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Impact of High-resolution Regional Climate Conditions on the Moisture Performance of Wood-frame Building Envelopes

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Abstract. *Climate data is one of the most important inputs for hygrothermal simulations and significantly influences the simulation results that are used for moisture performance assessment of building envelopes. Conventionally, climate data from representative weather stations are used for hygrothermal simulations to assess the moisture performance of the buildings. Recently, the Construction Research Centre of the National Research Council Canada generated historical and future climate data for 564 locations across Canada. In this paper, the climate data of four urban locations within Vancouver (a humid and warm coastal city in Canada) were selected for hygrothermal simulations. These include an open area at the airport, a city center, an area surrounded by plants, and an area surrounded by a water body. The 31-year-long simulations were performed for a typical wood-frame wall assembly complying with moisture protection designs as provided in the National Building Code Canada (NBCC 2020) but rain penetration was assumed considering the deficiency of exterior cladding. The differences in its hygrothermal response across the four locations were analyzed. It was found that some climate parameters are significantly different among the selected locations, although the values for moisture indices given in the NBCC 2020 for these locations are all similar. The results show that high values of WDR are the dominant factor that drives the moisture performance but there is no indication that the design of the assembly could be different among the tested locations.*

Keywords: *High-resolution regional climate conditions; Moisture performance; Wood-frame wall assemblies; Hygrothermal simulation*

1 Introduction

Climate data is one of the most important input parameters for hygrothermal simulation and significantly influences the simulation results that are used for moisture performance assessment of building envelopes. Conventionally, the climate data from representative locations are generally used for hygrothermal simulation to assess the moisture performance of the buildings located in a specific city or region. For example, in the most widely used hygrothermal simulation tool- WUFI Pro, there are only 9 representative Canadian cities that reflect different climate zones from 4C to 7 as prescribed in ASHRAE 90.1 (2022). However, the climate data of representative cities may not be able to reflect the impact of local landscapes, which influence the micro-climate conditions, thereafter, impact on the moisture performance of the building envelopes.

It has been well recognized that the local landscape can modify the key climate parameters such as temperature, relative humidity, wind speed, and rain intensity (Brown 1995), and these climate parameters will influence the heat and moisture-related environmental loads to built-environment, including the public area of the outdoor environment and buildings themselves. Yang et al. (2018) investigated the impact of seven landscape scenarios on thermal comfort in urban areas through ENVI-met simulations, they found that the combination of trees over grass is the most effective landscape strategy for cooling in the microclimate, while the high-albedo pavement and water bodies are not effective in reducing heat stress. Mughal et al. (2021) applied CFD simulation to investigate the vegetation effects on micro-climate conditions in tropical urban environments, they found that the thermal stress was reduced around a park. Recently, Zhou et al. (2023) compared wind-driven rain load on building façade in urban areas and open fields through CFD simulations, they found that the WDR loads in urban environments are much smaller than in the open fields.

The studies aforementioned are all performed in a domain within around 2 km, and simulations were performed for a short period or under a specific steady-state regional climate condition. Due to the high computational cost of ENVI-met and CFD simulation, it is difficult to conduct a long-term dynamic simulation of the climate data in urban area and prevents long-term performance analysis of the buildings under different types of local landscapes. Recently, the Construction Research Centre of the National Research Council Canada generated the historical and future climate data for 564 locations across Canada, which are distributed in different landscapes or urban morphology within or around major cities in Canada (Gaur and Lacasse 2021). The climate data in different locations, to some extent, reflected the impact of local landscapes. Although the spatial resolutions of the climate data are not as high as that used in CFD simulation, the generated climate data incorporated climate parameters required for long-term building simulations at different global warming scenarios, i.e., the 31-year period for GW0.5 to GW3.5. Also, the climate data in locations around a major city within the same climate zone showed significant variations in key climate parameters that influence the hygrothermal performance of building envelopes. In this paper, the climate data of four locations that are located in different landscapes (an open area at the airport, a city centre, an area surrounded by plants, and an area surrounded by water body of ocean) around Vancouver- a humid and warm coastal city in Canada was selected to demonstrate the variation in climate parameters caused by different landscapes and their impact on the moisture performance of the wall assembly.

