Thermal characterisation of Composite Insulation Panels using a vacuum insulated core

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Abstract

Composite Insulation Panels (CIPs) are used in building envelopes due to their thermal insulation properties, lightweight, aesthetics and ease of production and installation. In this paper, an advanced thermal insulation core material (vacuum insulation) with a thermal conductivity of 5-8 $mWm^{-1}K^{-1}$ has been investigated as core material for enhancing the thermal insulation performance of CIPs. Results revealed a significant reduction in heat loss and improvement in thermal performance of the vacuum insulation compared to that of the conventional extruded polystyrene (XPS) core material. It was determined that the CIP with a vacuum insulation core had a thermal transmission of 0.38 $Wm^{-2}K^{-1}$ compared to 0.78 $Wm^{-2}K^{-1}$ for XPS core of equivalent thickness at the centre of the panel. This represents a 51% reduction in heat loss through the vacuum insulated CIP.

Key words: Composite Insulation Panel, Vacuum Insulation, Extruded polystyrene thermal insulation, thermal transmission

1. Introduction

Buildings contribute significantly to energy consumption and approximately 60% of that energy is consumed for space heating (DECC, 2012). Achieving energy efficiency in buildings is one of the significant challenges that need to be addressed for reducing their impact on climate and meeting the emission targets as set in the Paris agreement (UNFCCC, 2016). Insulating the building envelope to achieve the lowest thermal transmission (U-value) is critical for saving on building space heat energy and reducing carbon emissions. New materials such as vacuum insulation with enhanced thermal performance can help in improving the thermal resistance of the building envelope. Vacuum insulation is a high thermal resistance and energy efficient alternative thermal insulation to conventional building insulation materials (Brunner and Simmler, 2008; Alam et al., 2011). Use of vacuum insulation in buildings as a component in thermal composite insulation systems along with other insulation materials for achieving higher thermal resistance has been researched in number of studies (Hayez and Kragh, 2013; Mandilaras et al., 2014; Voellinger et al., 2104). In modern buildings facades, Composite Insulation Panels (CIP, also called sandwich panels) are increasingly being used for building applications due to their lightweight, thermal and sound insulation properties, aesthetics and ease of production and installation (Davies, 2001; Alam and O'Flaherty, 2016). CIPs are generally composed of bonding polymeric foam, mineral fibre or honeycomb cores with metallic or non-metallic facings. To achieve higher

energy efficiency targets in buildings, it is required that CIPs with enhanced thermal insulation performance are developed. Currently, increasing the thickness of conventional core insulation materials is used to improve the thermal transmission values of CIPs. However, this approach may be not be suitable for achieving smart building envelope design. Within this context, this paper describes the development and characterising of CIPs made of evacuated core (vacuum insulation) to achieve higher thermal insulation. Thermal transmission through the CIP made with vacuum insulation as a core material has been experimentally measured in the laboratory and compared to that of a panel made with conventional extruded polystyrene (XPS) core.

2. Details of Composite Insulation Test Panels

The investigated CIPs were manufactured by sandwiching the core material between two outer aluminium facing layers. Two composite insulation panels of size 790 mm x 495 mm were manufactured with a core thickness of 26 mm. In one CIP, XPS core material was used while a second CIP was manufactured with vacuum insulation as the core material. The overall size of both CIPs was the same. However, to protect the vacuum insulation from puncture along the sides, XPS borders of 95 mm (width side) and 97.5 mm (length side) were placed around the vacuum insulation meaning none of it was visible once the aluminium facings were attached (the vacuum insulation measured 600 mm x 300 mm with a thickness of 20 mm). Thermal conductivity of the vacuum insulation was also measured before using it in the CIPs.

