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Experimental Quantification of Thermal Effects in Heritage Masonry Buildings

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ABSTRACT

Although for centuries, the vast majority of residential buildings have been built using massive wall technologies, information regarding the effects of thermal mass on building performance including thermal comfort, resiliency, durability and energy consumption are not well known and the information is all over spread. While it is generally accepted that buildings in warmer climates benefit most from using more thermally massive constructions, there are conflicting statements on whether it also provides significant benefits in colder climates like Canada. In this paper, the experimental investigation of a research group in Manitoba to assess the thermal effects of heritage buildings is discussed. The investigation consists in the construction and the monitoring of three huts built at the Notre Dame Campus of RRC Polytech. Manitoba Masonry Institute (MMI) with the collaboration of the Building Efficiency Technology Access Centre (BETAC) at RRC Polytech and the University of Manitoba. The huts were constructed with different building envelope systems.

KEYWORDS

Thermal efficiency, Thermal mass, Heritage masonry, Building envelope.

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INTRODUCTION

According to a 2001 survey, most people spend about 90% of their lives indoors [1]. About 50% of the energy utilized in residential and commercial buildings is absorbed by cooling and heating systems [2]. Growing concerns about sustainability of natural resources and the effect of greenhouse gas emissions (GHG) has raised awareness about the low efficiency of building energy performance. As a consequence, centralized and local governments around the world have invested several resources to reduce energy consumption nationally, with the aim at improving the sustainability of our living standards and reducing the consumption of natural resources. Therefore, mitigating energy consumption has become an important task of building performance. Several techniques have been developed to efficiently reduce energy consumption for cooling and heating operations in residential and commercial buildings. Among these approaches, passive thermal control methods, such as thermal energy storage systems, reduce energy consumption by balancing the temperature of a closed environment over a given period of time [3]. Thermal mass is defined as the ability of materials to absorb, store and release heat. Thermal mass materials, such as water, earth, bricks, wood, rocks, steel and concrete act as heat sinks in warm periods and as heat sources during cool periods. High thermal mass materials maintain indoor temperatures within desirable ranges without extreme energy consumption. While it is generally accepted that buildings in warmer climates benefit most from using more thermally massive constructions, there are conflicting statements on whether it also provides significant benefits in colder climates like Canada. Therefore, additional research is needed to clarify this aspect in cold climates, such that future editions of Canadian building energy standards could provide more robust guidelines for the design and the evaluation of buildings to help reaching the challenging Canada's Net-Zero emissions goal by 2050. On this premises, a joint effort between the Building Efficiency Technology Access Centre (BETAC), the Canadian Concrete Masonry Producers Association (CCMPA), Crosier Kilgour & Partners Ltd., the University of Manitoba, and the Manitoba Masonry Institute (MMI) aims at assessing the impact of thermal mass on building durability and energy efficiency using an experimental setup. The information gathered from this research effort will hopefully improve the state of knowledge on thermal mass effects to reduce energy performance gap, and provide a better characterization of the thermal mass's physical parameters that could be potentially implemented into future editions of Canadian building energy codes and simulation packages.

In this paper, the experimental setup and the adopted instrumentation to achieve the aforementioned objectives are discussed.

HUTS CONFIGURATION

Three test huts were built at the Red River College Polytechnic (RRC Polytech) located in Winnipeg, Manitoba which is located in the international Climate Zone 7A according to National Energy Building Code of Canada [4]. This region represents a significant portion of populated Canada. The three test buildings were constructed to reflect typical Canadian buildings envelopes; The first test hut has a steel stud wall structural back-up, finished in painted drywall with exterior gypsum sheathing, air/vapour barrier membrane, 100 mm rigid XPS insulation (R20), 25 mm air space and dark red brick veneer. The second test hut envelope is realized with a 200 mm Concrete block (CMU) structural back-up wall system within interior drywall finish, air/vapour barrier membrane applied to exterior surface of block, 100 mm rigid insulation, XPS (R20), 25mm air space and same dark red masonry veneer. The third and final hut was built with bonded masonry dark red brick veneer wall bonded to block wall (CMU) back-up with no insulation, typically found on warehouse and some heritage buildings. A painted parging was applied to the interior face to acts the wall systems air barrier. All test buildings are constructed on a reinforced concrete thickened edge slab-on-grade. Roof system comprises of, a wood joist/metal clad roof with XPS insulation and air-vapour barrier. Penetrations through the envelope are kept to a minimum and only one insulated door is used for interior access to the buildings. The three buildings were blower-door tested for qualitative and quantitative air leakage assessments. Any points of air leakage were sealed to ensure that the differences in quantified air leakage was less than 10% across all three buildings. The characteristics of the hut's envelopes are summarized in Table 1.

