An Experimental Framework for Investigating the Hygrothermal Properties of Multi-Functional Wood Fibre and XPS Panels for Residential Buildings

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ABSTRACT

In this paper, an experimental setup developed for an ongoing project to investigate the hygrothermal performance of wall systems under different climate conditions is presented. As a step toward establishing the hygrothermal performance of various wood-frame wall assemblies, this research focuses on field experimentation of two types of multi-functional panels (MFPs), along with a conventional wall assembly, in two different locations in Canada: Vancouver, British Columbia, and Edmonton, Alberta. The three wall assembly types are adjacent to one another along the north- and south-facing walls of the test huts in the two cities. This experiment focuses on the effect of the various ambient weather conditions on the two innovative MFPs and on the conventional wall assembly, and on determining the long-term hygrothermal performance of the tested assemblies; it also establishes the passive solar effect on the south-facing assemblies compared to the corresponding north-oriented assemblies. Both MFPs are fixed on the exterior side of a conventional wood-frame wall assembly. The components of the first MFP are 6.4 mm Oriented Strand Board (OSB), 40 mm wood-fiber insulation—an environmentally-friendly and fully recyclable material—and 6.4 mm OSB, while those of the second MFP are 6.4 mm OSB, 25 mm Extruded Polystyrene (XPS) core, and 6.4 mm OSB. Along with the details of the experimental setups, some sample data is presented.

KEYWORDS

Multi-functional panels; Wood-frame wall assemblies; Experiment; Thermal Resistance; Long-term field monitoring.

INTRODUCTION

Worldwide, it has been measured that more than 40% of energy consumption occurs in residential and non-residential buildings during the operational phase (Lemmet, 2009). In Canada, there are more than 11.5 million houses, and more than 70% of those houses are single-family, duplex, and low-rise condos (Stock, 2011). Over the last few decades, owners and regulatory authorities have become more concerned about high energy-efficient houses to decrease residential energy consumption. Today, several national programs are focusing on improving the energy efficiency of housing and relevant standards. A building is considered a high performance building if it is energy efficient and durable, and also provides comfort and a healthy indoor environment for the occupant (Tariku, 2014). The Eco Energy program was part of Canada's Economic Action Plan from April 2007 to March 2012; it has supported technology innovation and its initiatives are on-going for Aboriginal and Northern Communities (N.R. Canada, 2014). Energy Star certification began in 2005 and since then new houses in Canada could receive an ENERGY Star qualification which promotes energy-efficient building technologies (Energy Star, 2015). The energy performance of a building envelope is a frequent topic of discussion and research. For example, ENERGY STAR guidelines feature walls and ceilings that are insulated beyond building code requirements (Li, 2016). An enclosure's thermal performance within a house should be optimized to be considered energy-efficient since the thermal performance is one of the most important aspects of an energy-efficient building envelope. ASHRAE-90.1 Standard (ASHRAE, 2007) has specified the energy performance requirements for buildings for different climate zones. Edmonton, Alberta lies within the range of 5,000 to 6,000 Heating Degree Days (HDD) (ASHRAE, 2007; Awad et al., 2014). In climate zones of 5,000 to 7,000 HDD, ASHRAE-90.1 Standard (ASHRAE, 2007) recommends a minimum assembly R-value (RSI) for wood-frame buildings of R-19.6 (in SI unit 3.45). Field experiments (Carmeliet et al., 2012) and numerical simulation (Evrard, 2010) are commonly used to investigate the hygrothermal performance of different building components. Awad et al. (2014) investigated the long-term thermal and structural performances of innovative mid-rise wood-frame wall systems. In this study different wall-assembly configurations such as staggered and I-Joist wall systems, along with the conventional wall system, were tested for their in-situ long-term thermal performance. Li et al. (2016) conducted a long-term field testing of the hygrothermal performance of five wood-frame wall systems with different types of insulation under both field testing and occupied conditions. Sassine et al. (2016) proposed a practical method for the thermal characterization of walls based on complex Fourier to determine the thermal capacitance and the thermal conductivity for a building wall. In this experiment the researchers installed indoor and outdoor temperature sensors and an outdoor heat flux sensor where the data was collected and recorded at time intervals of 20 minutes.

