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Experimental and numerical investigations of thermal properties of insulated concrete sandwich panels with fiberglass shear connectors

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ABSTRACT

A new design of a structural sandwich panel, consisting of a combination of concrete, insulation and connectors, was tested using a hot box apparatus to evaluate its thermal properties and energy efficiency. The three materials of the prefabricated panel were arranged to provide both structural and thermal efficiencies. The main objective of this work was to find the thermal resistance (R-value) of the new panel for different designs. Ten different panels were tested using the hot box approach. Each panel had a unique design in order to determine the effect of the design on the thermal behavior of the panel. The design parameters included the number, size, distribution and material of the connectors, and the number and spacing of the concrete studs. Most of the connectors were made from glass fiber reinforced polymer (GFRP) while steel connectors were used in one panel for comparison purposes. The hot box apparatus was constructed using large precast concrete box culvert units with octagonal cross sections and was carefully insulated. The metering chamber air was heated up to a temperature of 24.5 °C and the climate chamber air was reduced to −4.3 °C in most cases of the tested panels. The experimental R-values ranged from 2.84 to 4.68 m^2K/W, compared to 2.74 m^2K/W for the steel-reinforced control panel. A one-dimensional heat transfer model was also developed to predict the R-values.

1. Introduction

Increasing economic and environmental costs of space heating and cooling have generated renewed interest in improving the thermal resistance of building envelopes. At the same time, rising construction costs are driving designers to select prefabricated elements which can be constructed with higher quality control and in less time than traditional construction. Precast Concrete Sandwich Panels (CSPs), also known as insulated concrete walls or integrally insulated walls, are thermally efficient prefabricated elements that address both of these needs.

CSPs have been used for commercial and industrial building envelopes for several decades, both as a cladding material and as a structural building component, as a result of their structural efficiency, low thermal energy transfer, high thermal mass, versatility, and durability. CSPs can be prefabricated with good quality control, a wide variety of architectural finishes, and are easy to install allowing interior work to commence earlier and reducing the overall length of a project.

CSPs are typically composed of two reinforced concrete skins (known as wythes) that surround a central layer of rigid foam insulation. Structural continuity between the concrete layers is provided by mechanical ties known as shear connectors. The insulation thickness is chosen depending on the building's required thermal resistance while wythes are sized based on the structural design loads.

The thermal characteristics of CSPs are primarily dependent on the properties of the insulation layer, the connector element, and the interior wythe. As the exterior wythe is located outside the insulation layer and generally provides little resistance to heat transfer, it has little effect upon the thermal efficiency of the panel. In modern CSPs, the insulation layer consists of between one and four inches of either expanded or extruded polystyrene insulation. The resistance of the insulation is mitigated by penetrations through the insulation layer, termed thermal 'bridges'. The principal source of thermal bridging is the connector elements which transfer structural forces between the two wythes. The heat transfer through the connectors depends upon the number of connectors required, the material used for the connector, and the size of each connector.

Steel connectors are widely used in industry, but also have the highest thermal conductivity of the connector materials available. Concrete is also used to connect wythes in fully composite pan-

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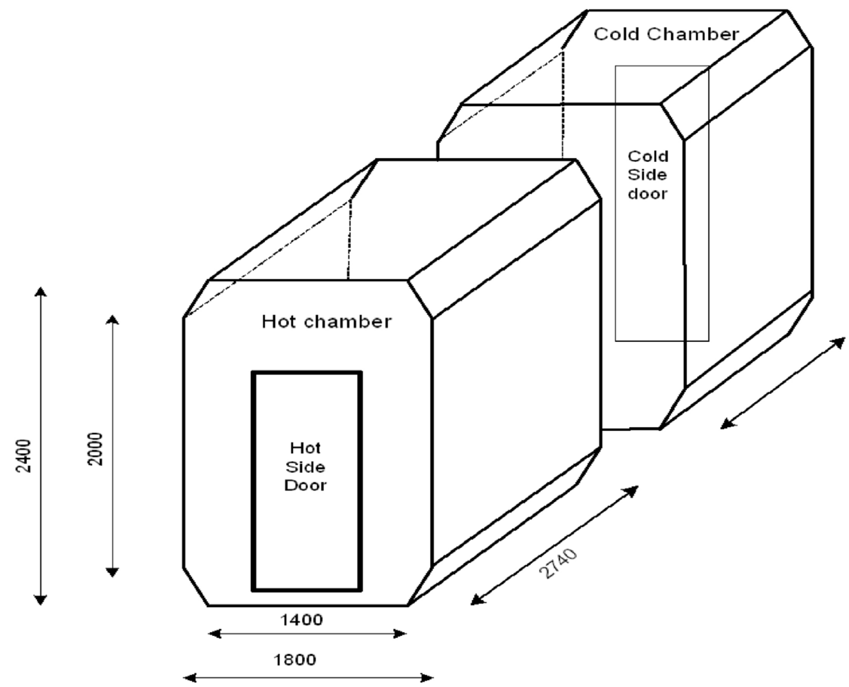