Table 1: Testing huts envelope characteristics

Insulated Masonry hut (1)	Heritage Masonry hut (2)	Steel stud hut (3)
100 mm Brick veneer	100 mm Brick veneer	100 mm Brick veneer
25 mm Air gap	20 mm Air gap	25 mm Air gap
100 mm Rigid insulation	200 mm Concrete block	100 mm Rigid insulation
Air vapour barrier	Cement coating	Air vapour barrier
200 mm Concrete block	-	Drywall sheet
Drywall sheet (interior)	-	150 mm steel studs
-	-	Drywall sheet (interior)

Figure 1: Testing huts during construction.

INSTRUMENTATION

The three test huts are equipped with several sensors and a data acquisition system to measure the energy efficiency of the envelopes. Specifically, the north, south and west wall of each hut was equipped with a HTM-2500LF capable of measuring the temperature and the relative humidity of the wall on the interior and exterior surface, respectively. The HTM-2500LF sensor was placed approximately on the centre of each wall as shown in Figure 2a).

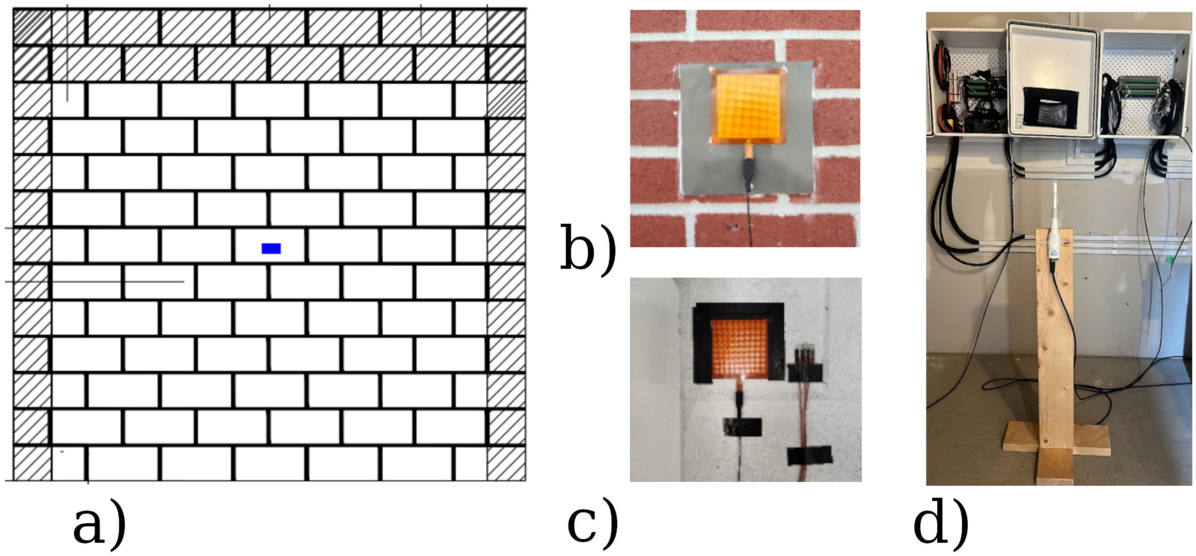

Figure 2: Sensors and location on walls.

Two heat flux readers FHF05 were installed on the interior and exterior side of the north wall to measure the flux in each direction as shown in Figures 2.b and 2.c. The north wall was chosen as a location because of its reduced sensitivity to solar radiations compared to other exposures.

Finally, the interior and exterior surface of the east wall were the entrance to the huts is located is equipped with TC-K ECON bolt surface thermistor to measure the temperature of the remaining wall. A similar sensor was installed approximately at the centre on the interior and exterior surface of the roof and on the interior of the floor slab to measure the temperature of the horizontal confinements of the huts. Additionally, a temperature and relative humidity sensor was also installed at the centre of the internal room as a probe as shown in Figure 2.d.