However, even though there are numerous experiments that investigate the hygrothermal performance of different building components, the significance of this ongoing research is that it investigates the hygrothermal performance of two multi-functional panels (MFPs) along with the conventional wall assemblies under the varying conditions of orientation (north and south), geographic location (Edmonton and Vancouver), and location within the same wall (middle and edge). The specific goals of the current paper are to describe the experimental setup and understand the methodology of the hygrothermal investigation of two types of MFPs. In this research, two different huts in Edmonton and Vancouver are used as experimental setups. Two different types of MFPs are installed in the north and south directions of the test huts. In these test huts, temperature, heat flux, moisture content, relative humidity, wind speed, solar radiation, atmospheric pressure, and precipitation are being measured and this data will be used to analyze the hygrothermal performance of the MFPs.

EXPERIMENTAL SET-UP AND IMPLEMENTATION

(a) (b)

Figure 1. Test hut in (a) Vancouver and (b) Edmonton.

Test Hut

Two demonstration buildings (test huts) are erected, making it possible to evaluate the panels' performance under real situations, in the humid coastal climate of Vancouver in Figure 1 (a), and the cold climate of Edmonton in Figure 1 (b). The 7.62 m x 3.66 m demonstration buildings are sheathed with innovative MFPs. The above mentioned test huts were constructed to demonstrate the in-service performance of the products. There are two types of MFPs: (1) A-type MFP consisting of 6.4 mm Oriented Strand Board (OSB), 40 mm wood-fiber insulation—an environmentally-friendly and fully recyclable material—and 6.4 mm OSB; and (2) B-type MFP consisting of 6.4 mm OSB, 25 mm Extruded Polystyrene (XPS) core, and 6.4 mm OSB. Both MFPs are fixed on the exterior side of a conventional wood-frame wall assembly. These MFP panels are installed on the exterior side of the north and south walls of each test hut. Each wall side has five wall panels: two A-type, two B-type, and one conventional wall panel (also named a C-type panel). Unlike the A- and B-type wall panels, the C-type panel does not contain any MFPs attached to its exterior side. Figure 2 is a demonstration of the actual test hut wall panel configuration. An overview of the positions of the temperature, moisture content, relative humidity, and heat flux are also shown in Figure 3. The detailed sensors configuration within each wall panel is discussed in detail in the following section. The naming of each wall panel in Figure 3 defines the wall's orientation (N stands for north and S stands for south), order within the same wall (1 to 5 from west to east), and wall panel type (A-, B-, or C-type).

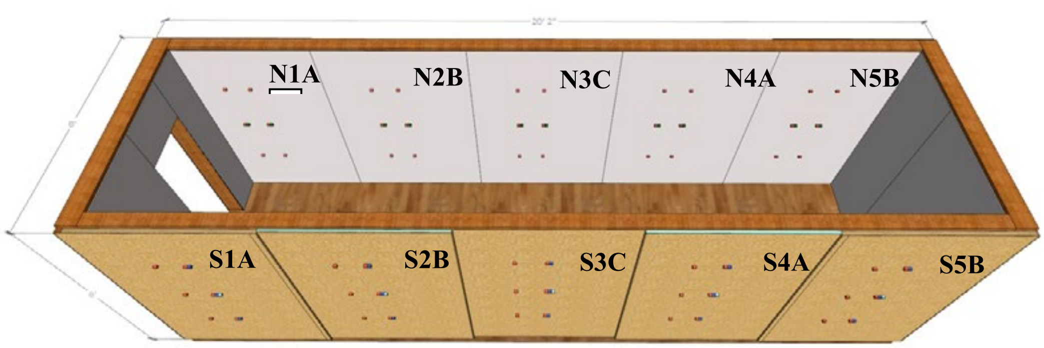

Figure 2. A 3-dimensional demonstration of wall panel positions in a test hut and sensor locations. The naming of each wall panel stands for orientation, order within the wall, and panel type.

