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HYGROTHERMAL PERFORMANCE ASSESMENT OF WALL SYSTEMS WITH VARIOUS CONCRETE AND INSULATION CONFIGURATIONS

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ABSTRACT

The moisture performance of building envelope assemblies has always been a major concern of designers. Building envelope is constantly exposed to moisture loads such as exterior and interior humidity, rain, groundwater, snow and construction moisture. Therefore, it is critical to control the moisture migration mechanism within building envelope walls. Moisture accumulation occurs when the wetting potential of building envelope exceeds its drying potential due to applying inappropriate construction materials or configuration designs.

Moisture accumulation in mid-rise and high-rise concrete buildings has negative impacts on microbial growth, occupants' comfort, energy consumption, freeze thaw and compressive and tensile strength of concrete which lead to spent of millions of dollars on the repair in North America every year. Therefore, evaluation and prediction of moisture performance of building envelope components are important design factors that should be considered to minimize the risk of moisture accumulation in concrete buildings.

In this paper, the hygrothermal performance of a number of concrete wall systems with various configuration of concrete and insulation are studied. The performance of these systems in wet and cold climates of Vancouver and Winnipeg are evaluated using a hygrothermal model. The water content of concrete layers and moisture fluxes at the interior and exterior surface layers are analysed and the overall performance of the systems as related to moisture storage and drying behaviour are determined.

The results indicate that assemblies with thermal insulation placed on the exterior side of concrete have the highest hygrothermal performance while assemblies with concrete layer sandwiched between two wythes of thermal insulations have the poorest hygrothermal performance.

KEYWORDS

Hygrothermal performance, Building envelope, Concrete multilayer walls, Thermal insulation, Moisture content (MC)

INTRODUCTION

By rapid growth of construction trends and materials walls have started to turn into more complex assemblies. Thermal insulation from one side and vapour and air barrier materials from other side assemble together to form a whole building envelope system that could perform well in response to different interior and exterior climatic loads. However, there are still confusions and deficiencies exist regarding correct arrangements of materials and barriers in building envelope components (Hemmati et al. 2017).

Precipitation (rain and snow), groundwater, and in-borne humidity form exterior moisture sources while Interior moisture sources come from people, activities, abnormal loads and construction stage moisture. The holistic approach of any moisture management strategy

includes three main stages of deflection, drainage, storage or exclusion and drying (Tariku et al. 2015). Deflection consists of applying approaches or materials to control moisture entry or deposition into and on the wall. Drainage, storage and exclusion focus on limiting moisture accumulations inside the wall. Drying mechanism itself should consider as evaporation of water at surfaces, water vapour transport by diffusion or air movement, drainage and ventilation drying by air exchange. Failure in drying mechanism which results in excessive moisture accumulation that has undesirable influences on building envelope in variety of ways such as discoloration, mould, fungi, deterioration, corrosion and etc. (Lstiburek, 2002). Therefore, it is essential to design walls by applying appropriate materials and layers arrangement such that while limiting vapour intrusion from either interior or exterior, also letting the existing moisture within walls evacuated from timely (Kunzel, 1995).

Principle mechanisms of moisture transport through building envelope materials are vapour diffusion, capillary suction and surface diffusion. The water vapour is transported by vapour diffusion. Driving force of vapour diffusion is water vapour pressure difference. Vapour diffusion control layers (retarders or barriers) with low or none vapour permeability should be placed on the side of highest vapour pressure where this is on the interior side of the insulation in cold climates and this may be on the exterior side of the insulation in warmer climates. Capillary suction pressure acts as driving force of liquid water transport by capillary conduction. Materials with larger capillaries and pores show lower resistance behaviour to liquid water transport through which (capillary active materials). Lastly, the adsorbed water on material surfaces is conveyed by surface diffusion. The driving force of the surface diffusion is relative humidity (RH) difference.