3. Methodology

3.1 Thermal conductivity measurement of vacuum insulation

Thermal conductivity (k) in one dimension can be described by the simplified form of the Fourier's law:

$$q_x = -kA\,(\Delta T / d)$$

where q_x is the heat flux in direction x, (wm^{-2})
A is area of the sample (m^2),
d is the thickness of the sample (m)
ΔT is the temperature difference between hot and cold surfaces of sample (K)

Thermal conductivity of the samples was measured by means of a hot/cold plate apparatus. The working of the apparatus is built upon the application of Fourier's law, by generating one-directional heat flux across both surface of the specimen. The apparatus consists of a cold/hot plate, heat flux sensors and thermocouples. Thermal conductivity was determined from the measured heat flux at steady state conditions and the temperature difference between the hot and cold sides of the samples. Figure 1 (a) shows the image of the apparatus in which the specimen is placed on top of cold plate and T-type thermocouples attached on both surfaces of specimen to measure temperature.
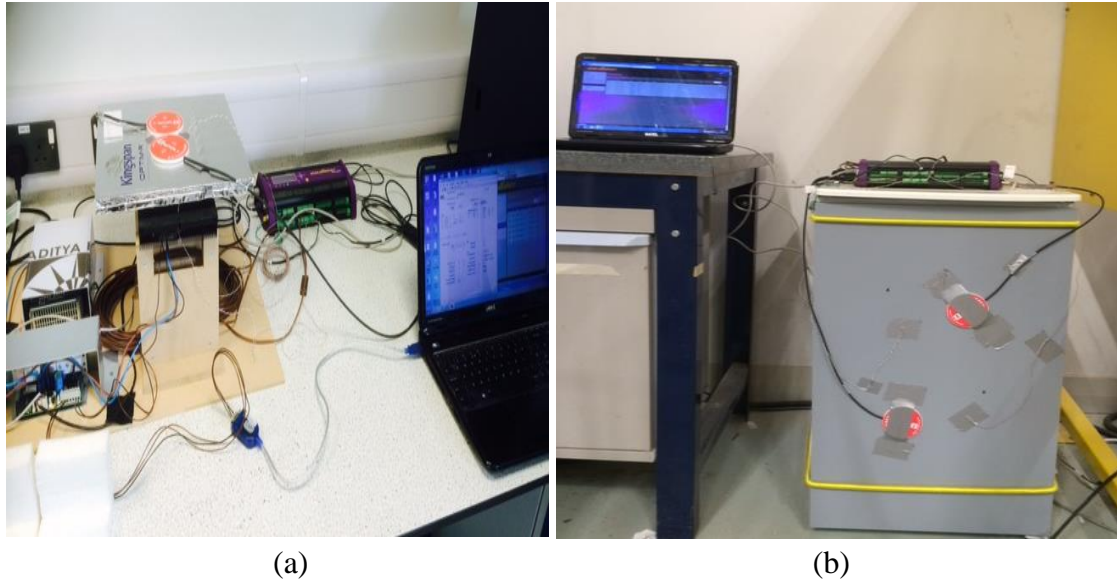
<div align="center">(a)   (b)</div>

Figure 1. (a) Thermal conductivity measurement equipment (b) U-value measurement setup

Heat flux plates have been attached to the specimen on the top surface to measure the heat flux across the specimen surfaces. Performance of the apparatus has been analysed by measuring the thermal conductivity of a 25 mm thick sample XPS (180mm×130mm) of known thermal conductivity (33 mWm^{-1}K^{-1}). Thermal conductivity of the reference sample has been measured to be 31.91(mW m^{-1}K^{-1}). This shows that the apparatus can measure thermal conductivity with good accuracy.

