Assessment of Moisture Performance of National Building Code Canada Compliant Wall Assemblies under Climate Change

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Abstract: *Due to climate change, higher temperatures and rainfalls are expected to happen in some areas of Canada, which might increase the climate loads on buildings and lead to premature degradation of moisture-sensitive materials in wall assemblies. To investigate potential durability issues in three cities across Canada (Ottawa, Vancouver and Calgary), code-compliant wood-frame walls with two types of claddings, stucco and brick, were simulated using Delphin 5.9. Two different climate data sets, historical and future when a global warming of 3.5ºC is expected to be reached were used. The hygrothermal performance in terms of mold growth risk was analysed with respect to cladding types, considering air leakage. All the three cities are similarly warmer in the future. However, wind-driven rain (WDR) is higher in Vancouver than in Ottawa and Calgary. With brick cladding the relative humidity is kept below the threshold for mould development only in Ottawa and Calgary. With stucco in future, while Ottawa shows greater mould indices than historical, Calgary shows opposite behavior. The results suggest that the risk of mould growth due to air leakage may decrease in the future.*

Keywords: *Code Compliant Walls, Moisture Performance, Climate Resilience, Air Leakage, Stucco Wall, Brick Cavity Wall.*

1 Introduction

Climate change has received increasing attention globally due to many possible consequences, including building long-term performance issues from temperature increases and more severe and frequent rainfall events. The Intergovernmental Panel on Climate Change (IPCC, 2014) has indicated that climate changes has resulted from anthropogenic action and, whereas temperature changes arising from human influence is indeed a global concern, it is known that in Canada annual average temperatures will rise about twice the global average.

It is also expected that weather extremes will intensify in the future from a warming climate and, even though rainfall events might decrease in some areas, these are likely to increase for over most of Canada (Bush and Lemmen, 2019). In some regions, increases in precipitation as high as 40% are expected and this will have significant effects on buildings: water infiltration, related mostly to wind-driven rain, will increase accordingly and might pose a higher risk to the premature degradation of moisture-sensitive materials in wall assemblies (Lacasse, Defo, *et al.*, 2018).

To address these issues of moisture accumulation in wall assemblies due to condensation or

water ingress, the National Building Code (NRC, 2015) set prescriptive requirements for all the walls separating conditioned from unconditioned spaces. These include: i) minimum thermal insulation according to the climate zone; ii) an air barrier system with an air leakage rate not greater than $0.1 \, L/(s.m^2)$ at 75 Pa; iii) a vapor barrier with permeance not greater than $60 \, ng/(Pa.s.m^2)$; and iv) position of low permeance material in the wall. As well, in case where an exterior insulation is added, NBC might also require a minimum ratio between outboard and inboard thermal resistance (NRC, 2015, p. B-9.159). All these technical requirements are intended to minimize the chance of moisture accumulation in wall assemblies, which can lead to deterioration of wood and wood-based building products.

Although the requirements were set based on historical climate loads, item 5.1.4.2 of NBC says that "… assemblies exposed to the exterior shall be resistant to any mechanism of deterioration that may reasonably be expected". As such, the impacts of climate change on moisture performance of code-compliant walls need to be assessed.

The primary objective of this study is to evaluate the moisture performance of code-compliant wall assemblies in both historical and future climate. The approach followed is the one provided in the "Guideline for the Design for Durability of the Building Envelope" (Lacasse *et al.*, 2018).

2 Methods

The methodology for the assessment of moisture performance of code-compliant wall assemblies as described in this paper follows the approach given in the "Guideline for the Design for Durability of the Building Envelope" (Lacasse, Ge, *et al.*, 2018). This approach essentially uses hygrothermal modelling as means to assess the response of wall components to climate loads acting on the exterior and environmental conditions on the interior of the assembly; so, the moisture performance of the wall can be determined on the basis of the risk of mould growth or wood decay in wood based components.

The simulation tool is first described and, thereafter, details in respect to input data for simulation are provided: wall configuration, which is dependent on the geographic location for which simulations will be completed; weather data, and the reference years to be used in simulations; boundary conditions, in which boundary parameters are defined; air leakage; and material properties.

