XV International Conference on Durability of Building Materials and Components
DBMC 2020, Barcelona
C. Serrat, J.R. Casas and V. Gibert (Eds)

Validation of Three Methods of Selecting Moisture Reference Years for Hygrothermal Simulations

Chetan Aggarwal[1], Maurice Defo[2], Travis Moore[3], Michael A. Lacasse[4], Sahar Sahyoun[5] and Hua Ge[6]

[1] Ph.D. Student, Concordia University, Montreal, Quebec, Canada; c_agga@encs.concordia.ca

[2] Construction Research Centre, NRCC, Ottawa, Ontario, Canada; maurice.defo@nrc-cnrc.gc.ca

[3] Construction Research Centre, NRCC, Ottawa, Ontario, Canada; travis.moore@nrc-cnrc.gc.ca

[4] Construction Research Centre, NRCC, Ottawa, Ontario, Canada; michael.lacasse@nrc-cnrc.gc.ca

[5] Ph.D. Student, Concordia University, Montreal, Quebec, Canada; s_sahyo@live.concordia.ca

[6] Associate Professor, Concordia University, Montreal, Quebec, Canada; hua.ge@concordia.ca

Abstract. *Hygrothermal simulations are necessary to permit analyzing moisture performance when designing building envelopes. Owing to the high computing time and cost of the long term simulations, a common approach is to select representative year(s), the Moisture Reference Year(s), from a long-term series of climate data. It is assumed that the use of Moisture Reference Year(s) (MRYs) provides equivalent results as those provided using long-term series. The selection of MRY(s) is by itself based on the one of the methods available in the literature. In the present study, three methods of selecting the MRYs were evaluated i.e. the moisture index (MI), severity index (Isev) and climatic index (CI). Simulations were performed using individual years of historical climate data extending from 1986 to 2016 and projected future climate data representing the scenario with a 3.5°C increase in average temperature which is expected to occur from 2062 to 2092. Brick cladding installed on a wood frame wall assembly subjected to the climate of three different Canadian cities was selected for analysis. The cities selected were Vancouver (BC), Calgary (AB) and Ottawa (ON). These cities have differing levels of moisture loads. The year having the mould index value more than 3 for highest number of hours among the individual years was compared with the MRY given by three selected methods. A method was considered to be accurate in terms of the prediction if the year selected by that method gives the number of hours with mould index more than 3 which lies in the same class as that of year having maximum corresponding value. In general, it was observed that none of the methods provides the worst year with 100% accuracy, however for most of the cases, Isev method performs better than other two methods in terms of MRY selection.*

Keywords: *Moisture Performance, Climate Change, Hygrothermal Simulation, Moisture Reference Year(s) Selection Method.*

1 Introduction

One of the parameters that influences the moisture performance of the wall is the outdoor climate. However, having large number of climate parameters and estimating the effects of these parameters over the entire service life would result in a large simulation effort. One of the approaches to cut down the simulation time and cost is to select a year or combination of years called Moisture Reference Year(s) (MRYs) which is assumed to represent the entire set of long term climate data.

