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Accuracy of using Moisture Reference Years for assessing the Long-Term Moisture Performance of Wall Assemblies

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Abstract. Hygrothermal simulation is commonly used to understand the effects of climate loads on wall assemblies. This helps determine the risk of deterioration of wall components due to factors such as mould, wood rot, corrosion, and other modes of degradation. Owing to the lengthy computing time and high cost of undertaking simulations over extended periods of time in excess of 30 years, common practice is to select representative years, generally referred to as moisture reference years (MRYs), amongst the climate data series with the assumption that they would provide results similar to that obtained using the entire climate data series. In this study, simulations were performed for a wood-frame wall having brick veneer and fibreboard as cladding and located in 4 Canadian cities using both a 31-year climate data series and MRYs. The mould growth index on the outer layer of the sheathing panel was used as the performance indicator to permit comparing the moisture performance obtained using the long-term climate series to that obtained using MRYs. It was determined that different strategies should be implemented to analyse the MRY simulation results for different types of wall assemblies to obtain a similar conclusion as that of 31-year simulations.

1. Introduction

Excessive moisture over a prolonged period of time in wall assemblies arising from climate loads is the cause of many detrimental effects, e.g., mould [1], wood rot [2], and corrosion [3], on wall components. Occurrence of these effects can be assessed by undertaking hygrothermal simulations for wall assemblies of interests. However, the numerical simulation can be time consuming, especially when considering 2 or 3-dimensional simulation. A means to reduce the large simulation effort is to select a set of representative years from the series of long-term climate data, the Moisture Reference Year(s) (MRYs), with the expectation to obtain similar results as those obtained from the long-term simulations.

The process of selecting MRYs comprises two steps. The first step is to rank the years of a long-term series in terms of their moisture severity using either climate-based indices or performance-based indices, e.g., the Moisture Index (MI)4, Severity Index (Isev) [5], Climatic Index (CI) [6], or Mould Growth Index (MGI) [1]. Thereafter, the MRY is selected as the worst year [7,8] or a combination of years having different moisture severities [9,10]. Chetan et al. [8] investigated the accuracy of using three methods to sort years in a given climate series for a brick-clad wall assembly in terms of their moisture severity for the purpose of selecting MRYs: MI, Isev, and CI. The cumulative number of hours when mould growth is greater than 3 for the MRY selected, i.e., the year having the 97th percentile value of the index, was compared to that obtained from all the individual years of the long-term series. This study concluded that no method investigated provided 100% accuracy in sorting the MRYs as expected. Whereas, the Isev provided a relatively more accurate results than the other two methods. Sahyoun et al. [7] also used the MI and Isev for selecting the MRYs. Hygrothermal performance of a brick-clad wall assembly and a stucco wall obtained from simulations using MRYs, which had the 97th percentile value of the indicators (e.g., MI and Isev), was compared with that obtained from 31-year simulations. Results of this study indicated that using MRYs derived from the two climate-based indices could result in inconsistent conclusions for moisture performance. It was also found that the orientation of the wall assembly was a critical factor to be considered when comparing the results for MRYs and the 31-year time period. Wang et al. [10] attempted to use hygrothermal simulation results of 7-year MRYs, selected by using both MI and MGI, for a brick-clad wall assembly to represent those for 31-year time period. It was found that simulations using 7-year MRYs could generate similar moisture severity levels as those using 31-year climatic data. Kalamees and Vinha [9] used the vapor condensation and MGI as criteria to select the MRY(s) for hygrothermal calculations using 30-year Estonian climate data; the hygrothermal performance of the wall assembly analyzed was estimated using the climate data for MRYs.

In the ASHRAE Standard-160 [5], it is suggested that, to evaluate the moisture performance of a wall, the Moisture-design Reference Year, i.e., the year having the 93rd percentile value of the severity index from an analysis of 30 years of weather data, must be repeated at least 5 times but not to exceed 10 times. The objective of this study was to evaluate the accuracy of using different numbers of repetitions of MRY for assessing the long-term moisture performance of a brick-clad and a fibreboard-clad wall assembly in four Canadian cities: Vancouver, Calgary, Toronto, and Halifax. The assumption was that fewer and higher numbers of repetitions may be required for cities having, respectively, wet and dry conditions.

