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# Preliminary Experimental Assessment of Building Envelope Integrated Ventilative Cooling design

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**Abstract.** To minimize energy consumption, high-performance buildings are being built with highly insulated and airtight building envelopes, high-performance glazing and efficient mechanical systems. But it has been observed that these buildings are prone to an overheating problem during the summertime. Literature suggests a ventilative cooling method, which is the use of natural ventilation for space cooling, as an ideal system for energy saving and overheating prevention. In this study, the behaviour of a building envelope integrated ventilative cooling (EV wall) design is experimentally studied to assess its cooling potential and ventilation capacity. The EV wall design has an opening at the bottom of the wall that allows ventilative air exchange between the indoor and the outdoor through the cavity behind the cladding. The suction pressure created by the buoyancy effect in the wall cavity drives the ventilation air. The experimental assessment has shown that there are two distinct night-time and day-time flows driven by indoor/outdoor temperature difference and solar radiation respectively. This preliminary study indicated the huge potential of ventilative cooling design and ways to further enhance the EV wall performance. For future studies, the EV wall will be considered by implementing an opening control system in a naturally ventilated building.

## 1. Introduction

To combat climate change and ease the adverse consequences of air pollution, the current clean energy revolution gives energy efficiency paramount importance. As the building sector takes up a significant portion of the total energy consumption, building codes and regulations are putting stringent energy efficiency requirements in place. As a result, high-performance buildings are becoming the new standard. However, The nature of these buildings, including high insulation levels and airtightness, makes them prone to overheating in the summertime [1]. Global warming is also predicted to increasingly exacerbate the overheating problem in the coming years [2].

Several passive cooling methods can be applied to mitigate buildings' overheating problem [3]. One of the convective cooling methods is the use of natural ventilation for cooling purposes also called the ventilative cooling method [4,5]. Direct cooling of the indoor space by allowing cool outdoor air to come into the building can be achieved by opening doors and windows and in some cases in combination with atriums and solar chimneys.

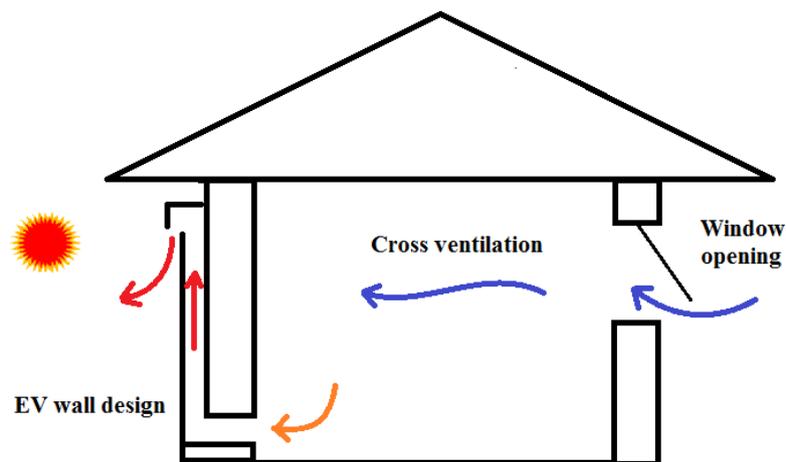
Naturally ventilated buildings can concurrently improve indoor air quality, lower the air conditioning energy cost and lower the carbon footprint of buildings [6]. It is predicted to have the potential to save 30% - 50% of the cooling demand in office buildings and available studies indicate "significant yet lower" saving for residential buildings [2].

Ventilative cooling is applicable only when the outdoor temperature is lower than the indoor and when there is sufficient thermal mass to cool down during the night-time in night ventilation mode [2]. Since the summertime outdoor temperature is close to the indoor temperature, bioclimatic designs use solar chimneys in various forms to harness the solar energy and create the necessary temperature difference to generate enhanced buoyancy-driven airflow in the building [7]. The typical solar chimney



construction includes a glazing exterior layer, an air gap and a dark absorber surface. The exterior glazing layer may be integrated with a photovoltaic cell or swapped for an opaque layer [6].