2.1 Geographic Location

Three cities were selected across Canada: Calgary (AB), Ottawa (ON) and Vancouver (BC), with low, medium and high moisture indices respectively. The main characteristics of the cities are shown in Table 1.

Table 1. Geographic location and climate details about the cities.

| City (Province)	Latitude (º)	Longitude (º)	HDD	Zone	RSI_{min} (W/m²K)	MI	Annual rain (mm)
Ottawa (ON)	45.25	-75.42	4440	6	2.97	0.84	750
Vancouver (BC)	49.28	-123.12	3100	4	2.78	1.93	1850
Calgary (AB)	51.05	-114.07	5000	7A	2.97	0.37	325

HDD - heating degree days below 18ºC
RSI - Effective thermal resistance
Zone - climatic zone
MI - moisture index

2.2 Simulation Tool

A state-of-the-art hygrothermal modelling software, Delphin 5.9, was used to undertake the hygrothermal simulations. The solver parameters were adjusted to 0.01 s initial time step, 60 s maximum time step, 10^{-6} relative tolerance and 10^{-7} moisture mass balance.

2.3 Wall Configuration

A wood frame wall of a 3.5-storey (10-m high) residential building located in suburban areas was considered. For each city, two cladding types were simulated: brick and stucco. Figure 1 shows the composition of the brick wall.
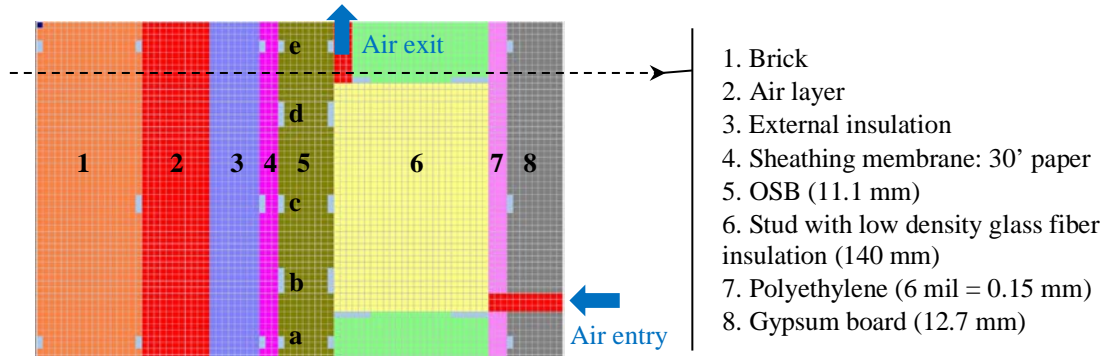
Figure 1. Layers of the brick wall and the locations for reading Relative Humidity and Temperature.

From the sheathing membrane to the interior side of the wall (from layer 4 to layer 8), all the layers are the same for all walls. The height of the wall was 2440 mm: 36 mm for the single bottom plate (spruce), 2332 mm for the insulation (low density glass fiber insulation) placed within the vertical wood studs, and 72 mm for the double top plate (spruce). For the outer part of the walls, complete details for each city are given in Table 2.

Table 2. Cladding details.

City	Cladding		Drainage cavity (mm)	External insulation	Air change (/h)	Air leakage
	Type	Thick (mm)				
Ottawa	Brick; Stucco	90; 19	25; None	EPS (6.5; 12.7 mm)	10; None	With and Without
Vancouver	Brick; Stucco	90; 19	25; 10	None; None	10; 10	
Calgary	Brick; Stucco	90; 19	25; None	EPS (6.5; 12.7 mm)	10; None	

In Calgary and Ottawa it was necessary to incorporate an external insulation to reach the minimum energy requirement (RSI $\geq$ 2.97 W/m^{2}K) whereas in the warmer climate of Vancouver (RSI $\geq$ 2.78 W/m^{2}K) the stud cavity insulation alone was enough.

2.4 Weather Data

Two sets of climate data were used: historical and future (when a global warming of 3.5°C is expected to be reached). Both sets were prepared according to Gaur *et al.* (2019) and encompass a 31-year time period, from 1986 to 2016 and from 2062 to 2092. From each set, the median and the wettest years were selected based on the moisture index (Cornick *et al.*, 2003) and were used as moisture reference years for simulations. Those years and the wall orientation with the

highest wind-driven rain load are summarized in Table 3. In all cases there is an increase in the temperature in the future; RH levels vary quite the same way in Calgary and Vancouver, but are higher in the future climate for Ottawa.