The π-factor method suggested by Hagentoft and Harderup (1996) compares the absolute humidity at the external wall surface with the absolute humidity of the outside air in order to compute the drying potential of the wall surface. They suggested that drying out potential is higher for a higher value of π-factor. Kalamees and Vinha (2004) used a method similar to π-factor method for selecting the MRY in terms of evaluating the risk of water vapor condensation. Carsten Rode (1993) proposed a construction dependent method, which compares the integral moisture content values for different wall constructions and orientations. He suggested that the higher the value of moisture content for a particular year, the more severe the year is in terms of moisture performance of the wall. Cornick *et al.* (2003) used an index called Moisture Index (MI) to categorize the years in terms of the severity. MI method uses wetting and drying function to compute MI and then further categorizes the year as dry, average and wet based on lowest, average and highest MI value respectively. From a dataset of years, the years having MI value in the range of more than one standard deviation (+/-) from the mean MI value are considered as dry and wet years, while those years having a value within (+/-) one standard deviation are referred to as average years. A method suggested by (ASHRAE, 2010) combines the climate load and durability to choose the “severe” weather years and provides a more representative ranking of the climate data. This approach, called the Severity Index (Isev), uses an equation to predict the RHT value as a damage function. Salonvaara *et al.* (2010) suggested the Isev equation as a reliable method of selecting representative years. A regression equation used for computing RHT value considers different climate parameters. The yearly average value of each climate parameter is used in the equation and the years are arranged in the descending order of the RHT values. The year with the third highest (top 10% years among 31 years) RHT value is selected as MRY for the hygrothermal simulations. The authors further compared their method with three other existing methods and concluded that their method performs better in predicting the severe years than other methods. The Climatic Index method suggested by Zhou *et al.* (2016) comprises wetting and drying components. The wetting component depends on the annual wind-driven rain and the drying component depends on the annual potential evaporation. Unlike MI method, this index takes into consideration the effect of many climate parameters such as net radiation, temperature, humidity, wind speed, wind direction and orientation of the façade. The authors made a comparison with MI method in terms of accuracy in predicting the MRY and suggested that the year predicted using climate index gives better result than MI method. However, based on the past research findings, none of the methods can be considered as a universal method for the selection of MRY.

The objective of this study is to investigate three MRY selection methods *i.e.* Moisture Index (MI), Severity Index (Isev) and Climatic Index (CI) in terms of their accuracy in predicting the worst year in terms of moisture performance among a series of long-term climate data. For all the methods, the year corresponding to the 97th percentile, (ranked second out of the 31 years) for each climate scenario was chosen as the MRY and is further compared with the individual year simulations to determine their capability in predicting the extreme year.

2 Methods

2.1 Description of MRY Selection Methods

Cornick *et al.* (2003) suggested the calculation of MI for every hour (MI_h) based on hourly wetness (WI_h) and dryness (DI_h) indices. Here, WI_h corresponds to the normalized hourly rainfall and DI_h corresponds to Δp_v *i.e.* the difference between the saturation vapor pressure and vapor pressure of the ambient air. The saturation vapor pressure, p_{vs}, as a function of ambient temperature (T), was calculated as suggested by ASHRAE (2009).

The magnitude of Δp_v is calculated using Equation (1):

$$\Delta p_v = p_{vs} - p_v \tag{1}$$

Both the indices are further normalized as per the Equation (2):

$$I_{normalized} = (I - I_{min})/(I_{max} - I_{min}) \tag{2}$$

Where, I is the Index of interest.

Normalized values of Δp_v and accumulated hourly rainfall were used as DI_h and WI_h magnitudes respectively and equal weights are assigned for both the indices.

$$MI_h = \sqrt{(1 - DI_{h,norm})^2 + {WI_{h,norm}}^2} \tag{3}$$

Based on ASHRAE (2010), the severity index (Isev) for each year is calculated according to Equation (4):

$$\begin{aligned} I_{sev} = {} & 108307 - 241.E_v - 1391.I_{cl} - 312326.\phi + 183308.r_{wd} + 15.2.p_v + 27.3.T^2 \\ & + 261079.\phi^2 - 0.00972.p_v^2 \end{aligned} \tag{4}$$

Where, E_v is the solar radiation (W/m^2) incident on the wall; I_{cl} is the cloud index; ϕ is the relative humidity; r_{wd} is the wind-driven rain (kg/(m^2.h) on the wall; p_v is vapor pressure (Pa), and T is the ambient temperature (°C). The method is explicitly valid for the orientation with highest amount of yearly Wind-driven-rain (WDR) and least solar radiation *i.e.* North orientation. A yearly average value is used for each climate parameter for each year.