The airflow path in solar chimneys varies depending on the specific application guided by the chimney openings. One of the summertime cooling designs called exhaust ventilative (EV) design ventilates the space behind the cladding by the indoor air as shown in Figure 1. The EV wall design has an opening at the bottom of the wall that allows indoor air to exhaust through the cavity behind the cladding creating a ventilative airflow inside the adjacent indoor space. The suction pressure created by the buoyancy effect in the wall cavity drives the ventilation air.



**Figure 1.** Exhaust ventilative cooling design.

Although various experimental and numerical studies have been done to optimize and quantify the performance of solar chimneys [8–13], the advantages of exhaust ventilative designs in light of high-performance buildings are not definitive. Also, most studies consider solar chimneys with a transparent exterior layer and less attention is given to EV designs with an opaque exterior layer. This preliminary experimental study assesses the potential energy-saving advantages of implementing an EV wall design under real climatic conditions.

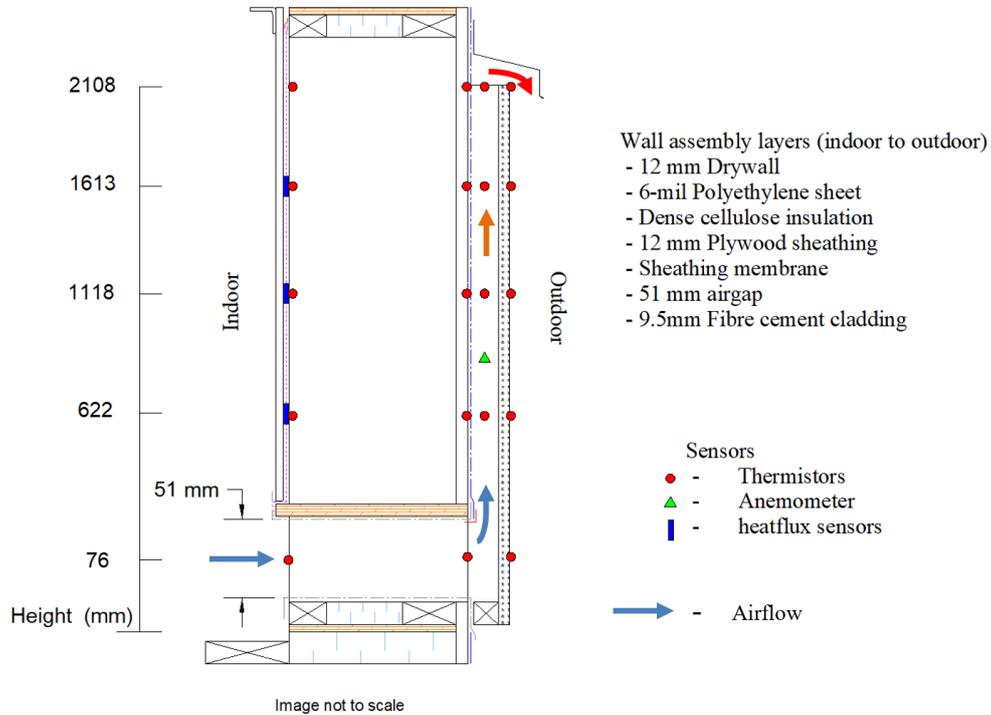
## 2. Approach

A field experimental investigation is performed for an EV wall design on the Building Envelope Test Facility (BETF) of the British Columbia Institute of Technology where the climatic condition is mild marine. A Test wall on the south-east orientation of BETF is selected since it is the highest solar radiation admitting facade. The test facility is equipped with a weather station and indoor sensors to monitor the environmental conditions around the test wall. The main focus of this study is the induced channel airflow, heat flux and temperature distribution inside the wall.

### 2.1. Wall setup

The test wall has a 51 mm cavity air gap with a 51 mm x 1143 mm wall inlet opening, white sheathing and opaque cladding. The wall construction is a double stud wood frame with dense cellulose insulation that has an effective thermal resistance value of 7.4 m<sup>2</sup>K/W. The vertical cross-sectional view of the

wall construction is presented in Figure 2 along with a list of the wall assembly layers and sensor layout. Figure 2 also shows the airflow path through the wall. Figure 3 captures the test wall construction at different stages and sensor installation.