Table 3. Moisture reference years and wall orientation for each city.

| City	H - Historical data (year)			Wall orientation (^{o})	F - Future data (year)			Wall orientation (^{o})
	Period	Median	Wet		Period	Median	Wet	
Ottawa	1986	1989	1991	180	2062	2074	2070	180
Vancouver	to	1988	1994	145	to	2091	2066	180
Calgary	2016	2015	2016	292	2092	2069	2063	315

2.5 Boundary conditions

2.5.1 Air Leakage

All the walls were simulated with and without air leakage and the exfiltration path (Figure 1) is one of the worst cases in terms of moisture accumulation suggested by Ojanen and Kumaran (1992; 1996). This path is also the same as the one used by Saber (2014). An air leakage rate of 0.1 L/(s.m^2) at 75 Pa was tested, which is the maximum rate prescribed by the NBC (NRC, 2015, p. B-5.27) when the indoor relative humidity ranges between 27 and 55%. An equivalent air leakage area was computed assuming a discharge coefficient of 0.6 and air density of 1.2 kg/m^3. For a 2.4 m high wall, the area of the orifice is around 35mm^2 at 75Pa, but since the real pressure difference between outdoors and indoors is roughly 10 Pa, this area was converted to 26 mm^2 (ASHRAE, 2017, p. 16.16). Indoor and outdoor air pressures were derived from the combination of wind and stack pressures and applied to the bottom and top openings of the wall respectively (Figure 1). Since the simulation was run in 2D, the opening was assumed to have a circular shape and its diameter was used as the width of the opening.

2.5.2 Wind-driven rain

Wind-driven rain (WDR), used as an imposed moisture flux on the exterior surface of the wall, was calculated according to ASHRAE 160 (ASHRAE, 2016, p. 6,7), assuming a 3.5 storey building (10-m high) located in a suburban area. The exposure (FE) and deposition (FD) factors were set to 1.0 and 0.5 respectively. Figure 2 shows the accumulated wind-driven rain for all cities, historical and future.
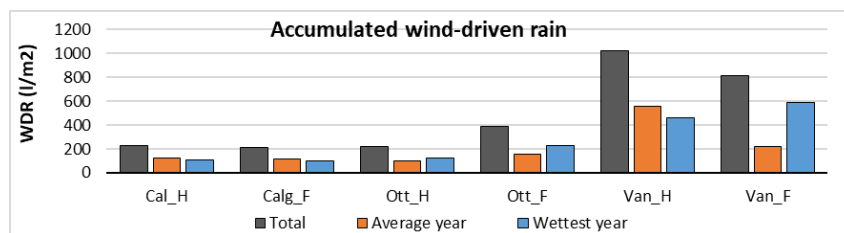
Figure 2. Accumulated wind-driven rain (ASHRAE) for all cities, historical and future.

Calgary has quite the same amount of rain in both scenarios for the two years together; Ottawa shows an increase in the rain in the future for both average and wettest years; Vancouver is less rainy in the future, but there is an important difference between the two years: in the

future, the average year is about 65% dryer and the wettest year is about 30% rainier.

2.5.3 Other parameters and conditions

Initial conditions for all layers were set to 21ºC and 50%, respectively for temperature (T) and relative humidity (RH).

Indoor conditions were calculated using the ASHRAE method, heating only (ASHRAE, 2016, p. 4), which means T ≥ 21.1ºC (no upper limit) and 40% ≤ RH ≤ 70%.

Other coefficients were adopted as follows: outdoor heat transfer coefficient: 4+4v W/m²K (v is wind speed) (ISO, 2017); indoor heat transfer coefficient: 8 W/m²K; outdoor vapor transfer coefficient: $2.44*10^{-8} + 2.44*10^{-8}v$ s/m; indoor vapor transfer coefficient: $1.52*10^{-8}$ s/m; ground shortwave reflection = 0.1; shortwave surface absorption = 0.6; ground longwave emission coefficient = 0.9; surface longwave emission coefficient = 0.9.