2. Methods

The four cities selected for this study are shown in Figure 1. They have different climate characteristics. For instance, their MIs as stated in the National Building Code of Canada [11] are: 1.44, 0.37, 0.87, and 1.49 for Vancouver, Calgary, Toronto, and Halifax, respectively. A higher value of MI represents a relatively wet climate. The year with the 90th percentile MI value was used as the criterion to select the MRY(s) for a 31-year time period over 1986-2016. The value of MI was used to rank the years because the severity index was not directly applicable in some Canadian cities. The simulated wall assembly was thereafter subjected to the climate of the selected MRY repeated 2, 3, 5, 7 and 10 times. The average mould growth index, the maximum mould growth index, and the distributions of hourly mould growth indices for the 31-year simulation were compared to those for different MRYs scenarios.

For each city, 15 realizations of 31-year hourly climate data were generated by the climate model with different initial conditions for the time period (1986-2016) analyzed [12]. However, not all 15 realizations were used for the subsequent analysis. Only those realizations for which the directions receiving the maximum WDR load for the 31 consecutive years were the same as, or within 20° difference to those for the MRYs, were selected to eliminate the effects of the wall orientation used for the assessment. The MI was calculated using values of annual rainfall, wind speed, temperature, and relative humidity (Eq. 1).

$$MI = \sqrt{WI_N^2 + (1 - DI_N)^2} \tag{1}$$

Where MI is the moisture index, WIN is the normalized wetting index derived from rainfall and wind velocity, and DIN is the normalized drying index representing the difference between saturated humidity ratio in the air and the actual humidity ratio. Eq. (2) is the method to normalize of the DI and WI.

$$X_{normalized} = \frac{(\mathrm{X} - X_{minimum})}{(X_{maximum} - X_{minimum})} \tag{2}$$

Figure 1. Selected Canadian cities. From left to right: VAN, Vancouver; CAL, Calgary; TOR, Toronto; HAL, Halifax.

The hygrothermal simulations of this study were conducted using Delphin 5.9.6. The cross-section of the simulated brick-clad and fibreboard-clad wall assembly are shown in Figure 2 and Figure 3. Material properties of wall components were obtained from Kumaran et al. [13], the thermal and moisture transport property database for common building and insulation materials given in ASHRAE Transactions [14] are illustrated in Table 1.

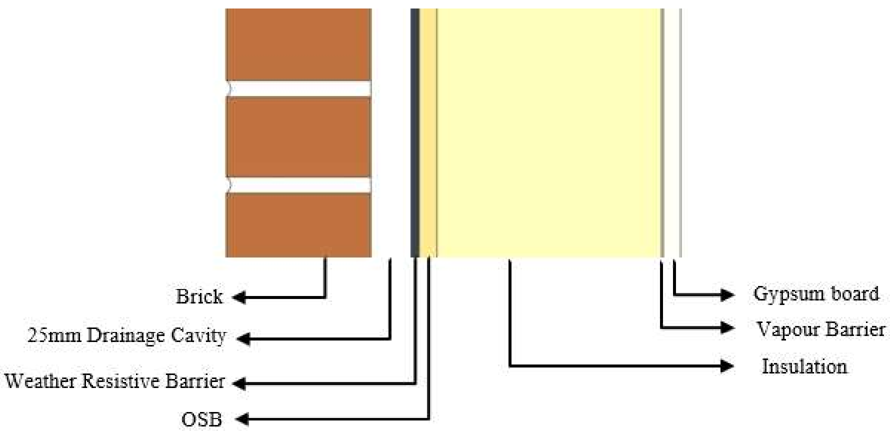


Figure 2. Cross-section of the brick-clad wall assembly.

