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EFFECTS OF CLADDING MATERIALS ON THE FIRE RESISTANCE OF EXTERNAL LIGHT GAUGE STEEL FRAMED WALLS EXPOSED TO INTERNAL FIRE

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ABSTRACT

This paper presents finite element heat transfer modelling of external light gauge steel framed (LSF) walls with autoclaved aerated concrete and brick veneer cladding exposed to fire from the inside. There has been research on the fire resistance of internal LSF walls (gypsum plasterboard layers on both sides of the cold-formed steel (CFS) studs) [1,2] and fire resistance of external LSF walls (gypsum plasterboard on the internal side and any cladding on the external side) exposed to fire from the external side [3–5]. But no research is available on the fire resistance of external LSF walls exposed to fire from the internal side and whether the cladding has any influence on the fire resistance of these LSF walls. Finite element heat transfer models were first validated against the fire test results presented in Refs. [3,5]. They were then used to evaluate the fire resistance of these LSF walls exposed to fire from the internal side. Two configurations with and without cavity insulation, when exposed to fire from the internal side, were investigated. When compared to internal LSF walls, while minor differences were noticed in the case of cavity insulated walls, a significant difference was observed when there was no cavity insulation in the wall.

Keywords: Cladding; light gauge steel; external wall; fire resistance

1 INTRODUCTION

Several cladding fire accidents have occurred recently endangering the lives of the occupants in those buildings. Unlike in high rise buildings where external cladding does not influence the structural performance of the building, external cladding is an integral part of the walls in light gauge steel framed construction. Hence fire resistance of cladding influences the structural fire performance of the cold-formed steel (CFS) studs as well as the stability of the wall and the entire building, especially in the case of load bearing walls. In Refs. [3–5] the fire resistance of three external LSF walls clad with autoclaved aerated concrete (AAC) panels, corrugated steel cladding and brick veneer cladding exposed to fire from the external side was investigated by conducting several fire resistance tests. But it is equally important to understand if the cladding has any influence on the fire resistance of LSF walls when exposed to fire from the internal side and how the stud temperatures compare with the results of an internal LSF wall exposed to fire. Figure 1 shows the cross-sections of typical external and internal LSF walls. This paper presents the results from a fire resistance test and finite element heat transfer models to understand the influence of cladding materials on the fire resistance of external LSF walls exposed to internal fires.

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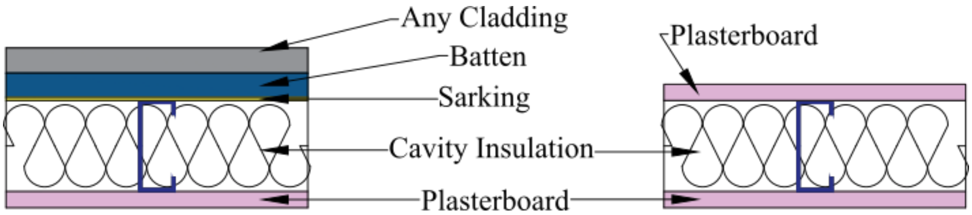
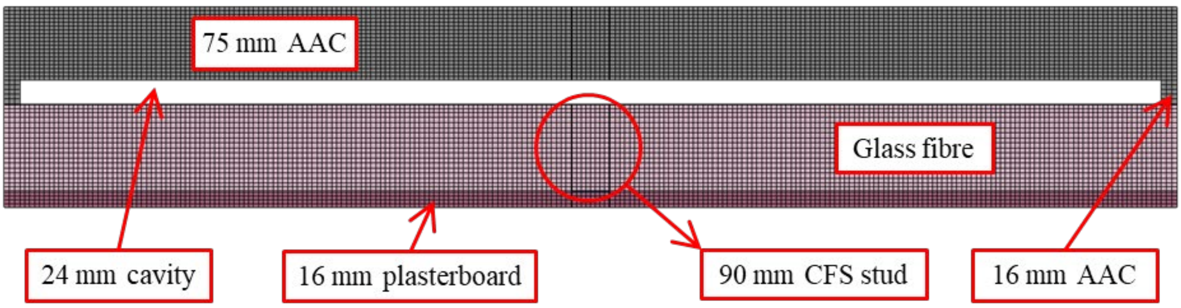


Figure 1. Cross-sections of typical external (left) and internal LSF walls (right).