For wall assemblies having a drainage cavity, the air change per hour (ACH) was set to 10.

2.6 Discretization of the Walls

Preliminary tests simulations with different number of elements were undertaken to select the optimal scheme in terms of accuracy and simulation time. The final mesh used in this paper was composed of 3465 elements for stucco and 4345 for brick.

2.7 Material Properties

Table 4 shows some basic properties of the materials for each of the two wall assemblies.

Table 4. Properties of the main materials according to Kumaran *et al*. (2002).

Material	Thickness (mm)	Dry density (kg/m³)	Specific heat capacity (J/kg.K)	Thermal conductivity (W/m.K)	Vapor permeance[1] (ng/m².s.Pa)
Brick (Br)	90	1900	800	0.500	19
Stucco (Stu)	19	1960	840	0.407	94
OSB	11	600	1880	0.094	101
Glass fiber batt	140	11.5	840	0.043	990
Vapor barrier[2]	0.15	1256	840	0.159	60
Sheathing membrane[3]	0.22	909	1256	0.159	907

1. Values at 50% RH   **2**. 0.15 mm polyethylene   **3**. 30' asphalt impregnated paper

2.8 Performance Assessment

The performance assessment focused on the mould index calculated according to the VTT model described in Ojanen *et al*. (2010). It is known that mould growth is a highly complex mechanism which is mostly influenced by relative humidity, temperature, material susceptibility, surface quality (Vereecken and Roels, 2012). Different models use different parameters, and not necessarily the same way and, then, distinct outcomes are expected; a deeper discussion about this is out of the scope of this paper and can be found elsewhere, as in Sedlbauer (2001), Vereecken *et al*. (2011), Viitanen *et al*. (2015), Gradeci *et al*. (2017). In this study, the VTT model was adopted because it is recognized by ASHRAE 160 (ASHRAE, 2016, p. 7).

The index was calculated for many different locations of OSB, bottom plate and top plate,

assuming a sensitive class for both material and surface, and 0.1 as decline factor (there is no suggestion in ASHRAE for OSB and then 0.1 was adopted as a conservative value). The high-lighted squares in Figure 1 show all the locations in the assembly where values of RH and T were acquired. However, the focus of this paper is in the worst position, identified with the letter "c" in Figure 1 (exterior layer of OSB at mid-height); RH and T values used to compute mould index were acquired on a portion with the dimensions of 0.5 mm x 500 mm.

3   Results and Discussion

Figure 3 shows the mould index profiles for stucco and brick claddings. Solid lines represent situations with no air leakage and dashed lines with air leakage.

Brick cladding in Vancouver (Figure 3a) develops mould, while in Ottawa and Calgary there is no mould growth. This may be explained by the higher amount of WDR in Vancouver compared to Ottawa and Calgary (Figure 2). In Vancouver, mould index profile is consistently greater for historical than future. In fact, the first year (average year) in the future has a lower amount of WDR, which may explain the fact that there is no mould growth, while the second year has more WDR in future than in historical.