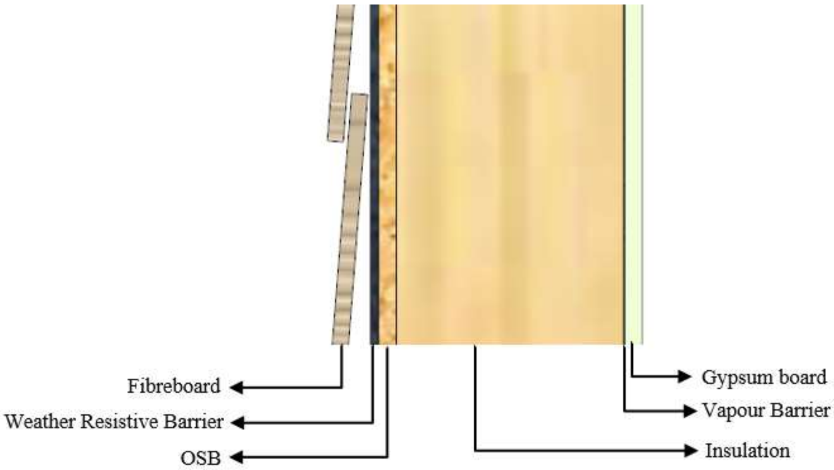


Figure 3. Cross-section of the fibreboard-clad wall assembly.

Table 1. Properties of materials

Components/ material	e (mm)	Density (kg/m^3)	kt (W/mk)	CE (J/kg K)	Porosity (m^3/m^3)	vper (s)	vperm (ng/m^{2}sPa)	A (kg/m^{2}s$^{0.5}$)	DL (m^2/s)
Weather Resistive Barrier	0.24	909	0.159	1256	0.97	9.7×10^{-14}	404.2	0.00093	3.72×10^{-12}
Red matt clay	90.0	1900	0.500	800	0.21	1.5×10^{-12}	16.2	0.02680	5.01×10^{-8}
Fibreboard	10.5	900	0.120	1880	0.58	5.0×10^{-13}	47.5	0.00060	2.39×10^{-15}
OSB	11.0	600	0.094	1880	0.96	2.5×10^{-13}	22.6	0.00220	2.11×10^{-11}
Gypsum	13.0	700	0.150	870	0.40	5.8×10^{-11}	4430.0	0.00100	6.35×10^{-11}
Mineral fibre	140.0	37	0.032	670	0.66	1.3×10^{-10}	928.6	-	1.00×10^{-18}

e: thickness; kt: thermal conductivity (0% RH); CE: specific heat capacity (0% RH); vper: vapour permeability (0% RH); veperm: vapour permeance (0% RH); A: water absorption coefficient; DL: Liquid diffusivity (maximum MC); RH: relative humidity; MC: moisture content.

Indoor ambient T and RH were set constant to 21°C and 50%, respectively. The initial T and RH for all components were set to 21°C and 80%, respectively. The indoor convective heat transfer coefficient was set to 2.5 W/m^{2}K, and the outdoor convective heat transfer coefficient was calculated using Equation (1) from ISO 15927-3 Hygrothermal performance of buildings - Calculation and presentation of climatic data [15].

$$\alpha_{ce} = 4 + 4V \tag{3}$$

Where α_{ce} is the outdoor convective heat transfer coefficient in W/m^{2}K and V is the wind speed (m/s). The outdoor and indoor convective vapor transfer coefficients were calculated using the corresponding convective heat transfer and the Lewis number. The indoor radiative heat transfer coefficient was set to 5.5 W/m^{2}K [15], whereas the longwave exchange between the cladding surface and the environment was explicitly calculated assuming a longwave emissivity of 0.9 for the surface and the surrounding ground, and 1.0 for the sky. The ground surface temperature and albedo were set to the air temperature and 0.2, respectively. The shortwave absorption coefficient of the cladding was set to 0.6, assuming a red-colored surface.

