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Comparative assessment of Airflex® insulation in roofs

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Contents *page*

Executive Summary

The Centre for Infrastructure Management (CIM) at Sheffield Hallam University were requested by KdB Isolation, Nantes, France, in the absence of a standard thermal conductivity test for Thermo Reflective Insulants, to evaluate the insulation performance of Airflex against 200mm of Mineral Glasswool in a custom built roof space at extreme winter temperatures.

The tests were conducted in series in an enclosure replicating a roof space which was placed in a temperature controlled environmental chamber. The aim of the test was to maintain a temperature of 21ºC in the enclosure whilst the external target temperature was varied between -5°C and +5°C in 5°C increments. The roof enclosure was insulated in accordance with standard procedures for the relevant materials. Six thermocouples were placed in the enclosure, two in the base, two at mid height on the rafters and two in the apex of the roof. One thermocouple was also used to measure the external temperature. Hotspot ceramic heaters were used to provide heat inside the enclosure and a thermostat was located in each enclosure to control the heaters. A data logger was used to record the temperatures within the enclosure and a single phase residential meter was used to record the power consumed in heating the enclosure throughout the monitoring periods. Each insulating material was monitored over a two day period.

The quantity of apparent specific heat required to maintain the internal target temperature (21ºC), taking into account variations in internal and external measured temperatures and volume of heated airspace, was determined for all tests. The results showed that the Airflex insulation exhibited a fairly consistent performance in all tests and required lower apparent specific heat input for all test increments (-5, 0, +5 °C). The Airflex was 44.5%, 40.1% and 43.7% more efficient at -5°C, 0°C and +5°C external temperatures respectively over a 40 hour monitoring period. The effective thermal resistance for Airflex in this comparative test, whilst not directly measured or calculated, is considered to be at least equal to the thermal resistance of the Glasswool (5.0 m^2K/W) as a result of the relative performances observed in this study.

1 Aims

The aim of the test was to carry out a comparative evaluation of Airflex thermo reflective insulation relative to a standard Glasswool insulation by conducting laboratory tests on a scaled down insulated roof truss exposed to winter temperatures.

2 Objectives

A custom built enclosure replicating a roof void was insulated with conventional Glasswool and the Airflex thermo reflective insulation in series to make a comparison between their performances. The enclosure was heated with a Hotspot ceramic heater and the power required to maintain a target temperature of 21ºC was monitored. In addition, the enclosure was instrumented with thermocouples to monitor both the internal and external temperature. The data was analysed to provide time-performance characteristics of the two insulation systems over the monitoring period.

3 Test Programme

The test programme was carried out as follows:

a) plan and specify the test programme
b) design and manufacture the test enclosure
c) instrumentation (calibration of thermocouples)
d) set up data monitoring equipment
e) monitor and collate data
f) analyse data
g) final report

4 Methodology

4.1 Enclosure

One enclosure was used to evaluate the comparative performance of Airflex against conventional Glasswool insulation. The enclosure was constructed of timber members (Fig. 1) and was supported on a 100mm polystyrene base to prevent heat loss to the ground. The plan area was approximately 1.77m x 1.77m with a height of approximately 1.2m.

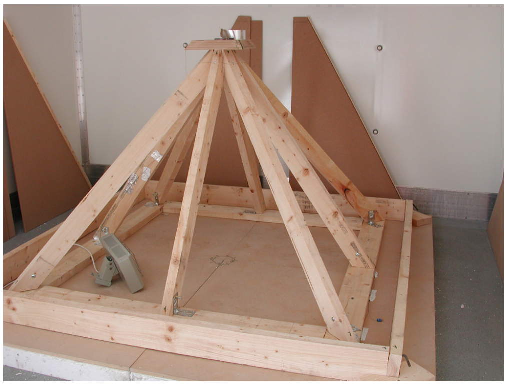


Fig. 1 Roof construction on polystyrene base

The insulation materials were applied in accordance with standard procedures. Referring to Fig. 2, 100mm thick Glasswool was placed between rafters (approx. 100 x 46mm cross-section) with a further 100mm layer placed at right angles over the top of the rafters. A 25mm air gap was maintained between the insulation and the external MDF boards. The same roof was used to monitor the performance of Airflex as shown in Fig 3 with the Airflex insulation wrapped over the outer surface of the rafters. Two types of jointing techniques were used in accordance with the