**Figure 2.** Vertical cross-sectional view of the test walls.



**Figure 3.** Experimental setup and sensor layout at different stages (a) thermistor installation on the sheathing layer (b) installation of weather barrier and strappings (c) wall opening viewed from the interior (d) thermistor installation on the cladding layer.

## 2.2. Sensor Specification

Thermistors, heat flux sensors and Anemometers were considered in monitoring the performance of the walls as illustrated in Figure 2. Temperature sensors were installed at five vertical positions or levels (L1, L2... L5) with 495 mm increment from the second level which measures 622 mm from the bottom of the wall. The airflow transducers were positioned in the air cavity at 870 mm from the bottom which is midway between the second and the third level. Lastly, the heat flow sensors were fixed on the drywall facing the insulation at L2, L3 and L4. The sensor's specification including model, measuring range and accuracy level is presented in Table 1.

**Table 1.** Sensor specification.

| Sensor<br>(representation) | Model   | Range                   | Accuracy               |
|----------------------------|---|-------------------------|------------------------|
| Air velocity Transducer    | Air Velocity Transducer 8475 (TSI incorporated) | 0 -5 m/s                | ±1% of F.S. (0.05 m/s) |
| NTC Thermistor             | Murata electronics<br>NXFT15XH103FA2B___        | - 40 °C to 125 °C       | 0.3 @ 20°C             |
| Heat flow sensors          | F-005-4 (Concept engineering)                   | ± 9.5 kW/m <sup>2</sup> | ±5%                    |

## 3. Result and discussion

### 3.1. Air Cavity Temperature

The temperature rise inside the air cavity is captured by Figure 4. The indoor temperature is kept at 21°C by the mechanical system which is shown to match with the inlet temperature, located at the interior side of the wall opening, during the day. The outdoor temperature is also given in the figure for reference. At high solar radiation, the cavity temperature goes up with height until it reaches the outlet temperature (L5). The maximum outlet air temperature can reach up to 45°C. There is a quick temperature rise when insolation intensifies then it peaks lagging by about an hour to the solar radiation followed by a slowed decline. At night, all cavity temperatures bundle up together except the inlet temperature which is seen to be few degrees higher.

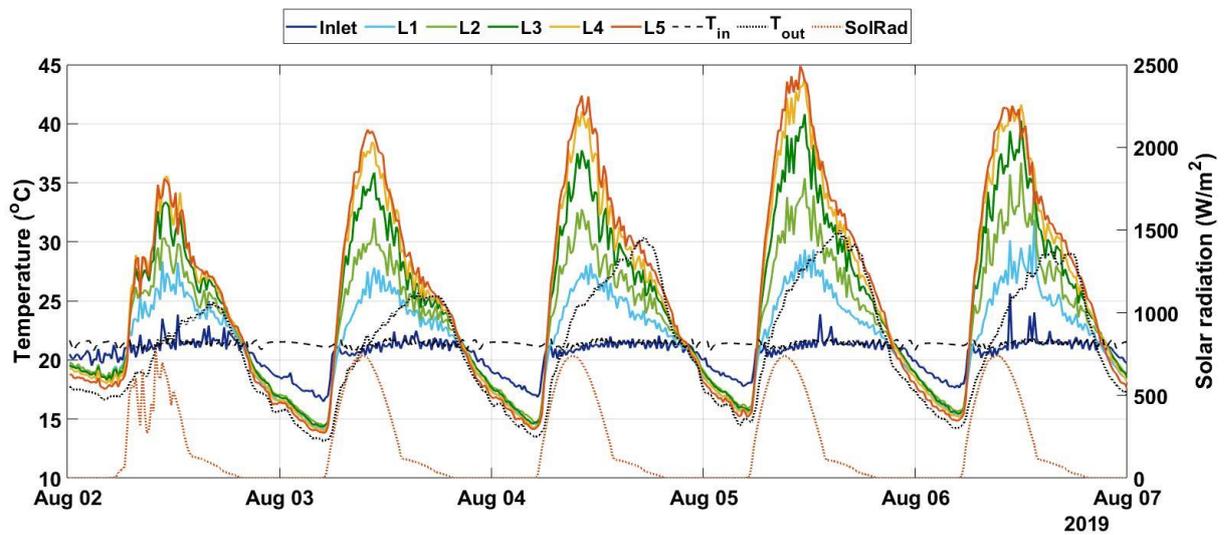


Figure 4. Cavity temperature stratification.