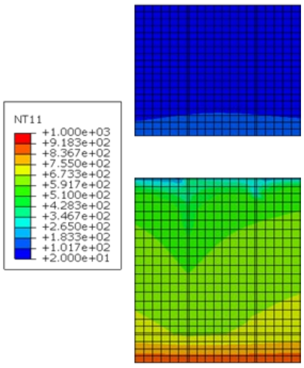
2 METHODOLOGY

In the case of external LSF walls with corrugated steel cladding [4], two layers of 16 mm gypsum plasterboards were used on both sides of the stud. Hence when exposed to fire from the internal side, the temperature development in the studs would be very similar to internal LSF walls as the configuration is the same. The steel cladding has no direct influence on the temperature development in the wall and the studs. In the case of external LSF walls with AAC panels and brick veneer, the configuration is very similar to the cross-section shown in Figure 1. They can influence the temperatures in the wall and studs when exposed to fire from the internal side. Hence, only external LSF walls with AAC panels and brick veneer are considered in this study.

Two-dimensional finite element heat transfer analysis models were developed in ABAQUS as shown in Figure 2 (a). The details of the model are presented in Table 1. A solid part was first created along with any cavities and then partitioned accordingly to assign the material properties. This way, the tie constraints required are eliminated reducing the running time. The models were first validated using the fire test results presented in Refs. [2,3]. Apparent thermal properties of AAC, brick and insulation were used to account for physical changes in the material such as cracks, melting, loss of moisture etc. Using the validated models, a parametric study was conducted. Two wall configurations were considered for each cladding material – with and without cavity insulation. Hence a total of four heat transfer models were developed for the external LSF walls with two cladding materials – AAC panels and brick veneer. The heat transfer model developed for cavity insulated external LSF with AAC panels and the temperature development is shown in Figure 2. The wall consists of 75 mm thick AAC panels, 24 mm cavity (for batten), 90 mm deep CFS studs and glass fibre cavity insulation and a 16 mm thick fire rated gypsum plasterboard. In the case of LSF wall with brick veneer cladding, the bricks were 110 mm thick and 50 mm cavity (for ties) were the only differences. Cored brick units of void ratio 0.38 were used.



(a) Two-dimensional heat transfer ABAQUS model



(b) Temperatures in the wall at 60 min (a small section of the model with CFS stud is shown)

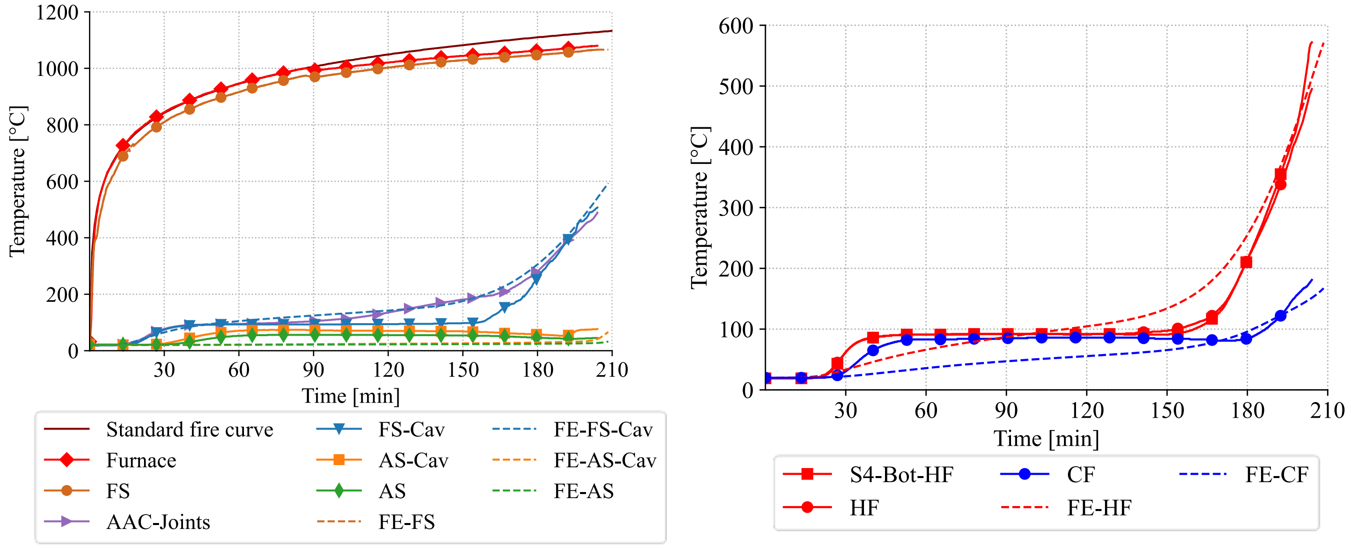
Figure 2. Heat transfer model and results of external LSF wall with AAC panels.