Fig. 2 Glasswool applied between rafters

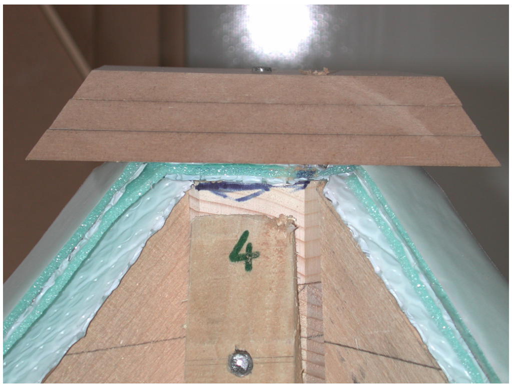


Fig. 3 Airflex applied at the apex

manufacturer's instructions as shown in Figure 4. Type A was used on the vertical joints along the hip rafters and at the apex of the roof with double sided tape used to join the interfaces. Type B was used horizontally towards the top of the enclosure as shown in Figure 5. The enclosure was located in a temperature controlled environmental chamber with a target set-point between -5°C and +5°C in 5°C increments for approximately two days per increment (Fig. 6). The same monitoring equipment was used to monitor the performance of both insulants (Section 4.2-4.4).

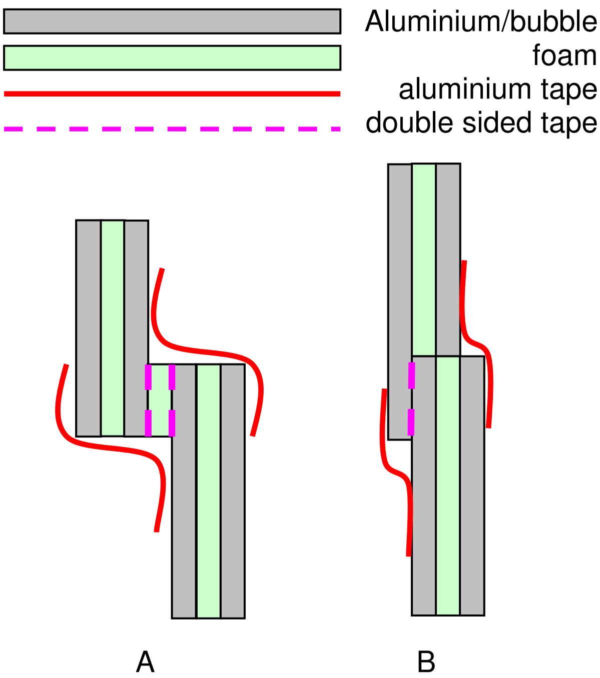


Fig. 4 Airflex jointing techniques

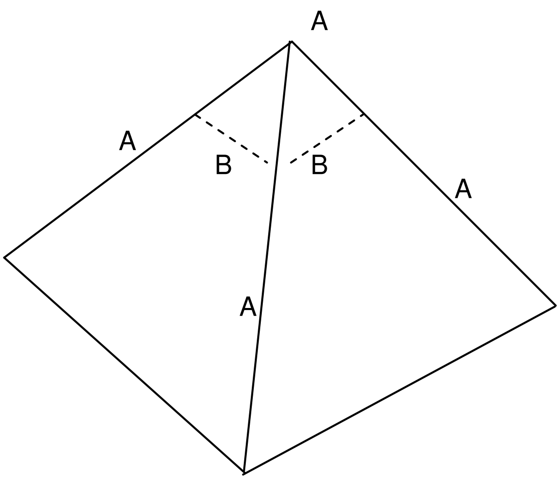
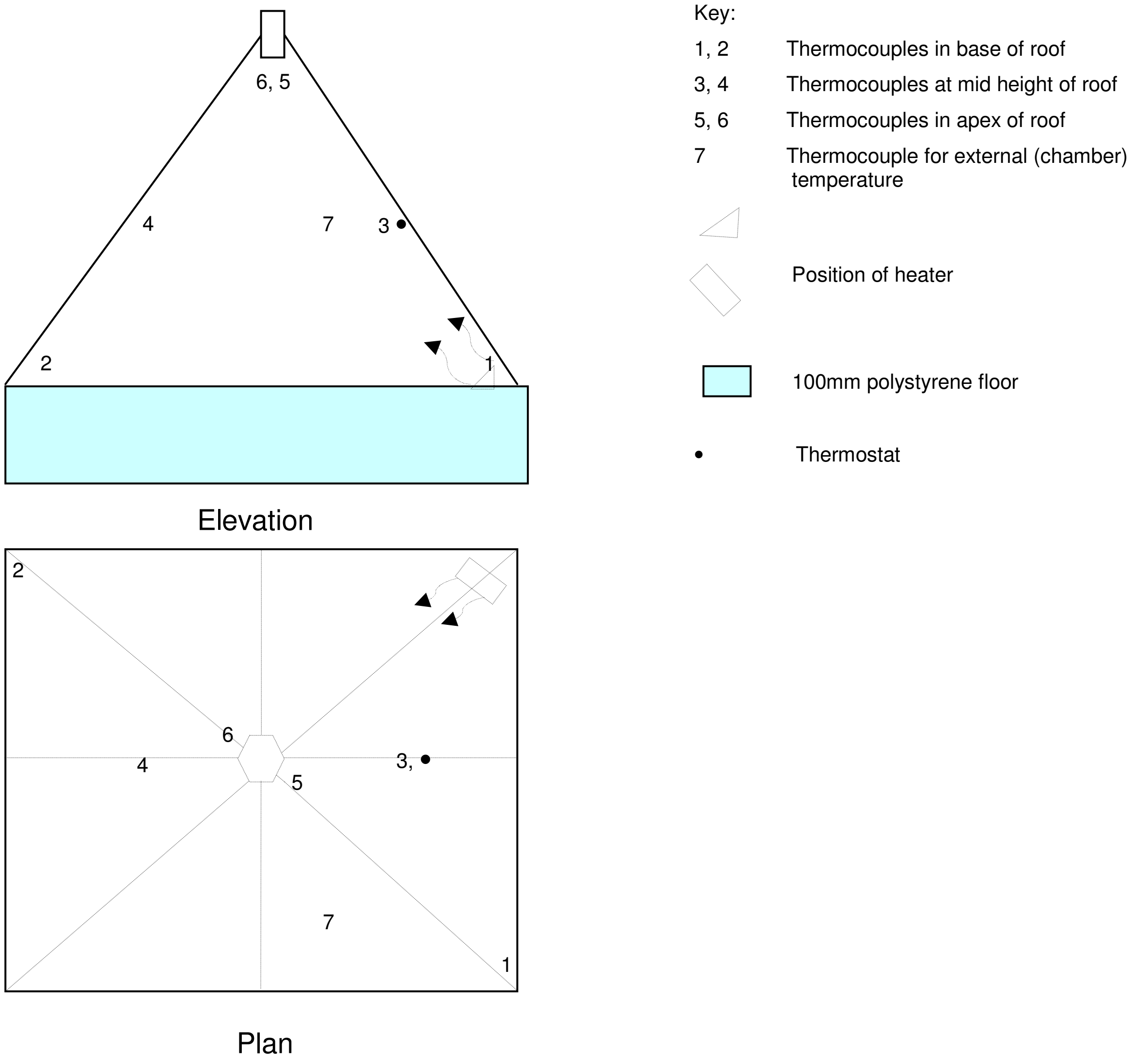


Fig. 5 Position and type of joints

Fig. 6 Finished enclosure under test

4.2 Thermocouples

A total of seven thermocouples (type T) were employed to measure the internal and external temperatures. All thermocouples were calibrated in the laboratory before application and a calibration factor, where necessary, was applied to the data. The approximate locations of the thermocouples are shown in Fig. 7. Two thermocouples were placed internally in the base on the roof (labelled 1 and 2), a further two thermocouples were placed internally on the rafters at mid height (labelled 3 and 4) and two were located internally in the apex of the roof (labelled 5 and 6) as shown in Figure 7. The external temperature was monitored by a thermocouple positioned at mid-height in the centre of one face of the roof (labelled 7, Fig. 7).