The moisture source was assumed to be 1.0% of WDR for the fibreboard-clad wall assembly and 0.3% for the brick-clad wall respectively and was applied on the exterior surface of the sheathing membrane. An air change per hour (ACH) of 3 was used in all cities for the brick-clad wall assembly, assuming a vented drainage cavity and an ACH of 0 was used for the fibreboard-clad wall assembly, considering a direct applied cladding. Wind-driven rain (WDR) impinging on the building façades was determined based on ASHRAE Standard 160, assuming an exposure factor of 1.0 (building less than 10-m height with medium exposure) and a deposition factor of 0.5 (low-slope roof). The wall orientation in each realization was selected as the direction in which the rain deposition rate was the highest for MRY of that realization.

The mould growth index was considered as the performance indicator. It was calculated for the outer layer of OSB using the procedure as specified in ASHRAE Standard-160 [5] with a Decline factor of 0.25 and the Sensitivity class.

3. Results and Discussion

The accuracy of the hygrothermal performance obtained from different repetitions of the MRY and that of the 31-year simulations was assessed using the following indicators: average mould growth index, maximum mould growth index, and distributions of hourly mould growth indices.

3.1. Average and Maximum Mould Growth

The ratios of the average and maximum mould growth indices at the OSB for the brick-clad wall assembly for different repetitions of the MRY to that for simulations using the 31-year climate data are shown in Figure 4. The boxplot covers the ranges of ratios obtained from 15 climate realizations. When the value of the ratio is 1, it indicates an identical result between MRY simulations and 31-year simulations. It is evident that for all cities analyzed, ratios increase with the increase in the number of repetitions of the MRY. For wet cities, Vancouver and Halifax, simulations using 5 repetitions (5 MRYs) could give similar values of average mould growth indices as those obtained from 31-year simulations, and only 3 repetitions were sufficient for the generation of the maximum mould growth index. For relatively dry cities, Calgary and Toronto, ratios of average and maximum mould growth indices were also greater for a longer repetition of MRY. However, even using 10 repetitions of MRY (10 MRYs), the averaged value of the average and maximum mould growth indices for different realizations were still less than 1 for both dry cities. In other words, more repetitions of the climate data of MRY would be needed to obtain similar average and maximum mould growth indices as those generated from 31-year simulations in these dry cities. Whereas, for wet cities, Vancouver and Halifax, 7 MRYs were needed for simulations to generate similar average mould growth indices and only 5 MRYs were required to generate similar maximum mould growth indices as those obtained from 31-year simulations.

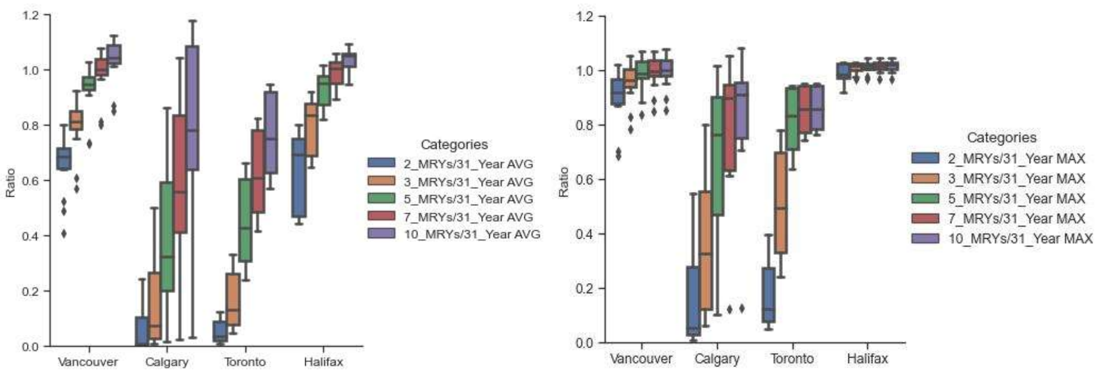
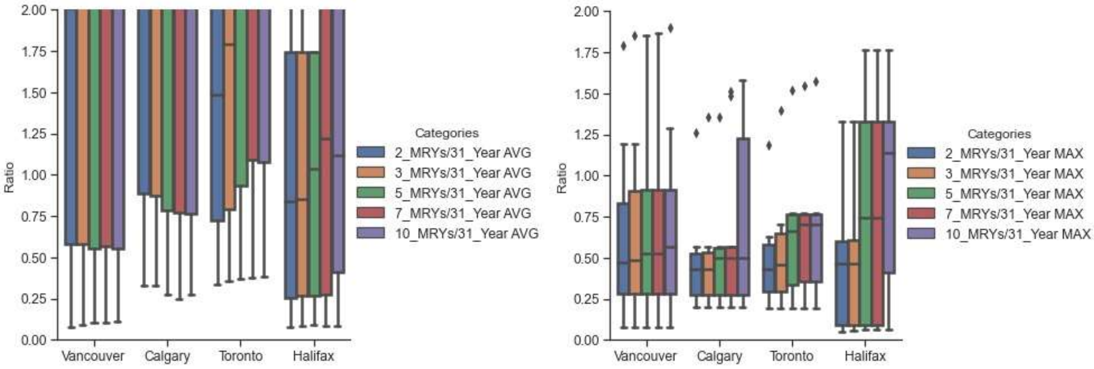