2 Methods

2.1 Selected cities

The National Building Code of Canada (NBCC 2020) uses the moisture index, which considered the wetting and drying potential of the locations, to measure the moisture severity of different locations and prescribe moisture protection designs. The building code provided the information of moisture index not only for major cities in Canada but also for the different locations around the major cities. In general, the locations around a major city are in a similar climate zone with the city and they have a similar moisture index. For example, Table 1 shows the basic climate zone information for the thermal and moisture design of Richmond, which is close to Vancouver International Airport, and three locations that are around Richmond and in the same climate zone. These four locations were selected for hygrothermal performance assessment of a typical wood-frame wall assembly.

Table 1. Climate zone information of four locations around Vancouver.

Location	Average temperature	HDD18°C	MI	Climate zone
Richmond (close to Vancouver International Air Port)	9.9 ºC	2800	1.2	4C
Victoria University (located in city center)	9.8 ºC	2650	1.0	4C
Nanaimo (close to Entrance Island located in water body of ocean)	10.2 ºC	2920	1.1	4C
Langford (close to Malahat located in a area covered by plants)	8.8 ºC	2750	1.2	4C

2.2 Description of the wall assembly

In this study, the modeled building was considered a 3.5-storey residential structure. The wood frame wall with brick veneer or stucco claddings is among the most commonly used wall assemblies for residential buildings in Canada. For this study, a lightweight wood-frame wall assembly featuring brick veneer cladding with air space behind the cladding (as depicted in Figure 1) was simulated, assuming no air leakage. Material properties were sourced from the National Research Council Canada’s (NRC) hygrothermal material property database (Kumaran et al. 2002).

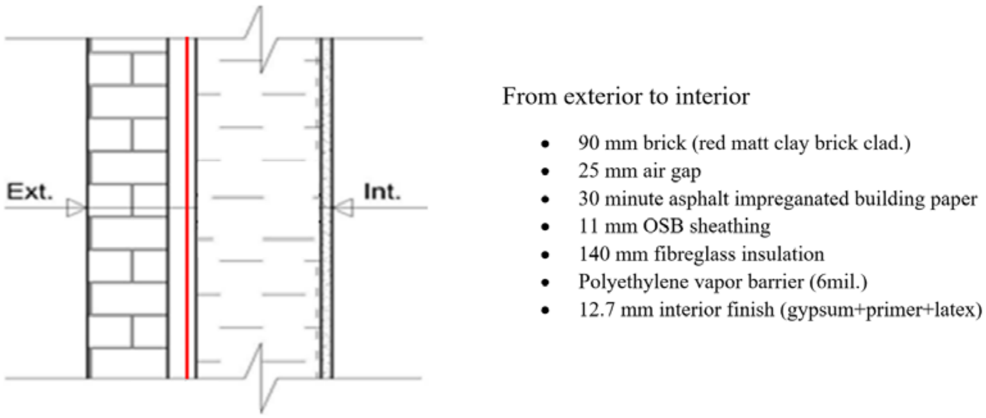

Figure 1. Cross-section of brick veneer cladding wood-stud wall assembly.

2.3 Climate data

The climate data used for simulations covers a 31-year period from 1991 to 2021 and includes hourly climatic parameters for the historical period. The climate datasets were produced by incorporating both internal climate variability and the effects of initial conditions used in the model across 15 hourly realizations or runs. These runs are part of a dataset derived from a large ensemble of climates simulated by the Canadian Regional Climate Model (CanRCM4) version 4, each initialized under a different set of initial conditions in the second generation of the Canadian Earth System Model (CanESM2). To account for climate uncertainties, simulations were performed for all 15 runs for a given location. The climate data sets were bias-corrected based on historical observational data. The details of climate data generation can be found in Gaur and Lacasse (2021).