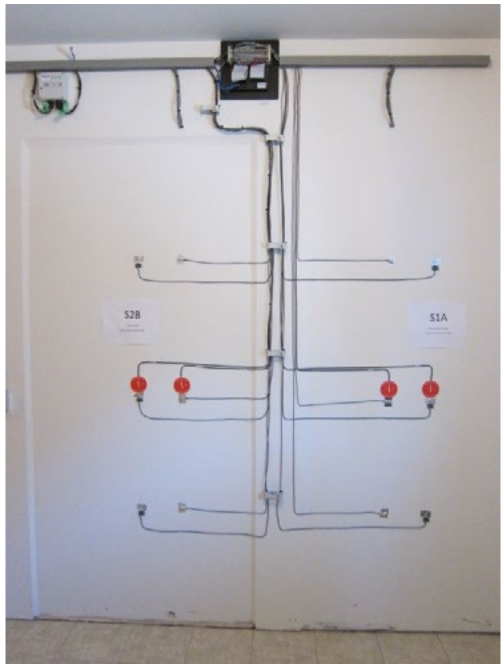

Figure 3. Installed sensors inside the hut.

Sensor and data log system

Each of the two test huts is identically monitored under controlled conditions, and is equipped with an under-floor heating system and an air conditioning unit, in addition to the installed sensors that will be explained in detail later in this section. The red (temperature), blue (moisture content), and white (heat flux) marks in Figure 2 and Figure 4 demonstrate the sensors installed on the interior, middle, and exterior sides of each wall panel. The sensors located in the middle layer of insulation are not shown in Figure 2, but are better demonstrated in Figure 4. Sensors are installed at three different heights (lower, middle, and upper levels) on each panel. For the hygrothermal investigation, two heat flux, 15 temperature, and nine moisture content sensors are installed (Table 1); also, each test hut is equipped with a weather station which monitors the ambient outdoor temperature, solar radiation, precipitation, atmospheric pressure, and relative humidity. The monitored data is collected at a time interval of 30 minutes and stored on the online database which is made for this experiment by which the research team can access the data off-site. Sensor type and quantity as well as total number of sensors installed in the test huts for the experimental setup are given in Table 1.

Table 1. Sensor type and quantity used in experimental setup.

Sensor Type	Qty in each test hut	Total quantity
Independent temperature sensors	66	132
PMM, point moisture measurement (with temperature sensor)	88	176
Cavity relative humidity & temperature	15	30
Heat flux	20	40
Long pin sets	4	8
Weather station	1	2

Data Analysis

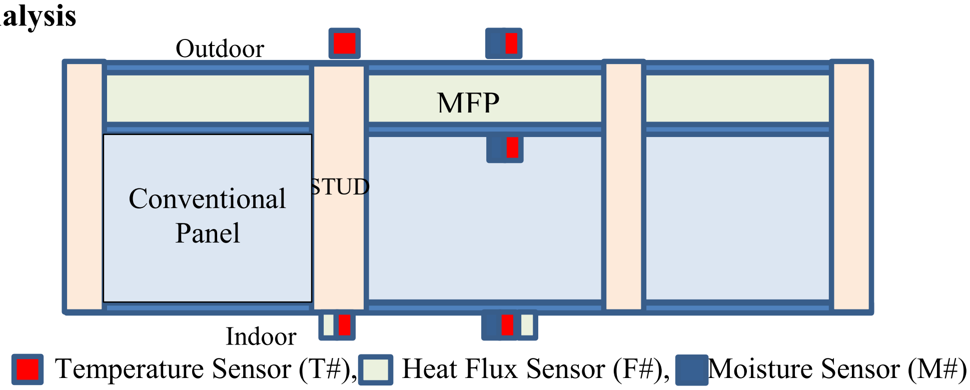

Figure 4. Top view of the MFP panel with conventional panel and sensors.