The three test buildings have been equipped with heating and cooling systems that were designed and installed heat pump systems are used for cooling the huts, while electric baseboards are used for heating. Measuring the energy consumption of the baseboards is straightforward, as it is not influenced by external climate conditions, unlike the energy consumption of heat pumps, which varies with exterior temperatures. The test buildings will be monitored for their heating and cooling loads for a period of three years to capture comparative data for each season and long-term effect. The design of the sensor suite and associated data acquisition have been designed in collaboration with our industrial partner Crosier Kilgour & Partners Ltd. It is generally accepted that heat will penetrate up to 100 mm into concrete during a 24-hour heating and cooling cycle. However, for longer cycles, i.e. that experienced during an extended period of hot weather, greater depths can be advantageous as the increased heat capacity delays or avoids the concrete becoming saturated with heat. The main criteria used to evaluate the effect of wall thermal mass on the thermal performance of the test buildings are heating energy and heater capacity, which affect heating costs, overheating frequency, which is used as a measure of discomfort and heating load profile, which also affects energy, costs in electrically heated houses.

To collect the necessary energy consumption data from the baseboard heaters during the heating season, a CS11 current transformer was selected due to its robustness and simplicity. As a data logger, a Campbell Scientific CR1000X was chosen which can automatically adjust the current amperage for the correct reading of the current in the heating system.

The HOBO Link weather station was chosen to gather information on environmental parameters such as external temperature, rain fall and solar radiation. Specifically, the current environmental parameters to be collected are solar radiation, wind, precipitation, wind chill, temperature, environmental relative humidity, barometric pressure and soil temperature and moisture. This station is simple and flexible. If additional environmental parameters are required, sensors can be easily added to the system.

PRELIMINARY RESULTS

Figure 3 shows the configuration of the typical wall system for each hut, while Table 2 summarizes the thermal conductivity and size of each component. Columns 5, 6, and 8 of Table 2 also show the thermal resistance of the components and that of the wall in series. The values of the thermal resistance in the table indicates that walls of huts 1 and 3 exhibit similar thermal resistances due to the insulated layer, while that of Hut 2 is about 4.4 times smaller.

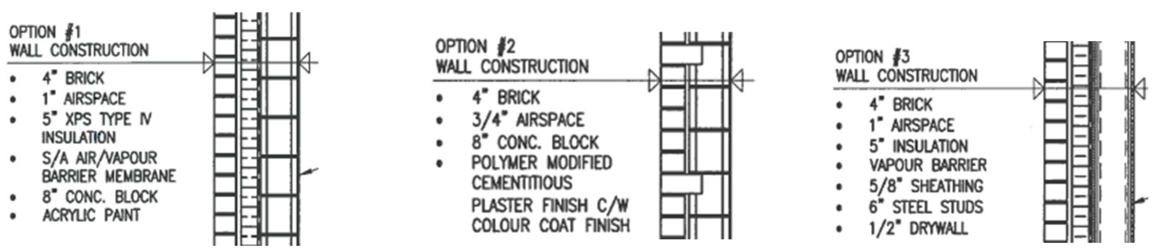

Figure 3: Wall section of hut (1), hut (2) and hut (3).

Table 2: Thermal Resistance of different huts.

Materials	Thermal Conductivity (W/m. C)	Hut (1) Thickness (m)	Hut (1) Resistance (C.m²/W)	Hut (2) Thickness (m)	Hut (2) Resistance (C.m²/W)	Hut (3) Thickness (m)	Hut (3) Resistance (C.m²/W)
Brick	0.72	0.10	0.14	0.10	0.14	0.10	0.14
Air Space	0.02	0.02	1.00	0.02	1.00	0.02	1.02
Insulation	0.03	0.13	4.33	-	-	0.13	4.33
Sheathing	0.18	-	-	-	-	0.02	0.11
Steel Studs	50	-	-	-	-	0.15	0.00
Drywall	0.20	-	-	-	-	0.01	0.05
Concrete Blocks	1.4	0.20	0.14	0.20	0.14	-	-
	-	-	**5.61**	-	**1.28**	-	**5.65**

Figure 4 shows the distribution of the internal and external temperatures for the three huts over 48 hours between February 9 and 10, 2025.