Table 1. Finite element heat transfer model details

Parameter	Details
Model dimensions	AAC panels: 1.2 m (width) x 0.195 m (depth) Brick veneer: 1.2 m (width) x 0.266 m (depth)
Mesh size	Global: 5 mm Plasterboard: 4mm
Element type	DC2D4
Fire side boundary conditions	Radiation: Emissivity – 0.9 Convection: Convective heat transfer coefficient – 25 W/m2°C Sink temperature: Standard fire curve (Parametric study) Fire side temperatures from fire test (Validation model)
Ambient side boundary conditions	Radiation – Emissivity: 0.9 Convection - Convective heat transfer coefficient: 10 W/m2°C Sink temperature: 20 °C
Cavity	Radiation – Emissivity: 0.9
Thermal properties	Based on the results presented in Refs. [3,5]

3 VALIDATION RESULTS

Ref. [3] presented the fire test result of an external LSF wall clad with AAC panels exposed to fire from the external side, that is, AAC panels exposed to fire. This test was used for validation, the model developed is shown in Figure 2 (a) and the boundary conditions are mentioned in Table 1. The validation of the finite element heat transfer model in terms of surface and stud temperatures comparison is shown in Figure 3. A reasonable agreement between the test and finite element model results could be observed. The model was similarly validated against the fire test results of external LSF walls with brick veneer cladding presented in Ref. [5].



(a) Comparison of AAC and plasterboard surface temperatures

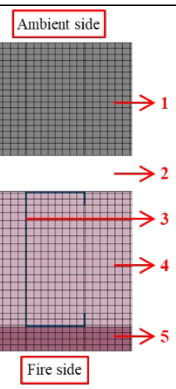
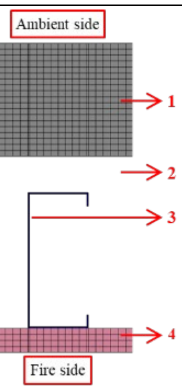
(b) Comparison of stud temperatures

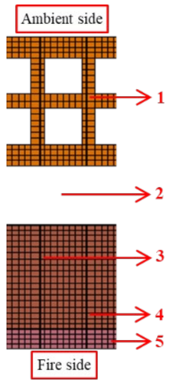
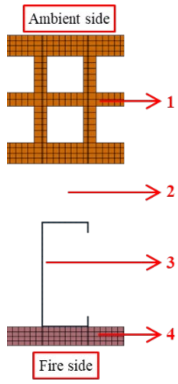
Figure 3. Validation of heat transfer FE model

4 PARAMETRIC STUDY

Finite element heat transfer models were developed for four different wall configurations. Wall configuration details and the FE model cross-sections are shown in Table 2.