(not to scale)

Fig. 7 Location of thermocouples, thermostat and heaters

4.3 Heating equipment

The enclosure was provided with a Hotspot Ceramic Heater (model HSE 1500, Fig. 7). This is a 1.5kW radiant heat source with dimensions of 340 x 210x x 210 mm. The heater had a set point of 21ºC and was controlled by a thermostat attached internally to the central rafter as shown in Fig. 8.

Fig. 8 Ceramic heater in position

4.4 Data logging equipment

The data logging equipment is shown in Figs. 9 and 10. The power consumption by the heater was monitored by a single phase residential meter (Fig. 9) and the cumulative usage in kWh was recorded. The temperature at the thermocouples (Fig. 6) was monitored at 10 minute intervals by an automatic logging device (Datataker DT615 and a channel expansion module) as shown in Fig. 10. Stored data was downloaded at the end of each test (approximately every two days) for analysis.

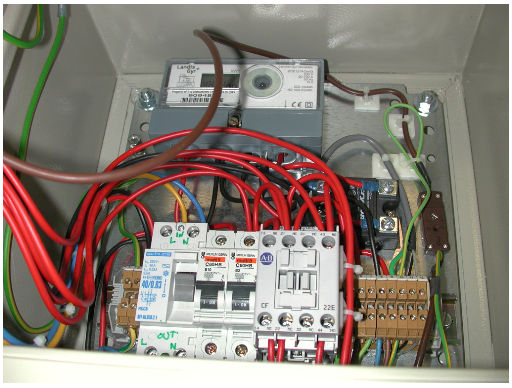


Fig. 9 Power consumption meter

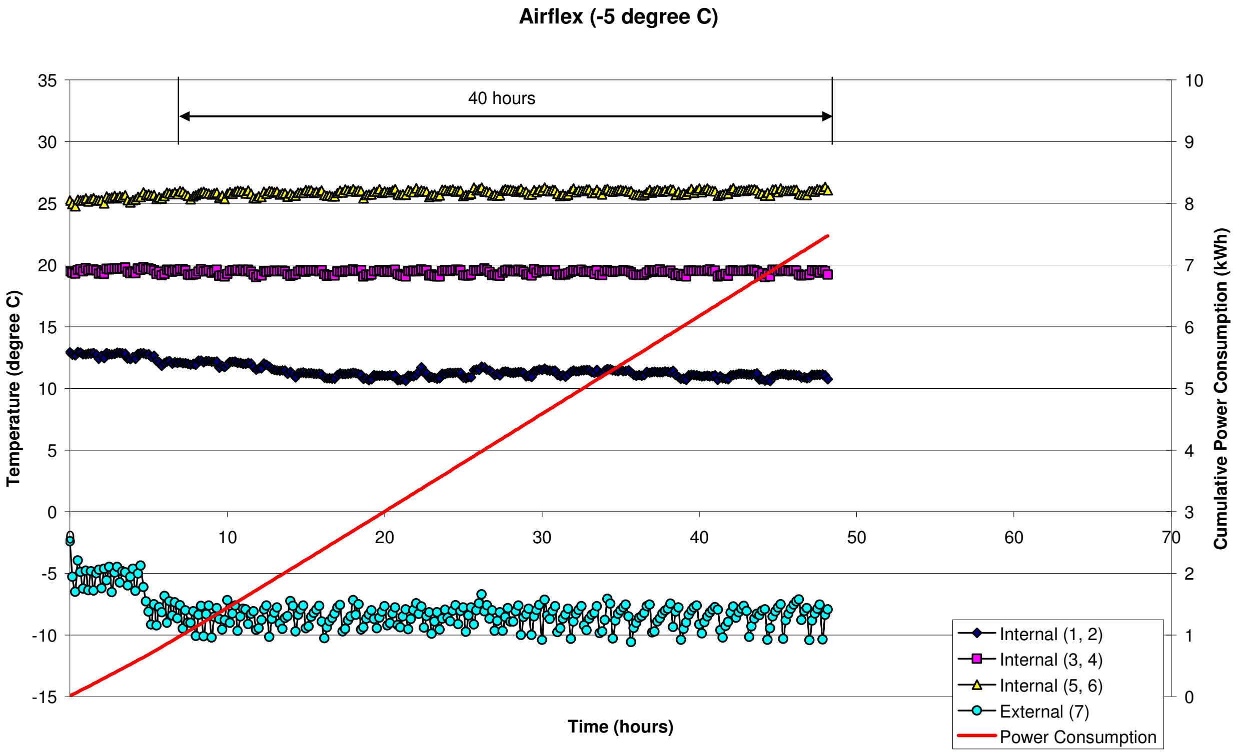
Fig. 10 Data logger (lower) and channel expansion module (top)