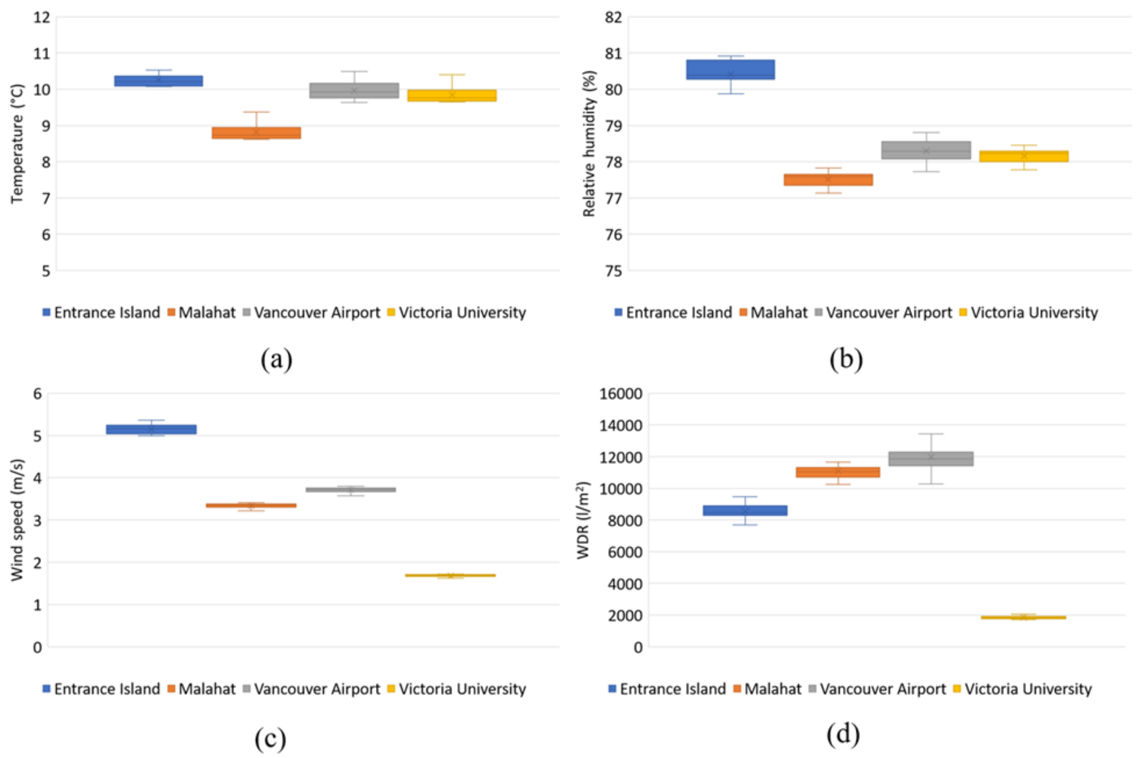

Figure 2. Climate characteristics of the four investigated locations.

Figure 2 displays a box plot distribution of various climate characteristics across four locations based on the run average. In terms of temperature, Malahat, the location within an area covered by plants, exhibits the lowest average temperature among the four locations at 8.5°C, which is approximately 1.5°C lower than the other three locations. Entrance Island, the location that is closest to the water body (ocean), has the highest relative humidity with an average of around 80.5%, while Malahat has the least average humidity at 77.5%. The other two locations stand at around 78%. As for wind speed, there is a notable difference between Entrance Island (average of 5 m/s) and Victoria University (average close to 2 m/s). Victoria University is located in the city center, which is surrounded by different types of buildings, resulting in a lower average wind speed. For Malahat and Vancouver airport, the average wind speed is approximately 3.5 m/s. Additionally, wind-driven rain (WDR) calculations were conducted (31-year total in a run), taking into account the wall orientation that receives the highest WDR (referred to as the default orientation in this study). The results reveal that Vancouver airport and Victoria University receive the highest and lowest amount of WDR, respectively.

2.4 Hygrothermal simulations

One-dimensional hygrothermal simulations were carried out using DELPHIN v5.9.5; a heat, air, and moisture (HAM) simulation program. The program is intended for coupled heat, moisture, and matter (salts, pollutants) transport in porous building materials. It was successfully validated with HAMSTAD Benchmarks (Sontag et al. 2013).

2.5 Boundary conditions

Indoor temperature and relative humidity were assumed constant and set to 21°C and 50%, respectively assuming that the residential building was equipped with air conditioning and dehumidification. Following the EN ISO 6946 standard (ISO 2017), the indoor surface heat exchange coefficient was set to 8 W/m^2K (convective heat transfer coefficient: 2.5 W/m^2K and radiative heat transfer coefficient: 5.5 W/m^2K). The convective heat transfer coefficient, h_{ce}, on the exterior surface was calculated using equation (1).

$$h_{ce} = 4+4v \tag{1}$$

The indoor and outdoor vapor diffusion coefficient was calculated using the convective heat transfer coefficient and Lewis number (Incropera and Bergman 2015). The reflectance of the surrounding ground (albedo) was set as 0.1 and the solar absorptance of the wall surface was set to 0.6.