Figure 5 shows the snapshot of the temperature profile across the wall at three vertical locations (L2, L3 and L4) during the daytime taken at 05-Aug-2019 11:29 and during night-time taken at 03-Aug-2019 05:14. The daytime and nighttime snapshots were selected based on the maximum and minimum temperatures registered on the sheathing layer during the monitoring period respectively. During the daytime, there is a clear temperature stratification inside the wall. The cladding has the highest temperature on the wall since it is directly exposed to the sun. The sheathing layer is the second hottest layer in the assembly followed by the cavity air layer. There is a steep temperature decline across the insulation layer (between the sheathing and the drywall). However, at night, the temperature difference between vertical levels diminishes and two straight lines (linear temperature changes) appear inwards and outwards of the sheathing.

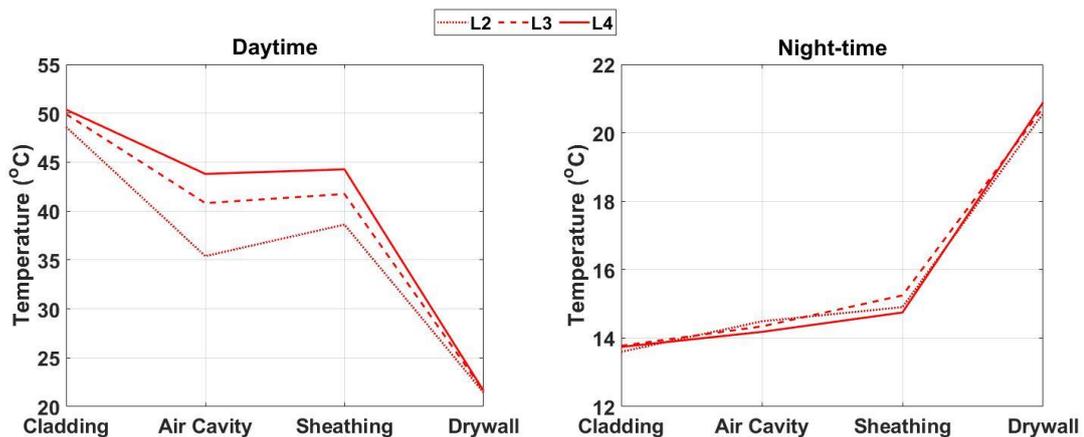
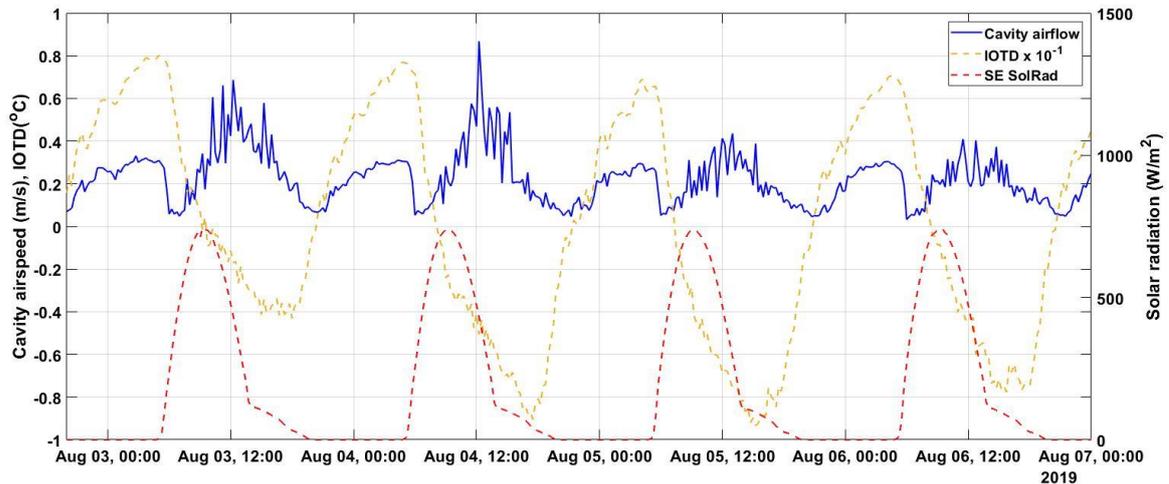


Figure 5. Snapshot of daytime temperature profile at 05-Aug-2019 11:29 and night-time temperature profile at 03-Aug-2019 05:14 across the wall.