Zhou *et al.* (2016) suggested calculation of CI based on annual wetting and drying. The wetting component includes annual wind-driven rain and drying component is based on the potential evaporation calculation based on Penman equation shown below:

$$E = \frac{\Delta}{\Delta + \gamma}\frac{K + L - A}{I} + \frac{\gamma}{\Delta + \gamma} h_m(e_a - e) \tag{5}$$

Where, $\frac{\Delta}{\Delta+\gamma}\frac{K+L-A}{I}$ represents the radiation term and $\frac{\gamma}{\Delta+\gamma} h_m(e_a - e)$ represents the turbulence term. E is the drying Index, K is the net short-wave radiation (Wm^{-2}), L is the net Longwave radiation (Wm^{-2}), A is the conductive heat flux to the porous material (Wm^{-2}), I is latent heat of vaporization (Jkg^{-1}), γ is the psychometric constant (PaK^{-1}), Δ is the slope of the relationship between saturation vapor partial pressure and air temperature, e_a is the saturated partial vapor pressure of the air, e is the vapor partial pressure in the air (Pa) and h_m is the convective vapor transfer coefficient (sm^{-1}). In the calculation of drying index, the conduction heat flux and long wave radiation were neglected since their values are much smaller in comparison to short wave radiation. Finally, the yearly sum values were taken and the CI was calculated as the ratio of Wetting Index and Drying Index.

2.2 Cities Selected & Wall Orientation

For the analysis, three cities were chosen from 3 different provinces of Canada: Ottawa (ON), Vancouver (BC), and Calgary (AB). Furthermore, the selected cities vary significantly in terms of their climate conditions. Amongst these cities, based on MI value; Vancouver and Calgary are the wettest and driest cities respectively and Ottawa being the city with an intermediate value of MI. The study was made for the orientation receiving least annual solar radiation *i.e.* a North-facing wall (N) for each city. Further details for these cities are listed in the Table 1.

Table 1. Characteristics of the selected cities.

City (Province)	**Latitude**	**Longitude**	**HDD18**	**MI**	**Annual rain (mm)**
Ottawa (ON)	45.25°	-75.42°	4440	0.84	750
Vancouver (BC)	49.28°	-123.12°	3100	1.93	1850
Calgary (AB)	51.05°	-114.07°	5000	0.37	325

HDD18 – heating degree days below 18ºC MI – moisture index

2.3 Wall Configuration

The modeled building was assumed to be a 3.5 storey type located in a suburban setting. Light weight wood frame wall assembly with brick cladding was simulated and the wall was assumed to be perfectly air tight. A detailed description of chosen wall assembly is shown in Figure 1.

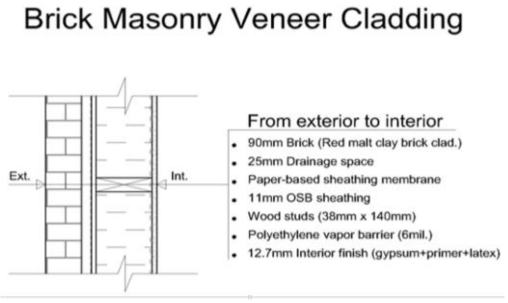

Figure 1. Description of the wall assembly.

The material properties were obtained from NRC material property database (Kumaran *et al.* 2002). For the air cavity, same value of Air Changes per Hour (ACH) was used for each city and climate scenario. Table 2 illustrates ACH values for different claddings and locations.

Table 2. Selected ACH values for different claddings and locations.

Ottawa		**Vancouver**		**Calgary**	
Brick	Stucco	Brick	Stucco	Brick	Stucco
6	10	12	40	3	5

Extensive trials were made for selecting an appropriate ACH value. For this purpose, simulations were made by repeating the average year (based on MI ranking) for 7 times and mould index value was computed at the exterior layer of the OSB. The aim was to choose a value of ACH that results in having mould index stabilizes around a value of 3.

2.4 Climate Data and Wind Driven Rain

The climate data used for the present study includes hourly climate for a consecutive 31 years: from 1986-2016 for historical scenario; and, similarly 31 years when the global temperature will increase by 3.5°C. (Gaur *et al.* 2019). An increase of 3.5ºC global increase is expected to transpire between the years 2062-2092 as per the projections made by Environment and Climate Change Canada (2018). It was observed that, there is a minimal variation in RH value and an increase of approximately 5°C (annual average) in temperature from historical to future climate conditions for each city. Wind Driven Rain (WDR) was calculated using the ASHRAE method (ANSI/ASHRAE, 2016) assuming a medium exposure with the rain exposure factor (FE) and the rain deposition factor (FD) set to 1.0 and 0.5, respectively.