Figure 4. Ratio of average (a) and maximum (b) mould growth indices obtained with different repetitions of MRY to that of 31-year for the brick-clad wall assembly. Upper and lower limits of box plots cover ratios obtained from selected realizations for each city.

The ratios of performance indicators at the OSB of the fibreboard-clad wall assembly are shown in Figure 5. Different from those observed for the brick-clad wall assembly, ranges of ratios obtained from different climate realizations for the fibreboard-clad wall assembly were much greater in all cities regardless the average mould growth index or the maximum mould growth index, which indicated a large degree of discrepancies in the results of MRY simulations and 31-year simulations. In addition, no clear trend of changes could be found for the ratios in respect to the changes in the length of MRYs. Thus, differences in the results of the MRY simulations and 31-year simulations were not affected by the number of repetitions of the MRY.



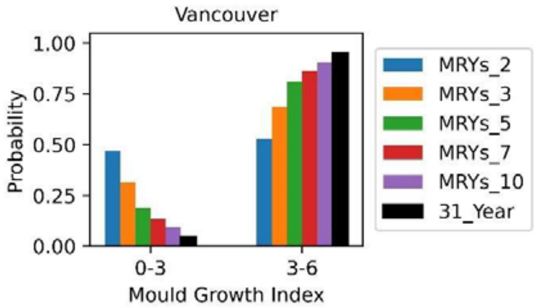
(a) (b)

Figure 5. Ratio of average (a) and maximum (b) mould growth indices obtained with different repetitions of MRY to that of 31-year for the fibreboard-clad wall assembly. Upper and lower limits of box plots cover ratios obtained from selected realizations for each city.

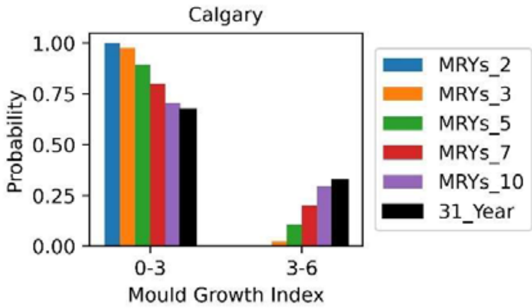
3.2. Distributions of Hourly Mould Growth

In addition to the average and maximum values of mould growth index, distributions of these values are also important as they can demonstrate durations of different levels of mould growth index. Distributions of hourly mould growth indices for each city analyzed are shown in Figure 6 and Figure 7 for the brick-clad wall assembly and fibreboard-clad wall assembly, respectively. The mould growth index was classified into 2 categories: mould growth index greater or equal to 3, and mould growth index less than 3, as ASHRAE Standard-160 suggests that the mould growth index should not exceed 3 to minimize mould growth related problems on the surface of building envelope components. The vertical axis of each plot represents the probabilities of occurrence of mould growth in the two categories.