### 3.2. Airflow

A time series plot of the cavity airflow is presented in Figure 6. The airflow influencing factors of indoor-outdoor temperature difference (IOTD) and solar radiation (SolRad) on the southeast wall is also

shown in the figure. The airflow is shown to have two peaks per day. One is in the daytime and the other at night. The night-time peak looks well behaved and it follows the trend of IOTD whereas the daytime flow follows the solar radiation intensity trend with three hours of delay due to the thermal mass effect.

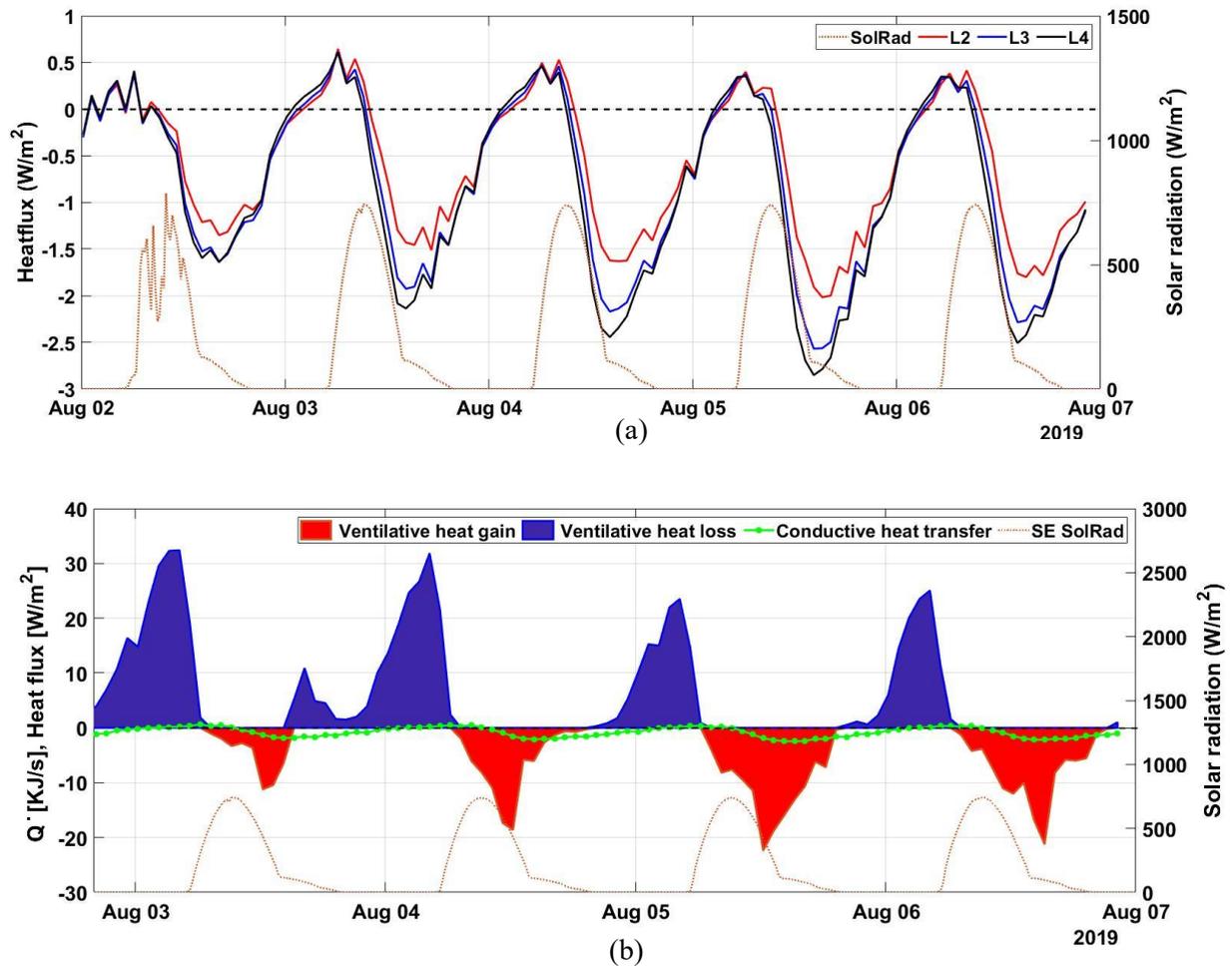


**Figure 6.** Cavity airflow and the influencing factors.

The cavity airflow is shown to increase as IOTD rises above zero and continues to rise until the morning sunshine. As the sun starts to intensify the outdoor temperature rises and the temperature difference (IOTD) for the airflow diminishes hence reduced thermal buoyancy therefore the cavity airflow decreases to a minimum. As the day goes by the cavity airflow regains back its intensity due to solar radiation which warms up the air cavity. At the end of the day, when the sun goes down, the outdoor temperature starts to cool down. At that time, the cavity flow will be at its minimum for the second time in a day and the cycle repeats for the next day.

### 3.3. Heat flux

Conductive heat flow at multiple heights (L2, L3 and L4) on the wall is shown in Figure 7 (a). Heat gain is denoted as negative and heat loss is positive. The figure shows a similar heat loss for the night-time but stratified readings for the daytime. During the day, the upper-level sensor at L4 reads higher heat gain followed by, the middle level, L3 and finally L2. Hence, the heat gain increases with the wall height which is concurrent with the temperature plots above. The thermal mass of the wall causes a thermal lag of about five hours. Thus, the highest heat gain was sensed after the wall solar radiation had subsided.