2.5 Boundary Conditions and Initial Conditions

Indoor temperature and relative humidity were assumed constant and set to 21ºC and 50% respectively. The indoor exchange coefficient for heat conduction was set to 8 W/m^{2}K and the indoor vapor diffusion coefficient was set to 1.52*10^{-8} s/m. As per the EN ISO 6946 standard, the convective heat transfer coefficient is $h_{ce} = 4 + 4v$, where v is the wind velocity at 10 m height. The convective vapor transfer coefficient is related to the convective heat transfer by the use of the Lewis analogy $\beta_v = 2.44 * 10^{-8} + 2.44 * 10^{-8}\ v$. The reflection coefficient of the surrounding ground (albedo) was 0.1 and the absorption coefficient for the brick cladding was equal to 0.6. The wall was conditioned with suitable climate by completing a consecutive seven (7) year simulation, repeating the average year (based on Moisture index ranking). At the end of simulation, the average value of temperature and RH for all the layers in the wall configuration were noted and used as initial conditions.

2.6 Simulations

Simulations were run over the individual years spanning a period of 31 years for historical and future climate using the Heat, Air and Moisture (HAM) simulation tool DELPHIN V5.9. For this study, only one-dimensional horizontal configuration of the wall was simulated. The water infiltration through the assembly was assumed to be 1% of the wind-driven rain and was applied to the exterior side of the sheathing membrane, as per ASHRAE 160 (2016). Manual meshing was opted for all the layers except sheathing membrane and vapor barrier. For these two layers, an equidistant mesh of 3 elements was assumed. For other layers, they were divided into 3 sections with first and last sections having equal thicknesses. For these two sections, a fine and variable mesh was used and an equidistant mesh was opted for the middle section.

2.7 Performance Indicator

For analyzing the moisture performance of the wall assembly, the mould index was computed at the exterior of the OSB layer (0.1mm thick element size) using the method proposed by Ojanen *et al.* (2010). The calculations were made assuming the sensitive class for material and surface and a decline factor of 0.5 (assuming significant decline) when the conditions become unfavorable for mould growth. Furthermore, for performance analysis, one way is to use the maximum mould index value to compare different results. However, this can be misleading, especially in a situation when there is only one peak followed by set of low values. To tackle this situation and capture the trend, a better idea would be to count the number of hours when mould index value is above a threshold value and use that value as a performance indicator.

3 Results and Discussion

The accumulated number of hours when mould index (MoI) value is more than 3 was calculated for each year of the 31-year series. Figure 2 shows the results obtained for the brick cladding wall in Calgary exposed to future climate. It shows the total number of hours throughout the year when the MoI value was above 3. On the secondary axis, the maximum MoI for a particular year is shown. Furthermore, the year selected by each MRY selection method is marked on the chart. For this particular case, it was observed that Isev method predicts the year which performs the worst when simulated for moisture performance analysis. The years predicted by the other two methods are far away from the extreme year (based on simulation) in that dataset.

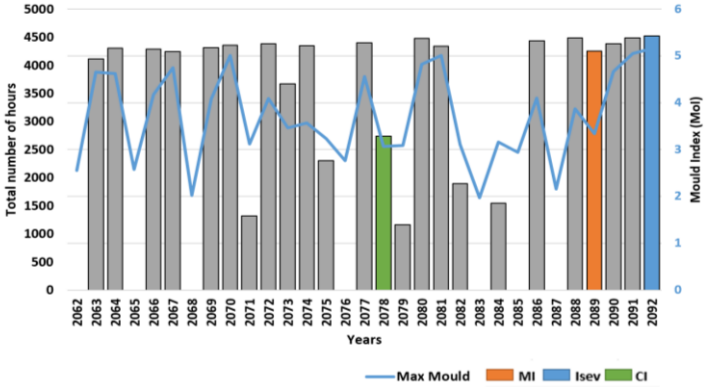

Figure 2. Total number of hours with MoI>3 for Brick wall in Calgary for future climate. Secondary axis shows the maximum value of MoI for each year**.**

To analyze the results in a more lucid way, further grouping was made wherein the hours were divided into classes having a range of 200 hours starting from 0 and ending with hours above 5000. The reason behind choosing a nominal value of 200 hours is to distinguish the years selected by different selection methods.

