it is based on the estimation of the probability of failure which is a function of the loads imposed on the components and the probability of occurrence of these loads. However, the probability of occurrence of loads still needs to be considered and this is discussed below. The use of the RHT-index is a means of relating who specific components of the structure respond to these loads; the variability of the material characteristics are not explicitly taken into consideration.

Does the proposed approach provide a basis for assessing the serviceability limit state (SLS) or indeed the ultimate service state (ULS)? Given that the ULS is related to the structural integrity of the wall assembly, the proposed approach, as described in this paper, does currently not provide a means to determine whether the ULS is attained. It has earlier been proposed by Nofal [1998] that damage functions for wood could readily be adapted to the results of hygrothermal simulation and the wood decay models developed by Viitanen [1997] were indeed implemented within a version on NRCs simulation model but not in fact used in the MEWS study described above. However, recent developments by Bastidas-Arteaga et al. [2015], Isaksson et al. [2013], Saito et al. [2012] and Viitanen et al. [2010] as relate to wood decay, mass loss and loss in structural resistance suggest that such models could be implemented to the proposed approach.

The approach as currently developed more appropriately relates to assessing the serviceability limit state (SLS) of components in the wall assembly. How then is the long-term performance determined on the basis of the proposed approach? Two methods are proposed: (i) by demonstrating performance of a wall assembly equivalent to that of a wall having known or accepted long-term performance as obtained from observations of in-service performance in the field; (ii) by subjecting the wall assemblies to climate loads of a specified return period.

The first of the two proposed methods is what is currently being used at NRC as the basis for assessing the performance of wall assemblies when technical opinions are rendered on new construction products to demonstrate compliance to the National Building Code of Canada in respect to hygrothermal performance of the assembly as a whole. A comparison is made between the hygrothermal performance of a code-complaint reference wall of known or accepted minimum level of performance to that of the wall whose performance is to be evaluated. Provided the performance of the wall being evaluated equals or is better than the reference wall, the "evaluated" wall is deemed to have met the minimum level of conformance to the building code.

The second method has not yet been fully explored but it nonetheless has merit as structural loads that arise from the effects of climate (e.g. wind loads; snow loads) are typically based on a given return period. Clearly for a given climate location, the greater the return period the more severe the climate loads. The severity of climate loads in respect to their return period and as regards the water tightness performance of wall assemblies has been explored by Cornick and Lacasse [2009], and more recently by Van Den Bossche et al. [2013] and Pérez-Bella et al. [2015]. This indicates that the SLS can be adapted to the proposed approach in the context of an adequate in-service hygrothermal performance.

ACKNOWLEDGMENTS

Thanks are extended to the Construction program of the National Research Council Canada for support of this work and to the following personnel of the Heat and Moisture Performance of the Building Envelope Group who contributed to the MEWS project: Mr. S. M. Cornick, Mr. W.A. Dalgliesh, Dr. M. K. Kumaran, Dr. W. Maref, Dr. P. Mukhopadhyaya, Dr. M. Nofal, Dr. D. Quirt, Ms. M. Z. Rousseau and Mr. M.C. Swinton.

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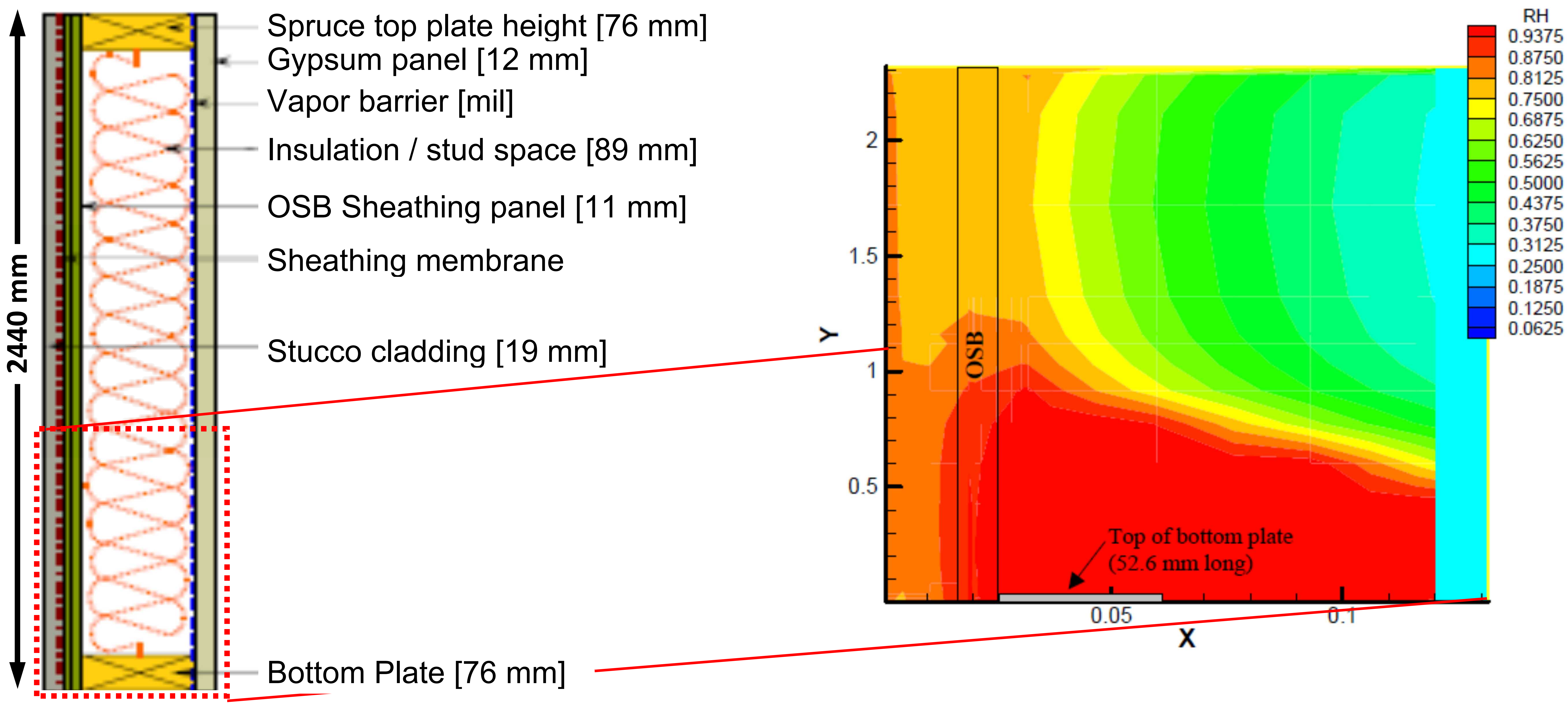

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