Table 2. Parametric study LSF wall configurations

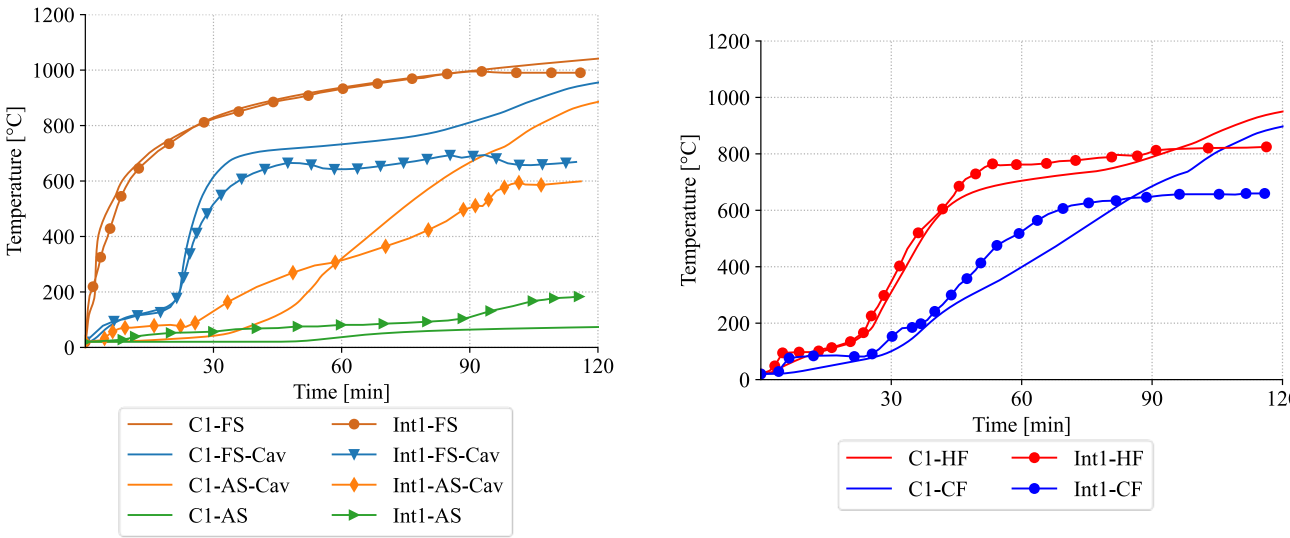
Case	Wall configuration	FE model cross-section
Case 1	75 mm AAC panels (1) 24 mm cavity (Battens) (2) 90 mm studs (3) with cavity insulation (4) 16 mm gypsum plasterboard (5) - exposed to fire	
Case 2	75 mm AAC panels (1) 24 mm cavity (Battens) (2) 90 mm studs (3) 16 mm gypsum plasterboard (4) - exposed to fire	

Case 3	110 mm cored (38 % void ratio) bricks (1) 50 mm cavity (2) 90 mm studs (3) with cavity insulation (4) 16 mm gypsum plasterboard (5) - exposed to fire	
Case 4	110 mm cored (38 % void ratio) bricks (1) 50 mm cavity (2) 90 mm studs (3) 16 mm gypsum plasterboard (4) - exposed to fire	

5 RESULTS AND DISCUSSION

5.1 External LSF walls clad with AAC panels

Figure 4 shows the temperature-time plots for Case 1 (referred to as C1) compared with those for an internal LSF wall with single layer plasterboard on both sides and glass fibre cavity insulation (referred to as Int1) from Ref. [6]. Fire side cavity temperatures are similar till 25 min after which differences are noticed, i.e., temperatures in the external LSF wall are higher compared to the internal LSF wall. Initially, the ambient side cavity temperatures of Case 1 are lower than those of the internal wall but then increase after about 60 min (Figure 4 (a)). Stud hot flange temperatures are very similar to internal LSF wall temperatures till about 90 min, after which they are higher in Case 1 (Figure 4 (b).