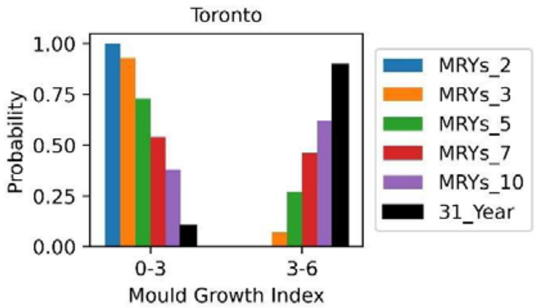
For the brick-clad wall assembly, clearly, probabilities of mould growth index greater or equal to 3 were higher in cities with a greater MI. Similarities of distributions obtained from simulations using different durations of MRYs approached that obtained from the 31-year simulations with the increase in the number of repetitions of MRY. For, Vancouver, Calgary, and Halifax, distributions of the 10-MRYs were very close to that of simulations using the 31-year climate series. Whereas, for Toronto, a city with an intermediate value of MI, distribution for the 10-MRYs was still very different from that of the 31-year. The trend of distributions indicated that more repetitions of MRYs were required to obtain a similar distributions of hourly mould growth index as those obtained from 31-year simulations for Toronto. For all cities analyzed, an inadequate number of repetitions of MRYs would result in an underestimation of mould growth situation given that more hourly mould growth indices obtained from 31-year simulations would be greater than 3.



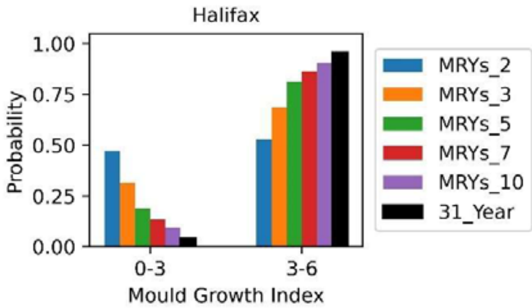
(a)



(b)



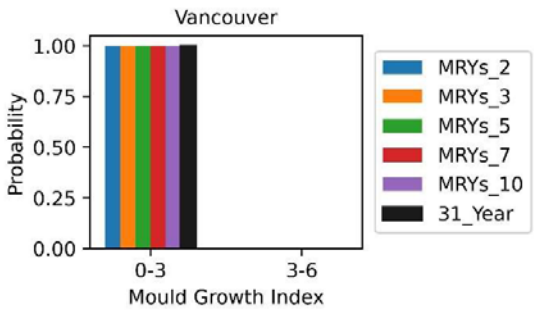
(c)



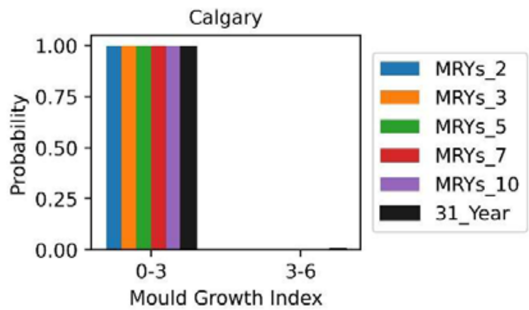
(d)

Figure 6. Distributions of hourly mould growth indices for the brick-clad wall assembly in (a) Vancouver; (b) Calgary; (c) Toronto; and (d) Halifax.