Fig. 1. – Hot box test setup.

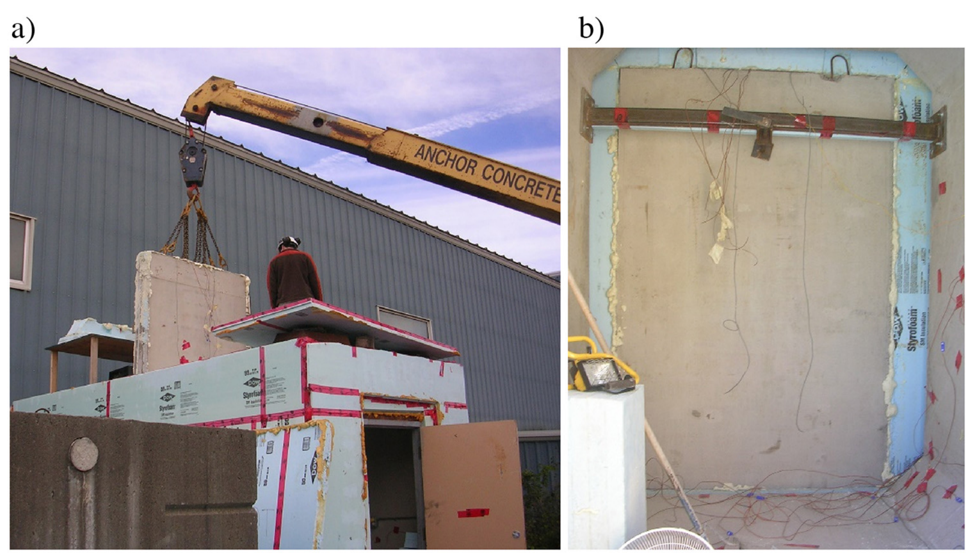

Fig. 2. – a) Installation of test panel, left, and b) test panel inside hot box apparatus, right.

els, however, a large area of concrete is required which creates a large thermal bridge. Over the past two decades, rising energy prices have encouraged the development of alternatives to traditional steel-reinforced designs [8]. GFRP (otherwise known as fiberglass) materials have a significantly lower thermal conductivity than steel (ranging between 1/60th and 1/13th that of steel), and require less bridging area than concrete to hold the two wythes together [18,5]. Nevertheless, while some studies on structural behavior are available (e.g. [6,16,3,4,15,10,11,17], research on the thermal performance of CSPs with GFRP reinforcement is very limited, especially for full scale wall panels.

McCall [9] reported that a steel penetration of 0.08% of panel area reduced the thermal resistance of the panel by 38%, whereas a concrete penetration of 21.2% reduced the thermal resistance by 77%. The study also found that the use of either steel trusses (for composite panels) or M-ties (for non-composite panels) reduced the thermal conductivity of a typical sandwich panel by 7%. Similarly, Van Geem and Shirley [19] reported a 7% drop in thermal resistance with stainless steel connectors, whereas the thermal resistance actually increased in panels with GFRP connectors. Kosny et al. [7] also found that structures built using GFRP-reinforced CSPs required much less energy to provide human comfort than traditional wood frame construction.

Despite significant improvements in energy efficiency of space heating and cooling systems in recent years, increasing population and housing trends have resulted in a net increase in energy use. The number of households in Canada, for example, increased 36% between 1990 and 2009 [12]. In addition, the floor area of the average Canadian home increased 11%, and the number of individuals per household decreased from 2.8 people per household to 2.5 people per household. As a result, the total energy to heat and cool residential homes increased 13.4% between 1990 and 2009, com-