The explanations given above indicate that material properties and their configurations within building envelope systems play significant roles on hygrothermal performance of assemblies. In designing of building envelope details not only energy efficiency of components has to come into account, but also their moisture performance should be considered. In other words, designing high thermal and moisture performance of building envelope systems has to be entirely based on building science principles to prevent improper hygrothermal performance designs that lead to damages to sensitive construction materials, increases of building thermal energy consumption and negative impacts on indoor air quality as well as occupants' comfort.

Comprehensive thermal analysis on a number of common concrete multilayer walls with similar material properties and thicknesses demonstrated that walls with two layers of insulation thermally perform more efficient compare to walls with single layer of insulation (Vaseghi, 2018). Also, it has been shown that among concrete multilayer walls with single layer of insulation, placing insulation material more toward exterior surface increases the thermal performance of wall.

In this research hygrothermal analysis has been performed on a number of common concrete multilayer walls. The goal is to compare moisture contents (MC) of concrete layers in various multilayer walls to indicate the impacts of configurations and properties of materials on moisture performance of walls.

SIMULATION SETUP

In this study, hygrothermal analysis is conducted using WUFI® Pro a simulation program for evaluating moisture conditions in building envelopes in dynamic conditions. WUFI® Pro takes into account hygrothermal properties including built-in moisture, driving rain, solar radiation, long-wave radiation, capillary transport, and summer condensation. The simulations

are performed for 10 years of hourly climate data. The outputs include moisture content of concrete layers.

Multilayer Walls Design

Seven multilayer walls are presented in this section (Figure 1). The walls are chosen in such a way to be relevant to ASHRAE standard 90.1 and local building code. The multilayer walls include:

- A. Concrete wall with interior XPS insulation wall,
- B. Concrete wall exterior XPS insulation wall,
- C. Insulated concrete form (ICF) with XPS insulation board on the interior and exterior side of the wall,
- D. Split insulation wall with XPS insulation board on the interior and mineral wool insulation on exterior face of the wall,
- E. Split insulation wall with XPS insulation board on the interior and fiberglass on exterior face of the wall,
- F. ICF with EPS insulation board on the interior and exterior of the wall,
- X. Also, a bare concrete wall is considered as a reference case as well

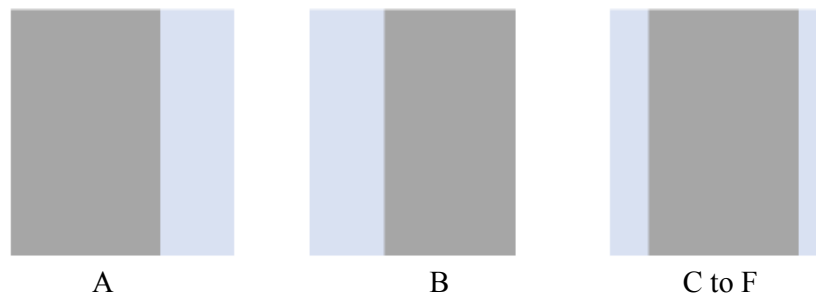


Figure 1. Schematics of multilayer walls, grey represents concrete and blue represents XPS

The hygrothermal properties of material are given as per WUFI material database. Some of the typical hygrothermal properties of the materials that are used in seven multilayer walls are described on Table 1. The total thickness of concrete layer is 0.20 meter while the total thickness of insulation layer for each individual multilayer wall is 0.10 meter.

Table 1. Hygrothermal properties of materials.

Material property	Concrete	XPS	EPS	Mineral wool	Fiberglass
Density (Kg/m ³)	2300	40	15	30	73
Porosity (m ³ /m ³)	18	0.95	0.95	0.99	0.95
Heat capacity (J/kg.K)	850	1500	1500	840	850
Thermal conductivity (kg/m.K)	1.6	0.03	0.04	0.035	0.032
Water vapour resistance diffusion factor (WVRDF)	180	100	30	1.3	1.1
Initial MC (kg/m ³)	150	0	0	0	0

Boundary Conditions

For the purpose of this study climate data of two locations of Vancouver and Winnipeg are considered. Vancouver represents a moderate oceanic climate (Köppen climate classification Cfb) while Winnipeg falls into the humid continental climate zone (Köppen Dfb). Simulation are done for south east elevation. For exterior vertical surface, heat transfer resistance of 0.0588 (K.m²/W) and for interior wall surfaces, the value of 0.125 (K.m²/W) are chosen. Short wave radiation absorptivity is equal to 0.4 while long wave radiation emissivity is 0.9.

