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Impact of future climates on the durability of typical residential wall assemblies retrofitted to the PassiveHaus for the Eastern Canada region

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A R T I C L E I N F O

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A B S T R A C T

Attention to the global warming has influenced many aspects of human activities. Worldwide effort toward energy consumption reduction in building sector is one of the areas affected by climate change. Building regulations demand the building construction industry to be more energy efficient. Studies have been carried out on the thermal performance of energy efficient buildings under future climates, while studies on the durability of energy efficient building envelopes over future climates are limited. This study assesses the impact of future climates on the durability of typical Canadian residential wall assemblies retrofitted to the PassiveHaus over the current, 2020, 2050, and 2080 climatic conditions for Montreal. The durability performance is evaluated in terms of the frost damage risk of bricks and the biodegradation risk of plywood sheathing through simulations using WUFI Pro program. The future weather files are generated based on weather data recorded at the Montreal International Airport weather station using General Circulation Model HadCM3 based on the A2 emission scenario by the Intergovernmental Panel on Climate Change. This study concludes that upgrading wall assemblies to the PassiveHaus recommended level would increase the frost damage risk of bricks, however, this risk would decrease under 2080 climatic conditions. While the decay risk of the plywood sheathing would decrease, the mould growth risk defined by RHT criteria would increase over future climates. Under future climates, mould growth risks of the plywood defined by the mould growth index exist only when rain leakage is introduced and would likely decrease for the double-stud assembly.

1. Introduction

Recent effort toward greenhouse gas emission reduction to address climate change issue requires many sectors to be more energy efficient. One of these sectors that are mainly influenced by the global climate change is building sector, which aims not only to reduce the energy consumption but also to enhance building designs to be more adaptive to the climate change. Globally the building construction and their operation accounts for a large proportion of primary energy consumption. Simons [1] found that building sector consumes four and seven times more energy than the commercial and public administration sector, respectively.

Several studies demonstrated that the housing stock turnover is low at around 1–1.5% worldwide [1–4]. The Sustainable Development Commission predicted that by 2050 about 70% of the housing stock in the UK has already been built [5]. Therefore, energy efficient retrofitting of existing buildings, particularly housing stock, would significantly reduce the energy consumption of the building sector worldwide. With regard to this, higher energy efficiency has been set in building codes in Canada and the USA in recent years. Beyond various energy codes that have been set worldwide, the German standard entitled PassiveHaus (PH), which attempts to reduce energy consumption by 90% within dwellings, is gaining popularity in North America [6,7]. This high level of energy reduction requires highly insulated building envelopes and high efficiency of heat recovery ventilation systems. While the standard aims to increase both thermal comfort and energy saving, there is a potential risk and uncertainty about the performance of houses built to the PH standard under the future climatic conditions.

The impact of future climates on the building performance have been investigated in recent years with the majority of studies focused on the future heating and cooling demand of buildings

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[8–22]. Most of these studies concluded that the heating demand would likely decrease over the future climates, while the cooling demand would likely increase. Several studies also evaluated the building indoor temperature and thermal comfort under future climates [9,17,23–29] and the general conclusions were that over the future climates the neutral comfort temperature would likely increase in the summer, while remain the same in the winter.

There are limited studies on the impact of future climates on the durability of buildings, especially for North America. A few studies on the durability of building envelopes under future climates for European countries have been reported [15,16,30]. Nijland et al. [15] concluded that the higher temperature and higher precipitation under future climates would decrease the number of freeze thaw cycles on porous materials, however, these conditions would likely speed up the biodegradation for timber, stony materials, and coatings. Grossi et al. [16] investigated the freeze thaw risk of porous materials for a number of European cities under the future climates. Their study concluded that the frost damage on the porous stone used in monuments of temperate areas would remarkably decrease over the future climates. Colio et al. [31] predicted that in the future temperature, precipitation and windiness would likely increase, consequently, facades would likely receive more driving rain. Nik et al. [30] assessed the impact of future climates on the mould growth risk in ventilated attics for Sweden through hygrothermal simulations for the period of 1961–2100 using RCA3 regional climate model (RMC) and the Intergovernmental Panel on Climate Change (IPCC's) A2, A1B, and B1 emission scenarios. The study concluded that the potential risk of mould growth would increase over the future climates. However, changing the emission scenarios would not change the mould growth risk of the attic.

The objective of this paper is to assess the durability of typical Canadian above grade wall assemblies retrofitted to the PH level under Montreal's current and future climatic conditions. The potential freeze thaw risk of brick and the biodegradation risk of plywood sheathing are used as the indicators for the assessment of durability performance. The following sections present methodology, results and discussion, and conclusions.