It is recommended by the American Society for Testing and Materials (ASTM, 2007) to maintain a constant temperature on the interior side of the wall, and a significant difference between the indoor and outdoor temperatures for rapid convergence. Each of the test huts is equipped with an underfloor heating system and an air conditioning unit to comply with this recommendation. Each wall panel has three sensor positions/levels at its cavity: at the lower, middle, and upper levels of the wall panel, and two sensor positions at its stud: at the lower and upper levels of the wall panel. Figure 4 shows that the RSI value of each MFP and the conventional (main) panel can be measured separately by using the collected data. The studs and cavities have different sets of sensors, and the RSI values for cavity and stud are measured separately and then combined into stud-to-cavity ratio to obtain the overall RSI value of the wall panel. Data from January, 2016 to May, 2016 have been considered for demonstration.

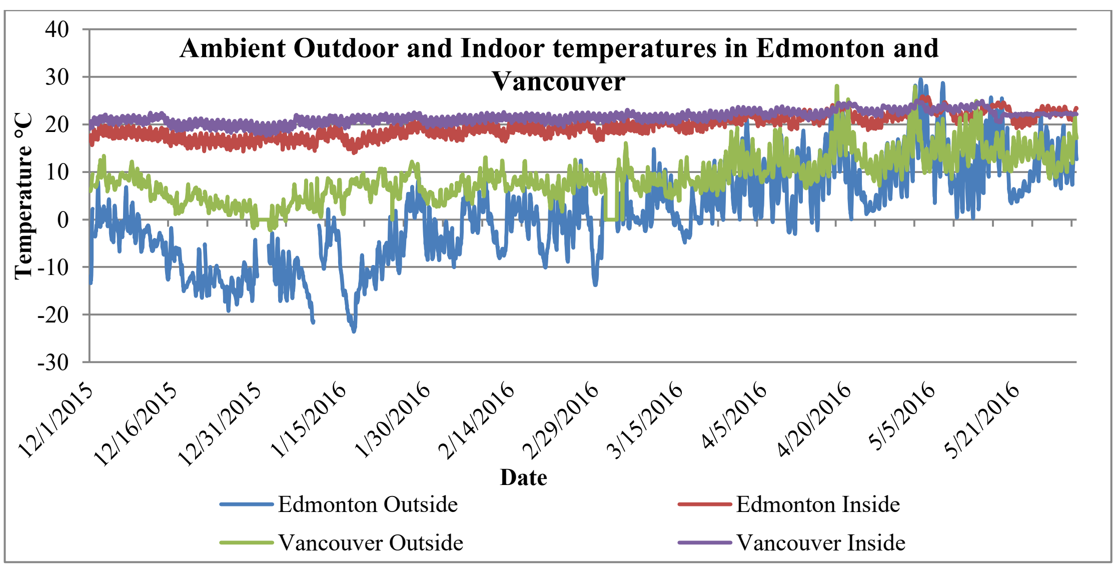

Figure 5. Ambient indoor and outdoor temperatures in Edmonton and Vancouver.

In Figure 5, the indoor and outdoor temperatures in the Edmonton and Vancouver test huts have been shown. The differential temperature and corresponding heat flux values are then used to calculate the RSI values in the future stages of this project. A sample data from the Vancouver test hut is collected and demonstrated in this section. One wall panel, an A-type wall panel at the middle of the north wall of the Vancouver test hut (namely V_N4A), has been selected to illustrate the ambient temperatures (Figure 6), indoor and outdoor surface temperatures (Figure 7), and heat flux profiles in the time period between January, 2016 and May, 2016.