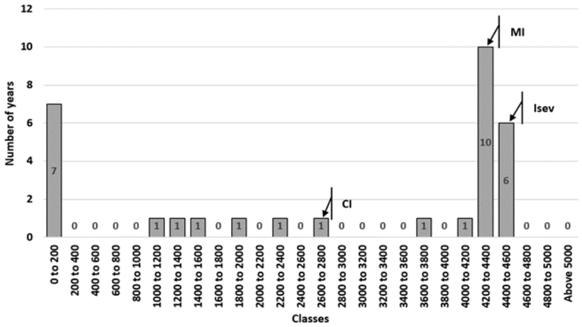

Figure 3. Grouping of years in terms of number of hours when MoI>3 for Brick wall in Calgary for future climate. Year given by three methods lies in one of the classes and are marked in with arrow in the chart.

Figure 3 shows the distribution of the 31 years among the different classes for brick cladding wall in Calgary exposed to the future climate. It is clear from Figure 3 that the year predicted by the Isev method falls in the same class as that of the year with maximum number of accumulated hours using simulation. For this case, the worst year is more in accordance with the year suggested by Isev method.

Similar analysis was made for different cities considered for historical and future climate scenarios. As a general trend, it was observed that the selection of year based on severity index method always lies closer to the class belonging to the worst year among the series of the years. It was observed that in Vancouver for a North facing wall, there is no risk of mould growth. This could be explained by the fact that in Vancouver, there was a very low amount of WDR falling on a North facing wall which in turn imposes almost no risk of mould growth.

Table 3. Summary of all the simulated cases. Year shows the year predicted by the method and class shows the range in which the corresponding year lies. (*Ott: Ottawa, Van: Vancouver, Cal: Calgary, H: Historical, F: Future).*

Case	**Simulation**		**MI**		**Isev**		**CI**	
	Year	**Class (in 100s)**	**Year**	**Class (in 100s)**	**Year**	**Class (in 100s)**	**Year**	**Class (in 100s)**
Ott_H	2009	42-44	2010	0-2	2009	42-44	2004	30-32
Ott_F	2081	>50	2085	0-2	2069	38-40	2070	46-48
Van_H	--	--	--	--	--	--	--	--
Van_F	--	--	--	--	--	--	--	--
Cal_H	1999	40-42	2005	34-36	1995	40-42	2014	40-42
Cal_F	2092	44-46	2089	42-44	2092	44-46	2078	26-28

Table 3 represents the results for all the considered cases. It shows the year selected by various methods and the year which actually performs the worst. Moreover, the table illustrates the class in which each method lies. Closer the class of each method to the simulation results, better the method is in its prediction. From the table it is clear that 3 out of 4 times, the year predicted by the Isev method lies in the same class as that of extreme year using simulations.

4 Summary and Conclusions

For analyzing the moisture performance of the wall assembly, 3 different Canadian cities were selected based on the different climate conditions. Number of hours when the mould index was more than 3 were calculated for each year and were then compared with the corresponding values for the MRY predicted using different methods. Different classes were made based on the number of hours and the years falling in the same class were grouped together. None of the three methods predicts the worst year with 100% accuracy when compared with the results from the simulation over the individual year for the 31 year data set. Furthermore, when the methods were compared against each other, it was observed that the severity index method was better in predicting the extreme year than the other two methods for both set of climate data *i.e.* historical as well as future climate scenario.