2. Methodology

Two existing above grade exterior wall assemblies are considered as the base assemblies for retrofitting. One assembly is the common Pre-World War II solid masonry construction and the other is the common Post-War 2″ × 4″ (38 mm by 89 mm lumber) wood frame construction. The solid masonry is retrofitted from the interior using two types of insulations, i.e. sprayed polyurethane foam and extruded polystyrene board to achieve an effective thermal resistance of 6.5 m^2k/W. The 2″ × 4″ wood frame wall is retrofitted using double stud with 89 mm gap between studs filled with fiberglass batt insulation to achieve an effective thermal resistance of 6.8 m^2k/W. Durability is investigated in terms of the freeze thaw risk of the brick and biodegradation of the plywood sheathing in wood-frame assemblies. The Frost Decay Exposure Index (FDEI) and the co-occurrence of relative humidity above 95% and crossing point (RHCP) are used as the performance indicators for freeze thaw risk of brick. The biodegradation risk of plywood is assessed using three criteria: 1) moisture content level above 20%; 2) relative humidity above 80% with temperature above 5 °C (RHT), and 3) mould growth index. Hygrothermal simulations are carried out using WUFI Pro 5.1. Detailed hourly weather data is generated for 2020, 2050, and 2080 based on weather data collected at Montreal International Airport.

2.1. Meteorological data

In this study future weather data used for durability assessment is generated by Climate Change Weather File Generator program 'CCWeatherGen' proposed by the Sustainable Energy Research Group at the University of Southampton [32] based on the WYEC2 hourly weather file provided by the Environment Canada at the Montreal International Airport (latitude of 45.4°N, longitude of 73.4°W, and elevation of 36 m). The widely accepted General Circulation Models (GCM) HadCM3 and the IPCC's A2 emission, which represents a medium–high scenario, are used. Fig. 1 plots the dry bulb temperature and Fig. 2 plots the relative humidity for the current and future years at Montreal International Airport.

As shown in Fig. 1, the dry bulb temperature in Montreal would increase over future years. Fig. 2 projects that the relative humidity would decrease over spring to fall under future climates. CCWetherGen programme does not predict the amount of rainfall for future years, however, the hourly rainfall data is an essential element of the detailed hygrothermal analysis for assessing the durability performance of building envelopes. Future rainfall data is created based on literature predicting future precipitation for Montreal region. The detailed procedure of generating hourly rainfall data is provided in Section 2.2 and Section 2.3.

2.2. Selection of base year for rain data

To choose the most reasonable year as the base year for future rain data generation, available hourly weather data collected by Environment Canada [33] between 1953 and 1994 are analysed in terms of the annual rainfall amount and annual airfield wind-driven rain (WDR) index (I_A). The airfield WDR index is the amount of WDR passing through an imaginary vertical plane in the airfield without the interaction with buildings. It is an indication of the level of exposure of building façade to wetting, which is a significant parameter influencing the durability performance of building envelope assemblies. The annual airfield WDR index is calculated following the ISO standard (*Equation* 1 [34]).

$$I_A = \frac{2}{9}\frac{\sum U \cdot R^{8/9}\cos(D-\theta)}{N} \tag{1}$$

Where, I_A is expressed in L/m^2a (a = annual), U is the unobstructed streamwise mean wind speed in m/s; R is the horizontal rainfall intensity in mm/hr; and, θ is the wind direction, D is the orientation of the façade, and N is the number of years of available data. To be representative of the climate, at least 10 years' data is required for calculating the annual airfield wind-driven rain. In this paper, the purpose is to compare the WDR exposure among different years, therefore, the airfield WDR is calculated for each year and N is taken as 1.

The airfield WDR is calculated for twenty-five orientations between 0 and 345° with an interval of 15° and the maximum airfield WDR at a specific orientation is identified for each year. Fig. 3 shows the airfield WDR calculated between 1953 and 1994 for Montreal International Airport. As shown in Fig. 3, the airfield WDR varies significantly with orientation over different years. The prevailing WDR direction is more towards the Southwest and the Northeast. Table 1 lists the maximum amount of WDR and the maximum annual rainfall for each year and the corresponding ranking between 1953 and 1994.

As shown in Table 1, year 1973 has a high annual rainfall amount of 842 mm (2nd rank among all years) and high amount of airfield WRD 406.1 (5th rank among all years) at 60° orientation, therefore, it is chosen as the base year for generating future rain data. Historically, at the Montreal International Airport the prevailing WDR