In the case of stucco, mould index profiles were quite similar in Vancouver for both climate scenarios (Figure 3b), which is different to the observations for brick. This may be explained by the fact that stucco cladding has higher liquid diffusivity, smaller thickness, and a drainage cavity of only 10 mm. As such, the liquid water reaches the drainage cavity quickly and maintains high RH levels. These factors together with higher temperatures along the year led to high mould indices. Ottawa (Figure 3c) shows higher mould index profile in the future than historical. This may be explained by the fact that WDR is higher in future than historical; in the historical climate, however, the first year is dry and there is no mold growth. Unlike Ottawa, Calgary (Figure 3d) shows lower mould index profile in the future than historical. As shown in Figure 3, the WDR in Calgary is quite similar for historical and future climates, but the temperature is higher and therefore might have increased the drying potential of the whole assembly, decreasing the mould indices.
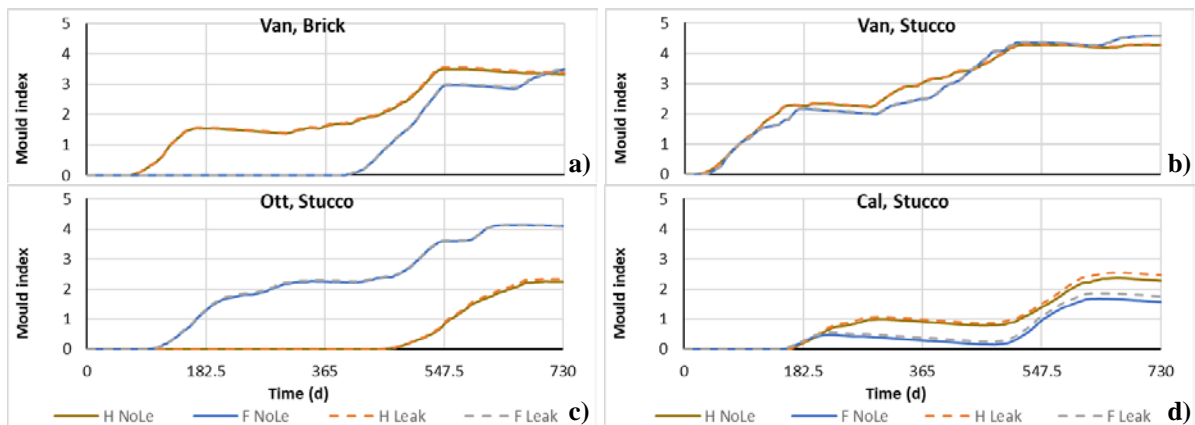
Figure 3. Mould index profiles in the worst position of OSB for both claddings, historical (H) and future (F) scenarios, with (Leak) and without (NoLe) air leakage.

In an attempt to assess the effect of future climate on the risk of mould growth, the difference between the maximum mould index for the cases with and without air leakage was calculated

for both historical and future periods. Table 5 shows the maximum mould values and the difference between historical and future scenarios, with and without air leakage. Those values are labeled as "Leak - NoLe" in the shaded columns.

Table 5. Maximum mould index in the worst position of OSB for each case.

City	Brick						Stucco					
	NoLe		Leak		Leak - NoLe		NoLe		Leak		Leak - NoLe	
	H	F	H	F	H	F	H	F	H	F	H	F
Ottawa	0	0	0	0	0	0	2.25	4.13	2.57	4.13	0.32	0
Vancouver	3.49	3.49	3.56	3.52	0.07	0.03	4.28	4.48	4.40	4.59	0.12	0.11
Calgary	0	0	0	0	0	0	2.36	1.68	2.55	1.86	0.19	0.18
H - Historical		F - Future		Leak - air leakage			NoLe - no air leakage					

Although this calculation is not exactly true because hygrothermal behavior is a combination of all the factors, it gives an idea of the influence of the air leakage itself. It can be seen that air leakage led to higher mould indices in all cases since the exfiltration process brings more humid air to the cavity. Also, the lower values of "Leak - NoLe" in the future suggest that there might be a decrease in the risk of mould growth due to air leakage in the future.

As a general observation of Figure 3 and Table 5, air leakage has a greater impact when the mould index is low, since the major factor responsible for mould growth is the moisture coming from brick and stucco layers. If this amount of moisture is already high, the contribution of the moisture brought to the cavity by the air leakage is very low when compared to the total, which means low impact over the mould indices.

4 Conclusions

Hygrothermal performance of two wall assemblies, stucco and brick cladding, has been assessed in three cities under historical and future climate with and without air leakage to see their response to a possible climate change. Mould index was used as a measurement of performance and the main findings for the cities and the wall configuration considered are:

– Future climate in Ottawa presents higher amount of WDR when comparing with historical, which means the moisture content of the assembly is higher and so is the risk of mould growth. In Calgary, the amount of rain is similar in both climates but the temperature is higher in the future, which means more drying potential and less mould development. Vancouver is rainy in both scenarios and the mould indices are similarly high.

– Brick cladding is safer than stucco in any case in future climate. The higher moisture capacity of the brick, the wider drainage cavity and the higher air temperature all together increase the drying capacity of the assembly, which helps on keeping lower levels of relative humidity and lower mould indices. This situation is more evident in Ottawa and Calgary, which have no mould with this cladding.

– Air leakage increases the mould development in all cases, but the differences are small and cannot be blamed for major changes in the indices. The results suggest risk to mould growth may decrease in the future climate.

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