3.2 Thermal transmittance measurement of CIPs

Thermal resistance, R, is the inverse of thermal transmittance (U-value, Wm^{-2}K^{-1}). It is the ratio of the mean temperature difference measured between the two sides of the sandwich panel and can be written as:

$$R = \frac{1}{U} = \frac{(T_1 - T_2)}{q_x}$$

To determine the U-value of a CIP, the average steady-state heat flow passing through the CIP installed in the laboratory setup as shown in the Figure 1(b) was measured along with the surface temperature of both sides of the CIP. Hukseflux heat flux plates, 80mm in diameter and 5mm thick, were used for heat flux measurements. T-Type thermocouples for temperature measurement were attached to either surfaces of sandwich panels using strong sticky tape to achieve good thermal contact. The heat flux data and temperature data was logged on a dataTaker DT85 data logger. Preferably, conditions on both sides of the CIP need to be as constant as possible. Although the laboratory room temperature was maintained, however fluctuations were expected during day time due to the ongoing activities in laboratory. To ensure the steady state conditions, 48 hours of data obtained over a weekend was used for U-value calculations where temperature fluctuations were minimal.

4. Results

4.1 Thermal conductivity of vacuum insulation

The thermal conductivities of two commercially available vacuum insulation specimens (VIP1 and VIP2) with same composition have been measured using the cold/hot plate apparatus method. The results of thermal conductivity (taken at the centre of the panel) of the tested VIP specimens are presented in Table 1. Thermal conductivity values of 4.31 and 3.91 $mWm^{-1}K^{-1}$ were measured for specimens VIP1 and VIP2 respectively. The manufacturer's thermal conductivity value was given as 4.7 $mWm^{-1}K^{-1}$ in the data sheet hence the specimens VIP1 and VIP2 performed better in the laboratory test. Furthermore, it shows that the vacuum insulation used in the CIP manufacturing were intact and not damaged during transportation and handling. Taking an average value of 4.11 $mWm^{-1}K^{-1}$, k for the vacuum insulation is 7.8 times lower than the equivalent value for XPS (31.91 $mWm^{-1}K^{-1}$).

Table 1. Measured thermal conductivity of vacuum insulation

Sample	Thickness (mm)	Dimensions (mm)	Mean Temperature ($^\circ$C)	Thermal Conductivity (mW/mK)
VIP1	20	300×300	9.78	4.31
VIP2	20	300×300	9.76	3.91
				Average: 4.11

4.2 Effect of vacuum insulation on thermal performance of CIPs

The CIP included 3 mm XPS on either side of 20 mm vacuum insulation to protect the vacuum insulation envelope surface and achieve better bonding with the outer aluminium layers. The U-value was measured at the edge and centre of the panel as shown in the Figure 2. CIP panels made with XPS core at the centre had the average U-value of 0.38 $Wm^{-2}K^{-1}$ compared to that of 0.78 $Wm^{-2}K^{-1}$ for the XPS panel. This shows that the presence of vacuum insulation has improved the thermal performance of CIPs by reducing the U-value by 0.40 $Wm^{-2}K^{-1}$, a 51% improvement in thermal performance compared to that of CIP with XPS core. Therefore, the thickness of XPS would have to be more or less doubled to achieve a similar performance to that of the vacuum insulation in the centre of the panel.