2.6 Initial conditions

The initial conditions were assumed to be 21°C and 50% for temperature and relative humidity, respectively.

2.7 Field conditions

An air change rate (ACH) of 6/h was assumed in the drainage cavity as recommended by Simpson (2010). Further, the rain leakage through the exterior cladding was assumed to be 1% of WDR and is assumed to be present at the exterior layer of the sheathing membrane (ASHRAE 160, 2021).

2.8 Simulation setting

To discretize the wall layers, a manual meshing approach was utilized for all layers except the sheathing membrane and vapor barrier. These two layers were meshed using an equidistant mesh consisting of three elements. The remaining layers were divided into three sections, with each section being divided in such a way that the first and last sections had equal thicknesses and were meshed using a fine and variable mesh. For the middle section, an equidistant (coarse) mesh was utilized (Aggarwal et al. 2022). All simulations were conducted for a 31-year period starting on January 1st, 1991. Hourly temperature, relative humidity (RH), and moisture content values were extracted from DELPHIN and were subsequently post-processed for analysis.

2.9 Performance Indicator

To analyze the moisture performance of the wall assembly, the accumulated moisture content in the whole OSB layer and mould index at the exterior layer of the OSB (0.1mm thick indicated by the red line in Figure 1) were calculated. The VTT model proposed by Ojanen et al. (2010) was used to compute the mould index at the exterior layer of OSB. The model indicates that the mould index can range from zero to six, with an index of 0 signifying no mould growth and an index of 6 indicating that the surface is entirely covered with mould. The hourly values of the moisture content and mould index were then utilized to calculate the average moisture content and mould index and these values were used as performance indicators to quantify the moisture severity of the wall assembly.

3 Results and discussion

When analyzing moisture content (MC) (Figure 3), it is clear that Vancouver airport shows the highest levels (25%), followed by Entrance Island and Malahat (about 22%) and Victoria University (only 13%). For the first three locations, it was noted that the moisture content reaches the highest average level in the first years, and this is due to the high amount of WDR in those locations. In Victoria University, due to the lower WDR, moisture content increases at a much slower pace and does not reach an average as high as the other cities. Moreover, MC above 20% is usually a factor that indicates problems with mould growth or wood decay and Victoria University is the only one below this threshold. Also, since WDR is the only source of moisture in the simulations, WDR has the same profile as Figure 3a, and the higher the cumulative WDR, the higher the MC. This situation can be clearly seen in Figure 3b, where Vancouver Airport and Victoria University show the highest and the least MC and the other two locations lie in between.

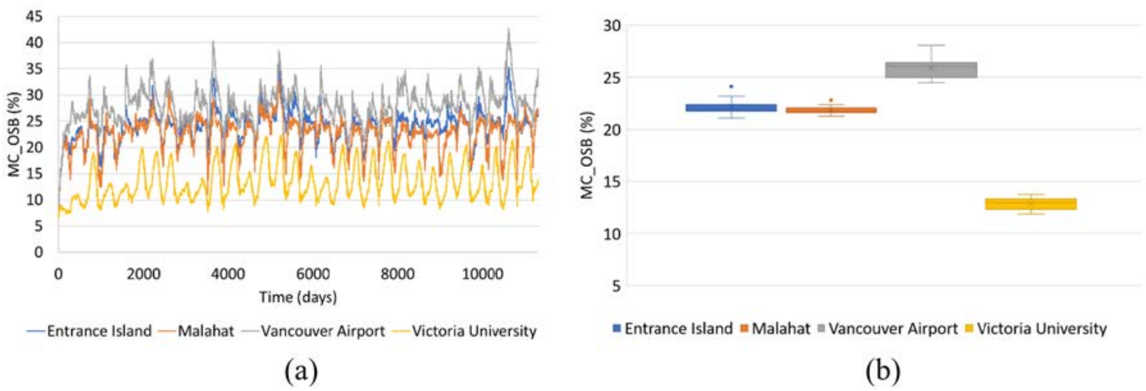

Figure 3. Moisture content profile and distribution for the four investigated locations: (a) time series of MC; (b) 31-year averaged MC.