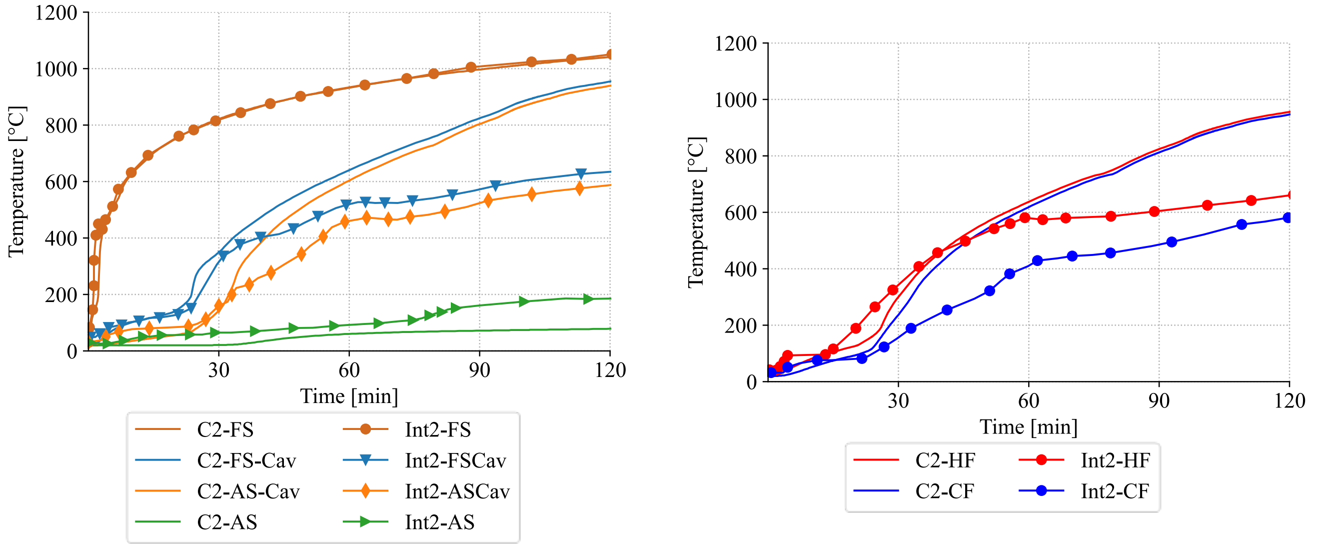


(a) AAC and plasterboard surface temperatures

(b) Stud temperatures

Figure 4. Comparison of temperature-time plots of Case 1 external wall (C1) with internal LSF wall (Int1).

The temperature-time plots for Case 2 (referred to as C2) are compared with those from another internal LSF wall fire test with single layer plasterboard on both sides of the stud and no cavity insulation (referred to as Int2) presented by Ref. [6] in Figure 5. Fire side cavity temperatures are similar till 30 min after which significant differences are noticed. Temperatures in the wall for Case 2 are much higher compared to those in the internal LSF wall (Figure 5 (a)). Stud hot flange temperatures in Case 2 are very similar to internal LSF wall temperatures initially, but they are much higher after about 40 min (Figure 5 (b)), which can lead to lower FRLs at low load ratios for Case 2.