Data also shows that at the U-value at the edge of the CIP were found to be higher compared to that at the centre of the CIP (Table 2). For CIPs with vacuum insulated core, the U-value was measured to be 0.64 $Wm^{-2}k^{-1}$ (an increase of 68%) while for the CIP with XPS was 0.97 $Wm^{-2}K^{-1}$ (an increase of 24%). This edge effect is, therefore, greater for the CIP with vacuum insulated core due to the low thermal conductivity of the vacuum insulation.
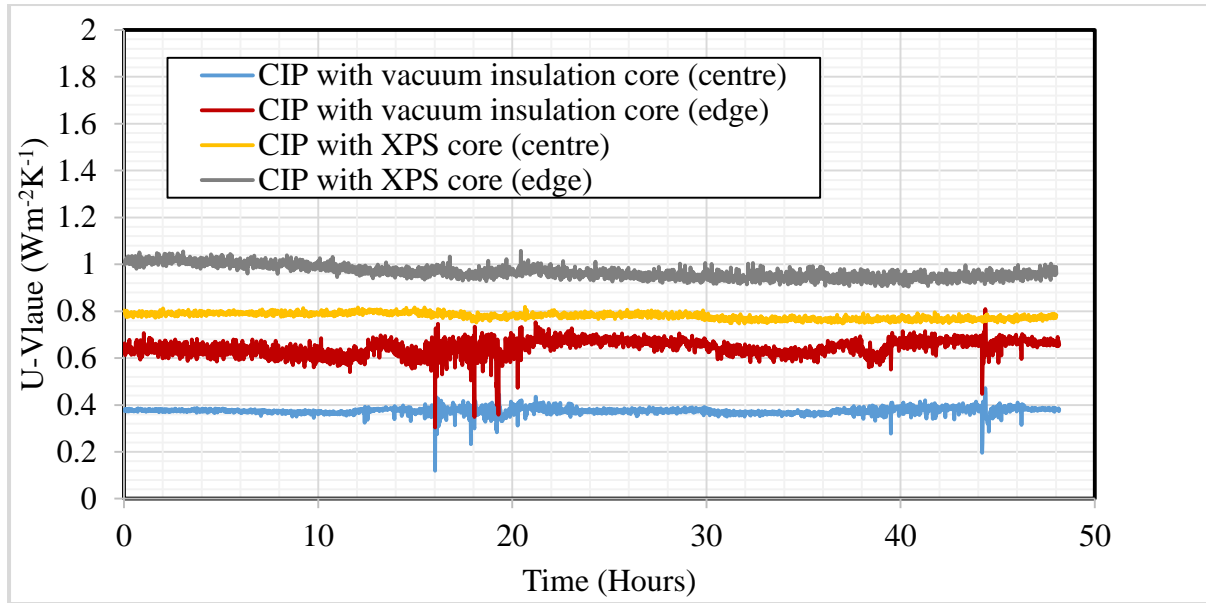
Figure 2. Measured U-value of CIPs with vacuum insulation and XPS core

Table 2. Average measured U-value at centre and edge of CIP samples

Sample	Centre U-value (Wm^{-2}K^{-1})	Edge U-value (Wm^{-2}K^{-1})	Difference between Edge and centre (Wm^{-2}K^{-1})
CIP with vacuum insulation	0.38	0.64	0.26 (+68%)
CIP with XPS	0.78	0.97	0.19 (+24%)

The significantly higher *U*-value at the edges of the CIP with vacuum insulation requires that the overall size of these panels and edges should be designed very carefully in order to effectively utilise the enhanced thermal performance of the vacuum insulation in the CIP. This could potentially be achieved by increasing the vacuum insulate core area and the overall panel dimensions and reducing edge width or using low thermal conductivity foams such as phenolic foam or polyurethane foam instead of XPS at edge.

5. Conclusion

In this paper, thermal properties of composite insulation panels composed of vacuum insulation and XPS were investigated. The thermal insulation performance of sandwich panels was evaluated by measuring thermal transmission (U-value) in a small scale laboratory facility. The panels with evacuated core (vacuum insulated) were found to have the lowest U-value of 0.38 Wm^{-2}K^{-1} compared to that of 0.78 Wm^{-2}K^{-1} for XPS core. This enhanced thermal insulation was achieved without an increase in the overall thickness of the CIP. Results also showed that the panel edge *U*-value was higher compared to that of at centre of the CIP. For the vacuum insulated CIPs, the difference between the edge and centre of panel *U*-value was 0.26 Wm^{2}k^{-1} (an increase of 68%). This edge effect can possibly be reduced by carefully designing and or using alternative low thermal conductivity materials at

edges e.g. replacing XPS with low thermal conductivity phenolic foam or polyurethane foam in order to effectively exploit the better thermal performance of the vacuum insulation in the CIP.

6. Acknowledgement

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