WUFI built-in climate data contains global radiation, diffuse solar radiation, normal rain and interior and exterior temperature and RH.

RESULTS

Results are presented in Figures 2 to 4. Figure 2 represents annual wetting and drying performance of concrete layer over a 10-year period. Figure 3 illustrates total MC comparison of concrete layer for 10 years. Finally, Figure 4 demonstrates ratio of existent MC to initial MC of concrete (after 10 years of exposure).

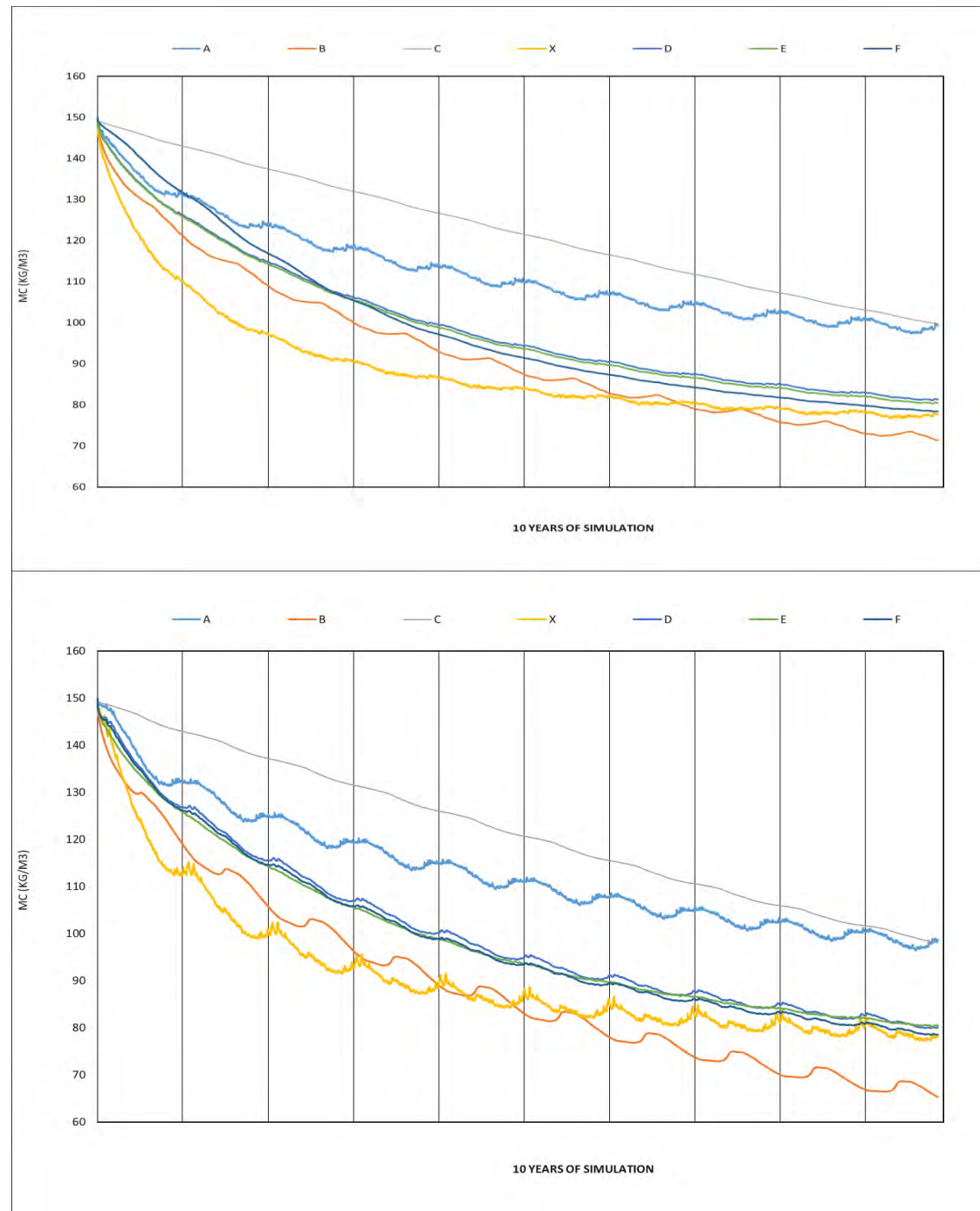


Figure 2. 10 years MC trends of multilayer walls (top: Vancouver, bottom: Winnipeg)

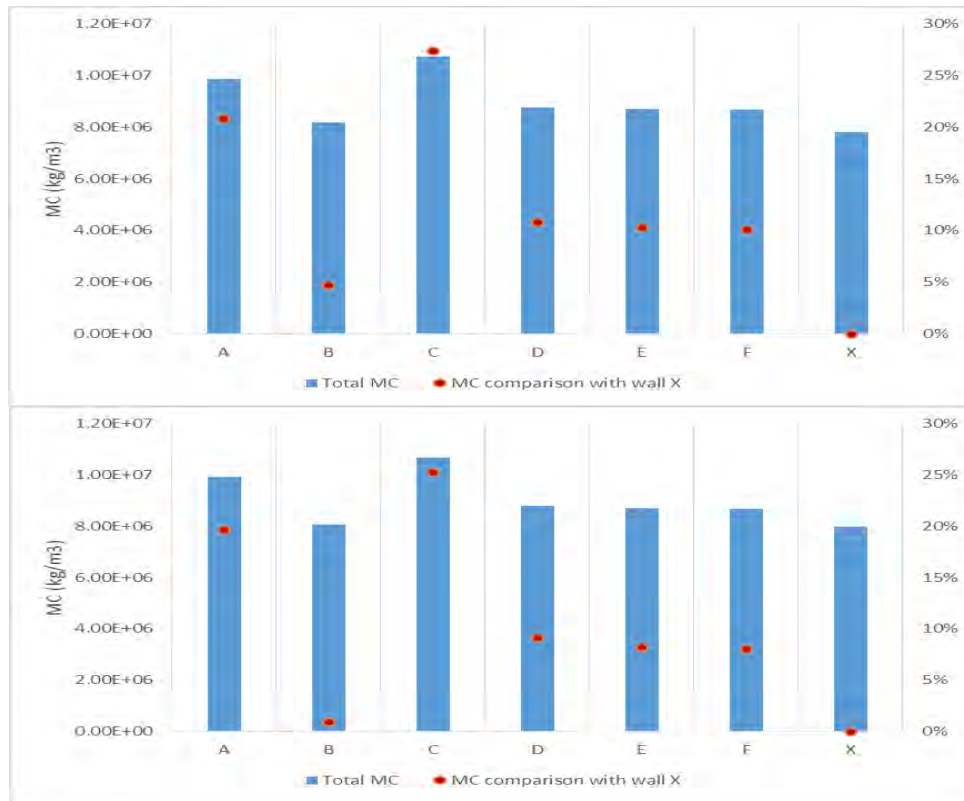


Figure 3. 10 years MC comparison of multilayer walls (top: Vancouver, bottom: Winnipeg)