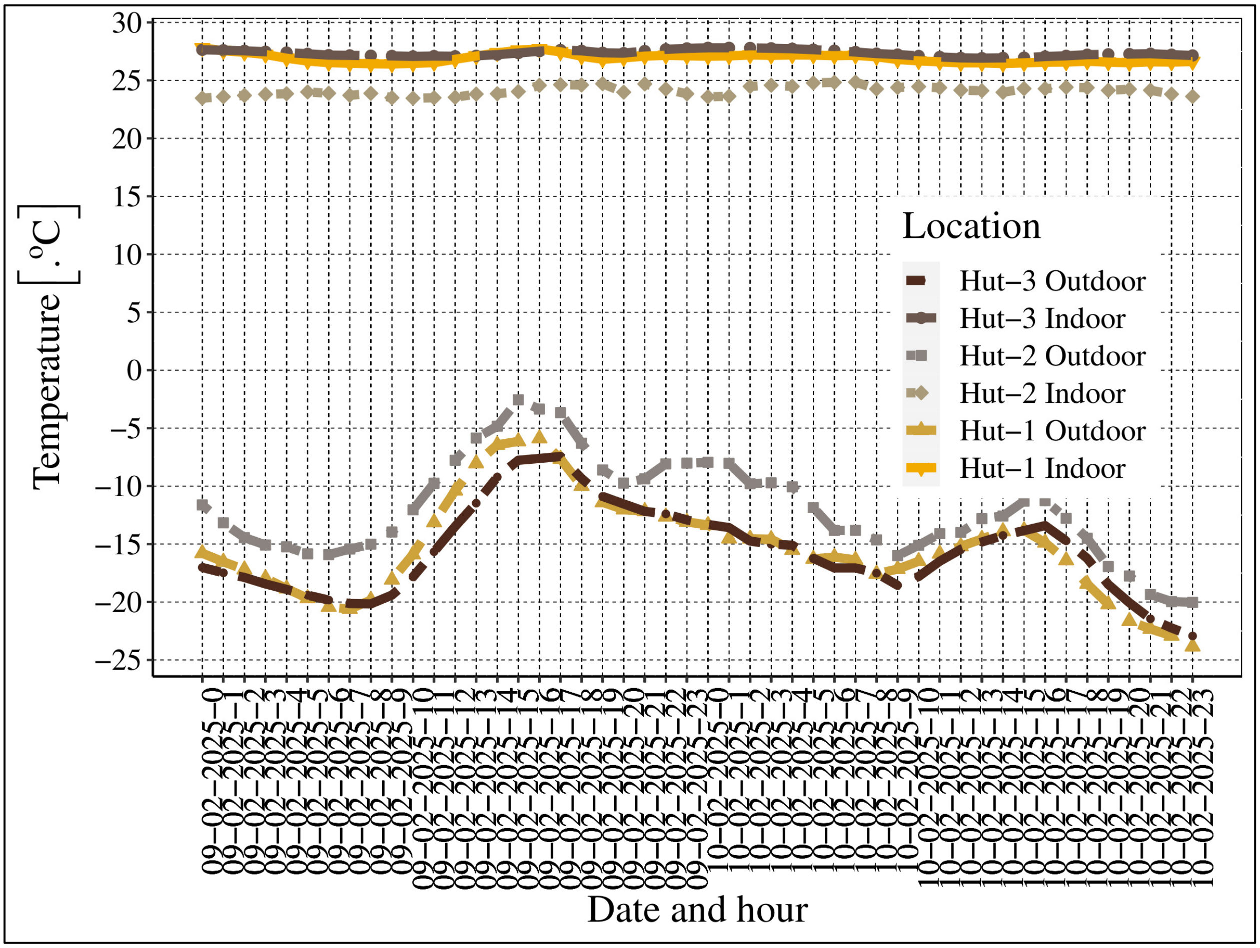

Figure 4: Interior and exterior wall temperatures for the huts.

The graphs shows that internal temperature is maintained fairly constant of 27 ºC for hut 1 and 3 over the monitoring period due to the heat supplied by the electric baseboards. The same is true for hut 2, however the temperature in this latter case is about 3 ºC below that of the other huts. This is probably due to the thermal dispersion caused by the lower thermal resistance of the walls of hut 2. The recorded outside temperature on the walls oscillates between -24 ºC and -2.5 ºC during the exposure period. The lowest temperature is observed around 5:00-6:00 AM, and the highest around 3:00 PM on February 9, 2025.