When analyzing the mould index, the temperature of all cities is very similar (Figure 2a) and hence the mould index is most likely to correlate with the WDR. Like the MC profile, mould index (Figure 4a) increases fast in the first years for Vancouver, Entrance Island, and Malahat and keeps high values (about 5.2) all the time. In Victoria, due to the lower WDR, mould growth is slower and stabilizes after 10 years (at about 4).

Mould index is assessed at the outer part of OSB, and this position is closest to water resistive barrier which receive the water load due to rain penetration. So, after a certain amount of WDR which is able to saturate the outer part of OSB, the impact of even higher WDR loads over the mould index becomes less significant because the local RH at outer layer of OSB does not further increase. Conversely, the MC of the whole OSB does increase even if the WDR loads have exceeded the level that saturate mould growth index since the MC level of the whole OSB is still lower than free water saturation.

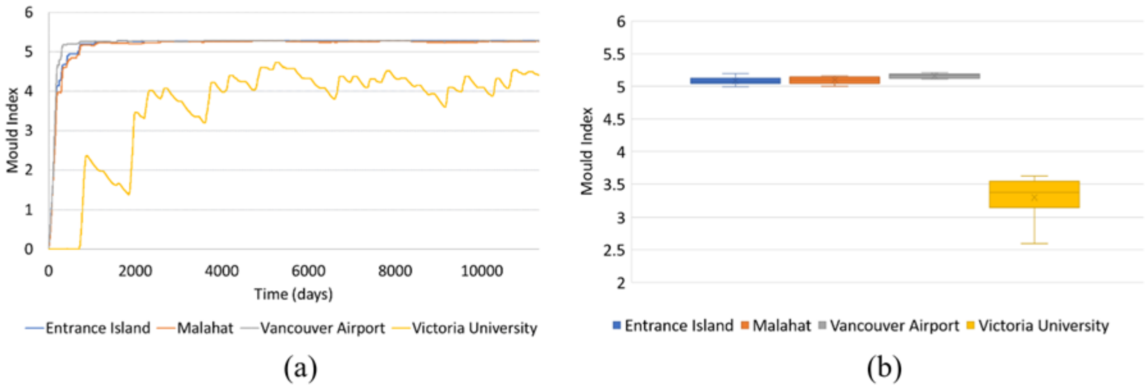

Figure 4. Mould index profile and distribution of the four investigated locations: (a) time series of Mould index; (b) 31-year averaged Mould index.

4 Conclusions

In this paper, the hygrothermal performance of a typical wood-frame wall was assessed under four different urban environments around Vancouver region; these include an open area at the airport (Vancouver), a city center (Victoria University), an area surrounded by plants (Malahat), and an area surrounded by a water body of ocean (Entrance Island). Simulations were performed over 31 years for the wood-frame wall assembly complying with moisture protection design as provided in the National Building Code Canada, but 1% of WDR was assumed to be penetrated into the wall assembly and retained on water-resistive barrier due to deficiency of exterior cladding. The main findings are:

- Victoria University, surrounded by different types of buildings, and Vancouver airport being an open area show the lowest and the highest MC respectively.
- RH does not play a significant role when WDR is high enough to saturate the mould growth index quickly in the 31-year simulation.
- The mould index increases rapidly for Vancouver International Airport, Malahat, and Entrance Island (up to 5.2) because these locations have high values of WDR, keeping the outer part of OSB wet for a long time. In Victoria University, the WDR load is much lower (about 25%) than in the other three locations, and then the mould index increases at a slower pace and the average value is lower (about 4).
- The mould index at the outer part of OSB does not increase much after a certain amount of WDR because the surface is already saturated with regard to mould growth, and RH levels do not further increase. On the other hand, the MC of OSB will increase until it is fully saturated if the outer surface is kept wet.
- Even though the results for Victoria University are better than for the other cities in terms of mould index and moisture accumulation, they do not suggest or imply there

is enough confidence to change the design of the assembly.

In general, the results showed that Victoria University is least prone to moisture risk owing to the low amount of WDR. As water penetration was considered in the simulations, it is clear that the weather station with the lowest amount of WDR will have the least risk of moisture problems. This study was limited to only one region (Vancouver region) and only one wall cladding. Future work will incorporate other Canadian regions with different weather characteristics along with other claddings so as to have a broader comparison.

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