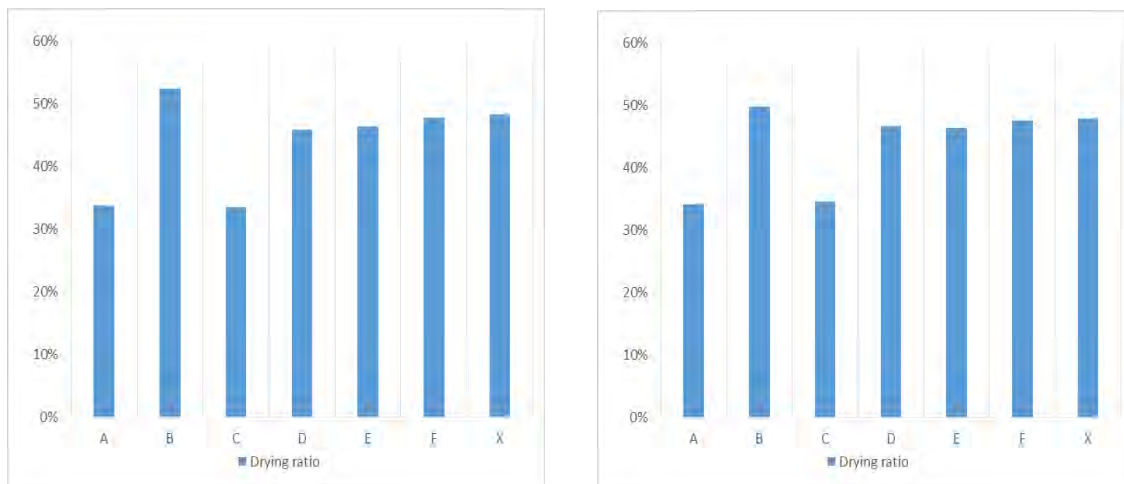


Figure 4. Drying performance ratio of multilayer walls (Left: Vancouver, Right: Winnipeg)

DISCUSSIONS

Studying the results for both climates indicates that wall “C” has the highest MC and the least drying ratio efficiency among the other walls. This is mostly due to the fact that concrete layer is sandwiched between the two low vapor permeable (high WVRDF) layers of XPS that limits the moisture flux and eventually drying potential toward exterior and interior sides of the wall. Following to wall “C”, wall “A” demonstrates fairly low drying performance too. Bare concrete layer in interior insulated wall is in direct exposure to frequent solar and rain which restricts the exterior drying potential. That likewise, explains the high fluctuation of its MC graph. Also, concrete is in direct contact with XPS on the interior side that reduces moisture flux toward inside. Walls “D” and “E” demonstrate a comparable hygrothermal behaviors.

Although both walls have a similar layers arrangement to ICF wall, however, the vapor open insulation materials on the exterior side of the walls increase the exterior moisture flux while protect the concrete layer from direct exposure to rain and wetness. Regarding total MC and drying behavior, wall “F” significantly performs better than wall “C” as EPS is more permeable compare to XPS which allows for more lateral drying potential. Wall “B” with exterior insulation has the best hygrothermal performance. Concrete layer in wall “B” is protected by XPS from rain deposition while it is exposed to interior condition that allows drying by vapor and surface diffusion. For the same reasons, drying performance ratio of wall “B” is slightly higher than reference wall. Although identical multilayer walls in both climates indicate similar wetting and drying trends, however multilayer walls located in Vancouver contain higher amount of MC. Solar heat gain of walls in much sunny weather of Winnipeg effectively increase their drying performance which result in lower existent moisture content compare to walls located in Vancouver.

CONCLUSIONS

Hygrothermal performance of six indivial concrete multilayer walls have been analysed. In contradiction with high thermal performance, multilayer concrete wall with two layers of XPS insulation has demonstrated the poorest moisture behaviour. This is an important factor for designers to take into consider that designing high thermal performance building envelope assemblies doesn’t necessarily lead to high efficient moisture performance or vice versa. The attention should be drawn to design building envelope details with “optimum performance” that consider all aspects of building science principles. Also, to increase the drying potential of ICF walls toward inside and outside space conditions, using material insulation with higher WVRDF are recommended. Overall, considering hygrothermal properties of building materials such as vapour permeability (WVRDF) along with their arrangement within the building envelope assemblies are key factors in a proper envelope design. Allowing for drying potential is only achievable by applying appropriate building materials and configurations.

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