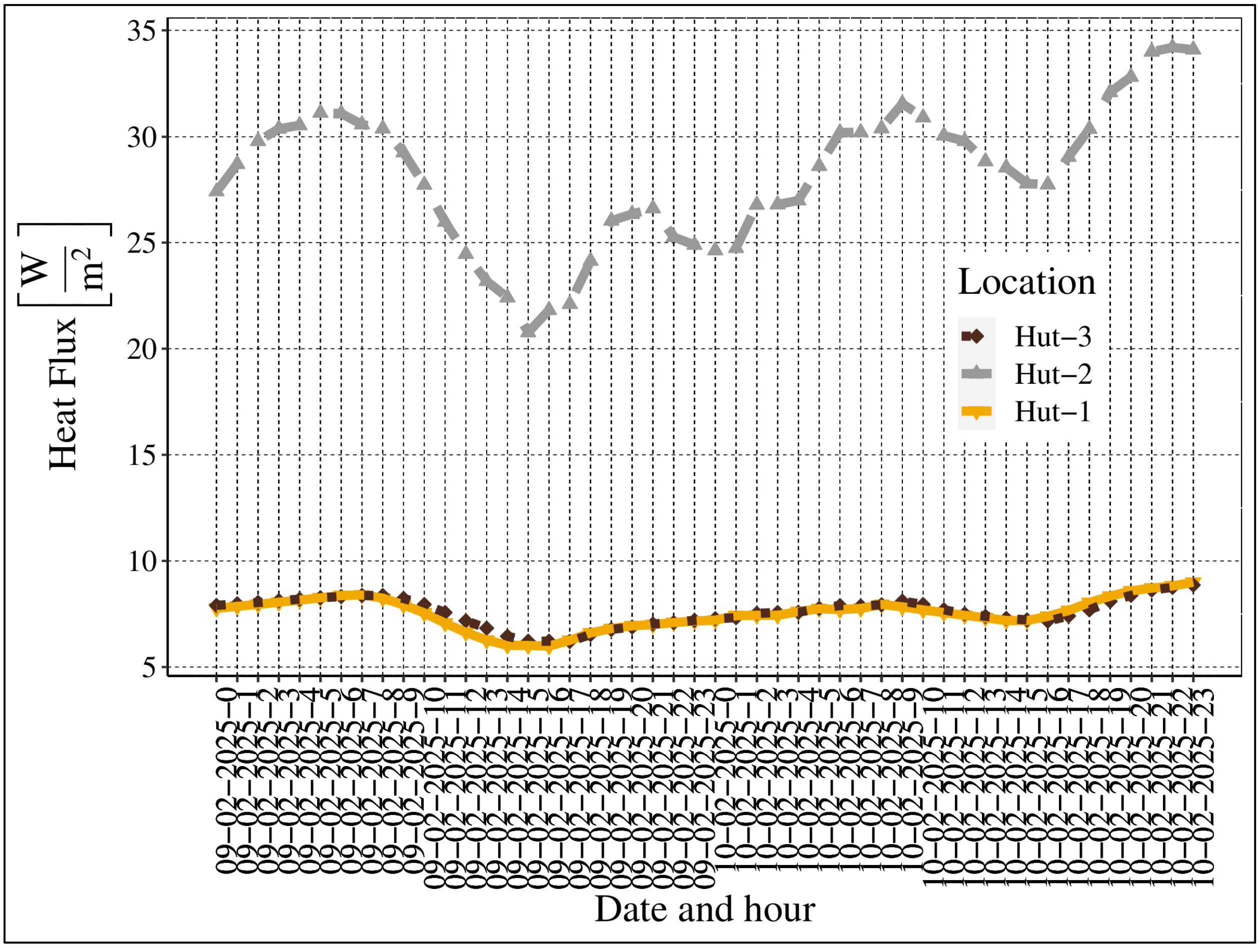

Figure 5: Computed heat flux on the huts.

Figure 5 shows the heat flux computed for the temperature depicted in Figure 4 for the three huts according to the Fourier's equation. The heat flux on the walls of huts 1 and 3 remain between 5.5 W/m² and 9.5 W/m² when the external temperature on the wall ranges respectively from -2.5 ºC to -24 ºC. On the other hand, the heat flux for hut 2 was higher, ranging from about 20 W/m² to 35 W/m² for the same range of temperatures.

Data from the heat flux sensors were also collected during the same period depicted in Figures 4 and 5. However, it was observed a noticeable fluctuation of the readings for the heat flux sensors compared to the variation of temperatures. This may be due to some calibration of the data acquisition system that has not yet been completed at the time of this writing.

Conclusions

This project aims at providing builders, investors, code officials, with guidance on the effects of thermal mass on the building performance. The research findings will help improve the assessment of building energy performance in the presence of thermal mass. In addition, the results can be used to more properly design buildings to be more resilient.

Preliminary results shows that the heritage walls shows a lower thermal resistance compared to the insulated walls and that the heat flux ranges between 20 and 35 W/m^2 when the external temperature ranges between

-24 ºC and -2.5 ºC, while the internal temperature is about +25 ºC. For the same temperature range, the heat flux of the insulated huts ranges between 5.5 and 9.5 W/m^2.

Designing energy resilient buildings have positive environmental benefits for Canada. Improving building construction and design have positive impacts on the Canadian economy through technological advancement, potential energy cost savings, and creation of jobs. The results obtained from this project have the potential to generate considerable environmental and economic benefits to Canada through improved assessment of building performance and building design.

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