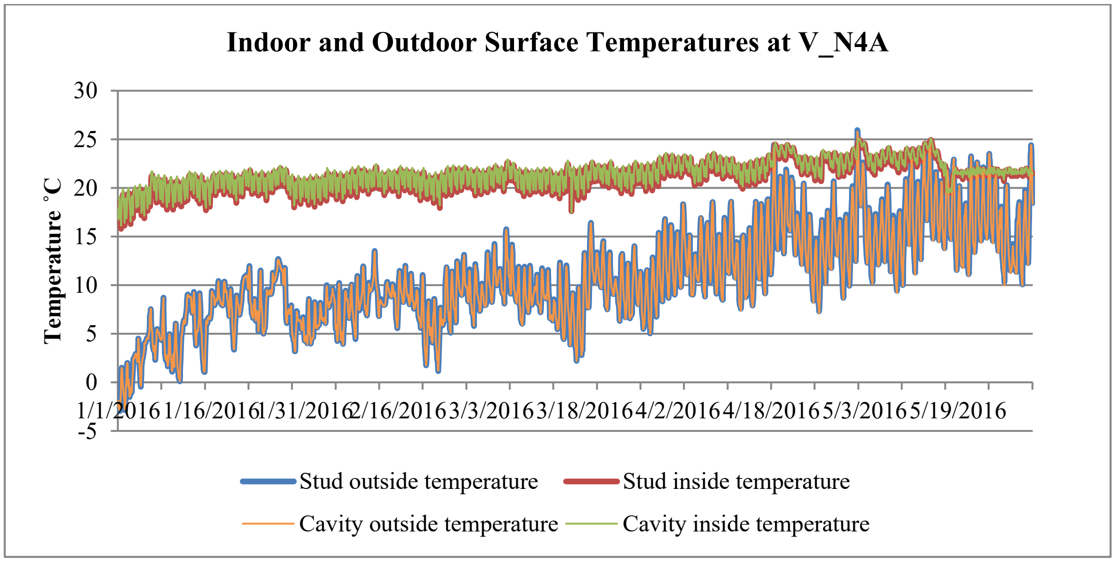

Figure 6. Outdoor and Indoor surface temperatures of A-type wall panel located at the middle of the north wall of Vancouver test hut.

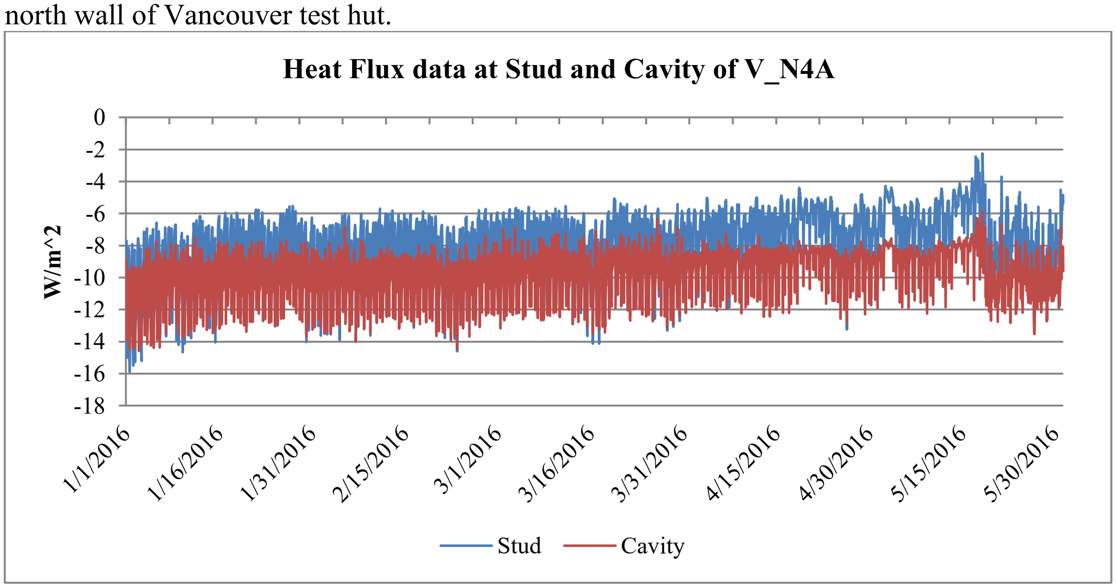

Figure 7. Stud and Cavity heat flux data of A-type wall panel located at the middle of the north wall of Vancouver test hut.