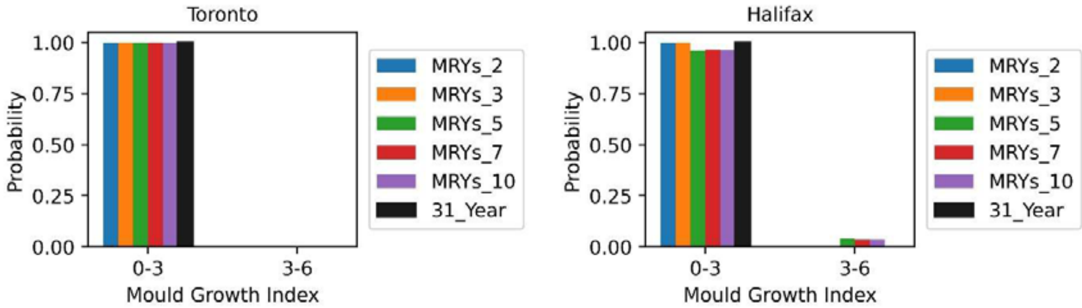
Distributions of the hourly mould growth indices for the fibreboard-clad wall assembly in all cities are almost identical for the given classification. Except for the Halifax, all hourly mould growth indices in other 3 selected cities were less than 3 for both MRY simulations and 31-year simulations. In the Halifax, only a small portion of hourly mould growth indices obtained from MRY simulations were greater than 3. If the decision-making is based on the 2-class values of mould growth indices, the distribution of hourly mould growth indices was sufficient for the MRY simulations to derive the same conclusion as those derived from 31-year simulations.



(a)



(b)



(c) (d)

Figure 7. Distributions of hourly mould growth indices for the fibreboard-clad wall assembly in (a) Vancouver; (b) Calgary; (c) Toronto; and (d) Halifax.

4. Conclusion

In this study, the accuracy of using MRYs to assess the long-term moisture performance for a brick-clad wall assembly and a fibreboard-clad wall assembly was investigated. Mould growth indices obtained from hygrothermal simulations results using repeated climate data of MRY selected as the year with 90th percentile MI was compared to that for 31-year simulations. It was evident that the accuracy of the assessment using the MRYs increased with the increase in the number of repetitions of the MRY for the brick-clad wall assembly. For wet cities, simulations only required climate data of 5 and 7 MRYs to generate similar maximum and average mould growth index respectively as those obtained from 31-year simulations. Distributions of hourly mould growth indices for the brick-clad wall assembly generated from MRY simulations for all cities analyzed showed a clear trend that distributions generated from simulations using a longer duration of MRYs was more similar to those obtained from 31-year simulations. Whereas, the degree of similarity for different cities having diverse MI were not uniform. For very wet and very dry cities, e.g., Vancouver, Halifax and Calgary, distributions obtained from simulations using 10 MRYs were in a good match with those obtained from 31-year simulations. For Toronto, a city with an intermediate value of MI, 10 MRYs was still inadequate to provide a similar distribution of hourly mould growth index as those obtained from 31-year simulations. In respect to the fibreboard-clad wall assembly, a great range of ratios of mould growth indices in all cities indicated that mould growth indices obtained from MRY simulations couldn't match those obtained from 31-year simulations. At the same time, distributions of hourly mould growth indices obtained from the two types of simulations are almost identical in all analyzed cities for the given classification.

Evidently, when the MRY was used for moisture performance assessment, different strategies should be implemented to analyze the MRY simulation results for different types of wall assemblies to obtain a similar conclusion as that of 31-year simulations. The ASHRAE standard should suggest to consider using multiple methods to analyze the results of MRY simulations to ensure the accuracy of the conclusion. Simulations in this study only considered two types of wall systems. Other wall systems may have a different response to the same climate. In addition, similar ACH values, which is a decisive factor in determining the moisture performance of a wall assembly, were used for all the cities considered in this study. Hence, in future studies, the accuracy of using MRYs to assess the long-term moisture performance for other types of wall assemblies will be investigated by considering ACH values as may prevail in each respective city. Other cities in other climate regions having a wider range of MI will also be included. It would also be important to evaluate the accuracy of using MRYs for comparing different design scenarios or for assessing the impact of climate change.

5. Acknowledgement
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