**Figure 7.** Conductive heat flux (a) and bulk energy transfer due to airflow (b) across the EV wall.

Figure 7 (b) shows the instant ventilative energy exchange ( $\dot{Q}$ ) of the building with the ambient due to bulk airflow. The ventilative heat loss is shown in blue and the ventilative heat gain is shown as red area plots. The average conductive heat transfer is also superimposed on the ventilative plots which illustrate that the bulk energy exchange is much larger compared to the conductive heat transfer through the insulation. Equation 1 gives the formula for the ventilative heat exchange ( $\dot{Q}$ ) where  $h$  is the enthalpy of air,  $\dot{v}$  is volume flow rate and  $\rho$  is the air density. The energy exchange depends on the indoor ( $h_i$ ) and outdoor ( $h_o$ ) conditions and the cavity airflow ( $\dot{v}$ ).

$$\dot{Q}[\text{kJ/s}] = (h_i - h_o) \cdot \dot{v} \cdot \rho \quad (1)$$

Figure 7 (b) illustrates that there is a high rate of heat loss during the night and the reverse happens during the day when the outdoor temperature surpasses the indoor. It is also possible to further reduce the heat gain due to ventilation by closing the wall opening which suggests that the performance of the design can be enhanced by the implementation of an opening control system. For future work, the performance of the EV wall will be considered on a naturally ventilated building with an opening control system controlled by the outdoor temperature.

#### 4. Conclusion

To reduce the impact of buildings on the environment and reduce the air condition energy cost of high-performance buildings during summertime, exhaust ventilative cooling design is proposed and its thermal behaviour has been assessed in this paper. The EV design has an opening at the bottom of the wall that allows indoor air to exhaust through the cavity behind the cladding creating a ventilative airflow inside the adjacent indoor space. The results show a higher and distinct flow pattern for the day and night-time flow indicating two sources of driving forces. One is daytime solar and the other, night-time indoor/outdoor temperature difference. The heat flow assessment indicates the huge potential of ventilative cooling and the performance can be further improved by implementing an opening control system. Hence, future studies will consider the performance of EV walls on a naturally ventilated building with an opening control system.

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