Figure 7 shows that the heat flux at stud and cavity vary widely due to the fact that wood (stud) has a significantly higher thermal conductivity than the insulation (cavity). Figure 8 shows one example of inside-the-cavity temperature and moisture content ratio.

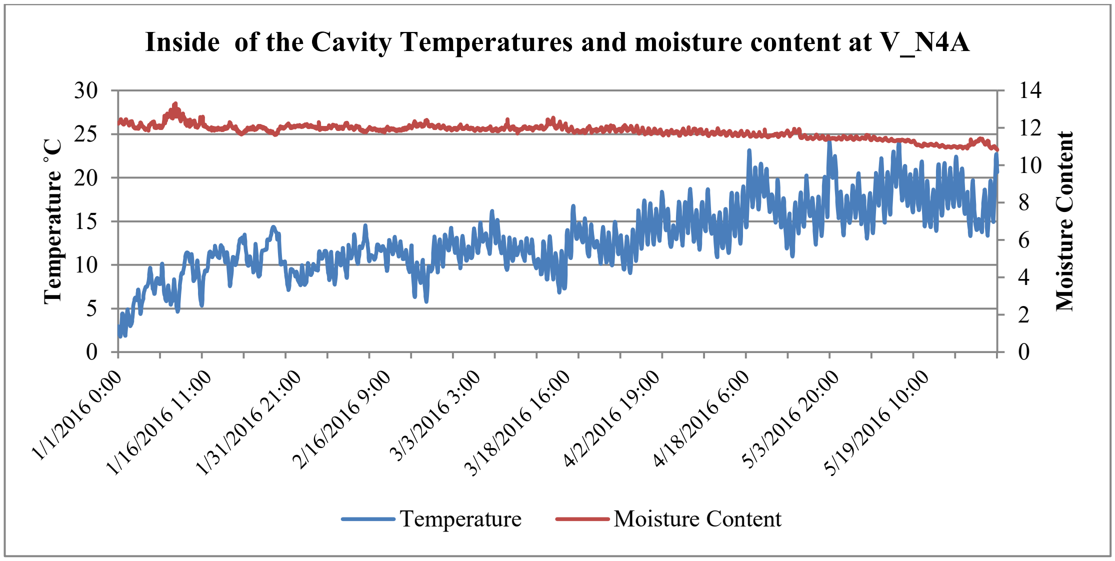

Figure 8. Inside cavity temperature and moisture content ratio of A-type wall panel located at the middle of the north wall of Vancouver test hut.

DISCUSSION AND CONCLUSION

In this paper, the experimental setup of the two multi-functional panels (MFPs) is discussed and different hygrothermal parameters are measured. RSI values will be calculated in the future stages of this project by using the monitored temperature and heat flux data which helps to analyse the thermal performance of each wall panel. On-going investigation of humidity inside and outside of the panel is conducted to understand the moisture characteristics of the wall panel components. Correlation between wind speed, precipitation, solar radiation, and atmospheric pressure with the MFPs' hygrothermal performance can be obtained from the experimental setup. These will help to analyse the optimum performance and damage factors of the MFPs. January, 2016 to May, 2016 data are used to demonstrate a sample data and discuss some preliminary findings. This is an on-going project, and future studies will discuss the project results and finding in detail. This experimental setup has been installed to investigate and analyse the hygrothermal performance of the abovementioned MFPs.

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