5 Results

5.1 Influence of insulation materials on internal temperatures

Figs. 11-13 show the recorded temperature profiles and power consumed within the monitoring period which enables a comparison of performance between Airflex and Glasswool as insulation materials when tested as described in Section 4. The data is presented over a period of up to 70 hours but the analysis concentrates only on the steady state data (the last 40 hours of monitoring). Therefore, the early age data is ignored as this will include the influence of changeover of test increment where the climatic chamber is either heating up or cooling down to reach the desired target temperature. Referring to Figs. 11-13, four temperature profiles are presented in the graphs. Internal (1, 2), (3, 4) and (5, 6) refers to the average of the two thermocouples at locations 1 & 2, 3 & 4 and 5 & 6 respectively (Figure 7). However, thermocouple 2 in Figs. 11 and 12 malfunctioned during the +5 and 0 degree tests hence the temperature for thermocouple 1 only is used in these figures. External (7) refers to the external temperature recorded from thermocouple 7 (Fig. 7). External (7) in the relevant figures represents the target external temperature of -5°C (Fig. 11), 0°C (Fig. 12) and +5°C (Fig. 13). The heater inside the roof space had a set point of 21ºC as described in Section 4.3. Analysis of the data presented in Figs. 11-13 is presented in Section 5.2.

In addition, it was also evident upon the completion of initial testing that the jointing system used on the hip rafters (Type A, Figs. 4 and 5) had failed on one rafter since the aluminium tape was not strong enough to keep the overlap in place. These results were discarded and the tests were redone with a stronger joint. Since the Airflex insulation is quite a stiff material, consideration should be given to strengthening the jointing system where the material is curved to form an overlap.