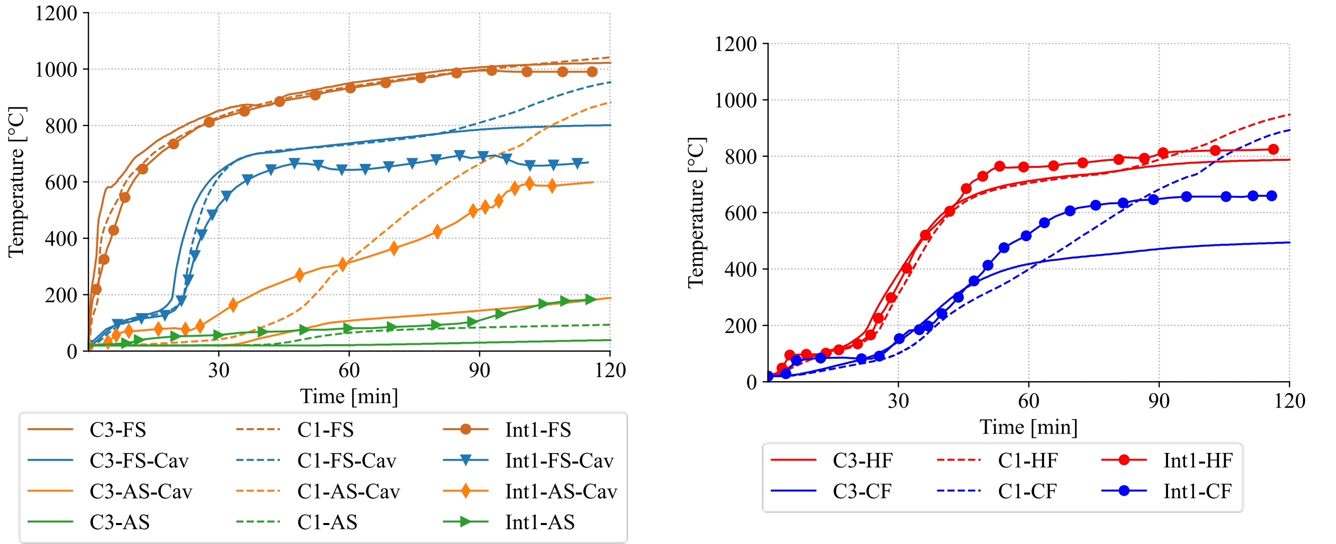


(a) AAC and plasterboard surface temperatures

(b) Stud temperatures

Figure 5. Comparison of temperature-time plots of Case 2 external wall (C2) with internal LSF wall (Int2).

5.2 External LSF walls with brick veneer cladding exposed to fire from the internal side

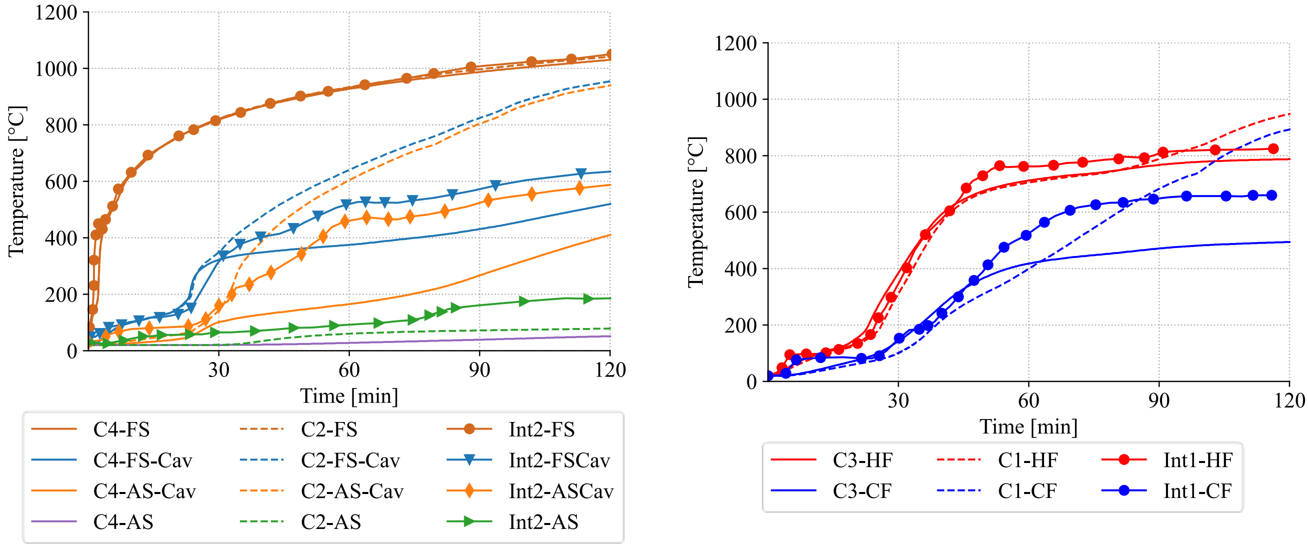


(a) Surface temperatures

(b) Stud temperatures

Figure 6. Comparison of temperature-time plots of Case 3 wall (C3), Case 1 wall (C1) and internal LSF wall (Int1).