The study is limited to only 3 Canadian cities and it is of utmost importance to test more cities with varying climatic conditions. Furthermore, among the three MRY selection methods chosen for the study, Isev method is limited to only North facing walls. Finally, the study uses total number of hours when MoI>3 as the damage criteria for one set of historical and future climate. The study could be further extended to analyze other damage functions for different sets of historical and future climate scenarios. Future work will be to incorporate the abovementioned limitations along with developing the moisture performance data for different wall systems obtained by completing hygrothermal simulations over a consecutive 31-year series of historical and future climate data. Later step will be to validate the (MRY), or a series of MRYs using the results from the consecutive year simulations.

ORCID

Chetan Aggarwal: https://orcid.org/0000-0002-7224-9740
Maurice Defo: https://orcid.org/0000-0001-9212-6599
Travis Moore: https://orcid.org/0000-0002-4920-9193
Michael Lacasse: https://orcid.org/0000-0001-7640-3701
Sahar Sahyoun: https://orcid.org/0000-0001-5131-6134
Hua Ge: http://orcid.org/0000-0003-1368-4301

References

ASHRAE. (2016). ASHRAE 160 (Criteria for Moisture-Control Design Analysis in Buildings). ASHRAE Standards Committe, Atlanta, GA.

ASHRAE. (2010). Environmental weather loads for hygro- thermal analysis and design of buildings. RP-1325, American Society of Heating, Refrigerating and Air- Conditioning Engineers, Inc. Atlanta.

ASHRAE. (2009). ASHRAE handbook: Fundamentals. Atlanta.

Cornick, S., Djebbar, R. and Dalgliesh, W. A. (2003). Selecting moisture reference years using a Moisture Index approach. Building and Environment, 38(12), 1367–1379. https://doi.org/10.1016/S0360-1323(03)00139-2.

Environment and Climate Change Canada. (2018). Memorandum of Understanding between National Research Council and Environment and Climate Change Canada…. Government of Canada: Ottawa, ON, Canada.

Gaur, A., Lacasse, M. and Armstrong, M. (2019). Climate Data to Undertake Hygrothermal and Whole Building Simulations Under Projected Climate Change Influences for 11 Canadian Cities. Data, 4(2), 72. https://doi.org/10.3390/data4020072.

Hagentoft CE, Harderup E. Climatic infuences on the building envelope using the π factor. IEA-Annex 24 Hamtie Task 2, Environmental Conditions. Closing Seminar, Finland, 1996.

ISO, 2017. ISO 06946 (Building components and building elements-Thermal resistance and thermal transmittance-Calculation methods), ISO, Switzerland

Kalamees, T. and Vinha, J. (2004). Estonian Climate Analysis for Selecting Moisture Reference Years for Hygrothermal Calculations. Journal of Building Physics, 27(3), 199–220.

Kumaran, M.K., Lackey, J. Normandin, N., Tariku, F. and van Reenen, D. (2002). A thermal and moisture transport property database for commom building and insulation materials (No. 1018- RP). ASHRAE.

Ojanen, T., Viitanen, H., Peuhkuri, R., Lähdesmäki, K., Vinha, J. and Salminen, K. (2010). Mold Growth Modeling of Building Structures Using Sensitivity Classes of Materials. Eleventh International Conference on Thermal Performance of the Exterior Envelopes of Whole Buildings, 10. Clearwater Beach, FL, US.

Rode C. Reference years for moisture calculations. Denmark. Report T2-DK-93/02, International Energy Agency, Energy Conservation in Buildings and Community Systems Program, Annex 24 Heat, Air, and Moisture Transfer in Insulated Building Parts (HAMTIE).

Salonvaara, M., Sedlbauer, K., Holm, A. and Pazera, M. (2010). Effect of selected weather year for hygrothermal analyses. Proceedings of thermal performance of the exterior envelopes of whole buildings XI. ASHRAE.

Zhou, X., Derome, D. and Carmeliet, J. (2016). Robust moisture reference year methodology for hygrothermal simulations. Building and Environment, 110, 23–35. https://doi.org/10.1016/j.buildenv.2016.09.021