Case 3 wall with cavity insulation and Case 4 wall without cavity insulation were exposed to fire on the internal plasterboard side with brick veneer cladding on the ambient side. To understand the influence of different ambient side sheathing materials (AAC panels, brick veneer cladding and gypsum plasterboards) on the temperatures, Case 3 results (brick veneer wall, referred to as C3) are compared with Case 1 results (AAC panel wall) and internal LSF wall with single layer plasterboard and cavity insulation (Int1) results from Ref. [6] in Figure 6. Similarly, Case 4 results (brick veneer wall, referred to as C4) are compared with Case 2 results (AAC panel wall) and internal LSF wall with single layer plasterboard and no cavity insulation (Int2) results from Ref. [6] in Figure 7.



(a) Surface temperatures

(b) Stud temperatures

Figure 7. Comparison of temperature-time plots in Case 4 wall (C4), Case 2 wall (C2) and internal LSF wall (Int2).

Although the wall configurations are very similar except for the cladding/sheathing on the ambient side, clear differences were observed. For the cavity insulated walls with AAC panels (C1), the temperature-time plots were very similar to those of the internal LSF wall (Int1) when exposed to fire from the internal plasterboard side. But in the case of the brick veneer wall (C3), the ambient side cavity temperatures were much lower compared to the other two walls (C1 and Int1) (Figure 6 (a)). In the case of stud temperatures, hot flange temperatures were very similar in all three cases. But cold flange temperatures were similar in the initial 45 min after which they were lower in C3 wall (Figure 6 (b)) compared to the other two walls (C1 and Int1).

In the case of non-cavity insulated walls (Figure 7) also, the ambient side temperatures are lower in C4. It was observed that AAC panels (C1) on the ambient side resulted in higher temperatures in the stud compared to internal LSF wall (Int2) as AAC panels block the heat. But in the case of brick veneer wall (C4), the stud temperatures including the hot flange are much lower after 30 min compared to the other two walls (C2 and Int2).

Thermal conductivities of plasterboard (0.26 W/m°C) and AAC (0.104 W/m°C) are very low compared to bricks (1.45 W/m°C). Hence plasterboard and AAC panels block the heat resulting in higher ambient side cavity and stud cold flange temperatures in both non-cavity insulated, and cavity insulated walls. A higher cavity depth (50 mm) in brick walls compared to AAC walls (24 mm) and comparatively very high thermal conductivity of bricks (more than 10 times AAC) resulted in much lower stud temperatures. The cross-sections and thermal conductivities of AAC, plasterboard and brick are presented in Table 3.

Table 3. Thermal conductivity of AAC, plasterboard and brick

Thermal Conductivity (W/m°C)	AAC	Plasterboard	Brick
	0.104	0.26	1.45

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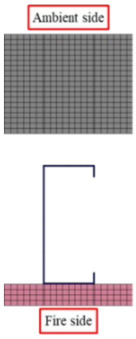
<td></td>
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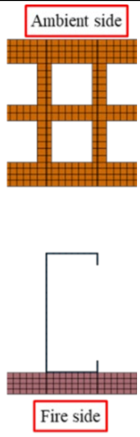
<td></td>
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6 CONCLUSIONS

The main conclusions from the finite element heat transfer modelling results of the four external LSF wall configurations and comparison with internal LSF walls are,

- The temperatures were very similar to the internal LSF wall temperatures in the case of cavity insulated walls and hence the FRLs of internal LSF walls can be used.
- In the walls with no cavity insulation exposed to internal fires, AAC panels with very low thermal conductivity block the heat resulting in higher stud temperatures (thus reduced FRLs) compared to brick veneer walls and internal LSF walls.
- The reason for the differences in the stud temperatures is simple, i.e., the thermal conductivity of the unexposed side (ambient side) cladding/sheathing.
- AAC with the lowest thermal conductivity acts as insulation blocking the heat in the cavity, resulting in higher temperatures.
- Brick on the other hand with high thermal conductivity and moisture takes away heat resulting in lower temperatures in the cavity and studs.
- The difference in the cavity (24 mm in the case of AAC walls and 50 mm in the case of brick veneer walls) could also have an impact on the difference in the temperatures.

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