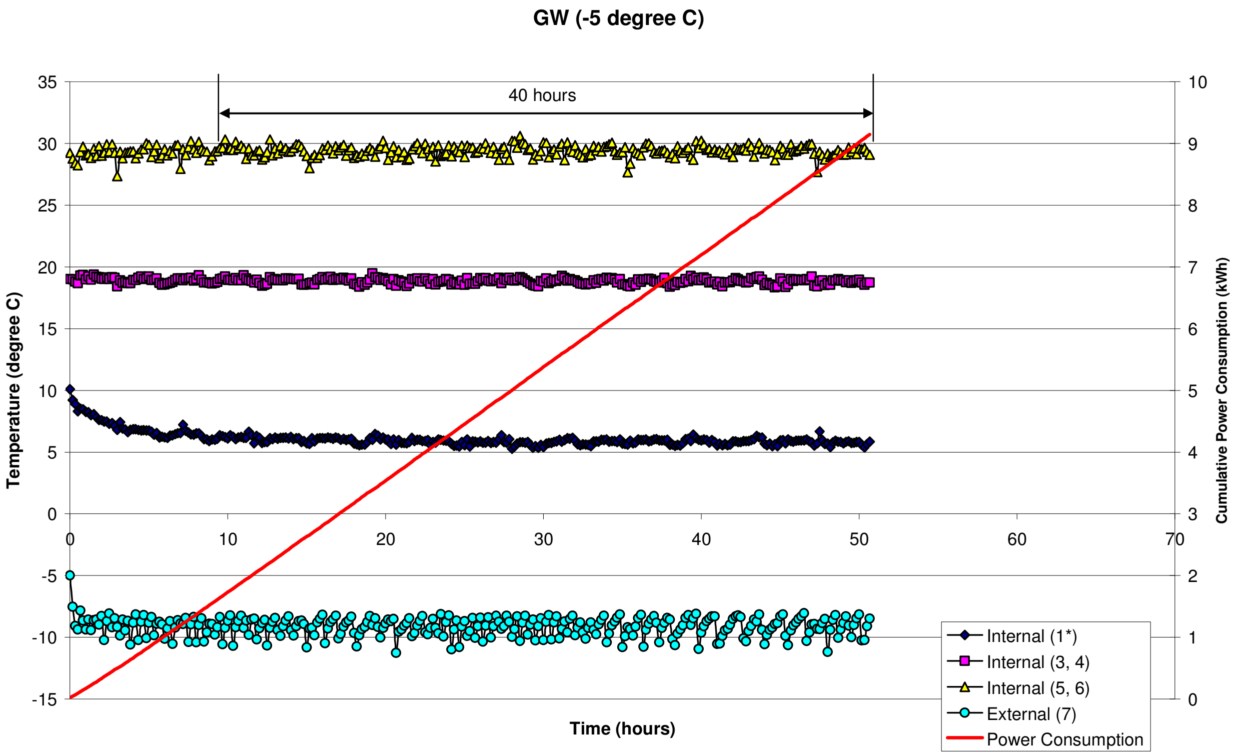
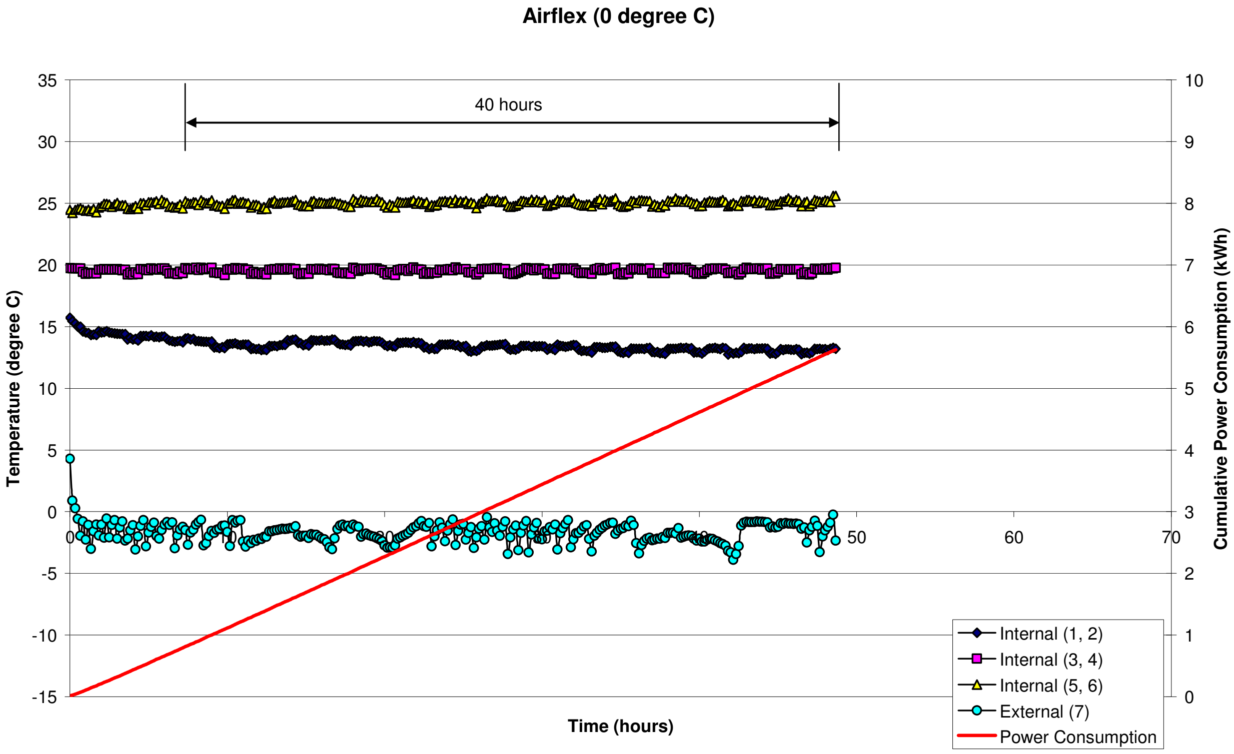


Fig. 11 Temperature profiles at -5°C



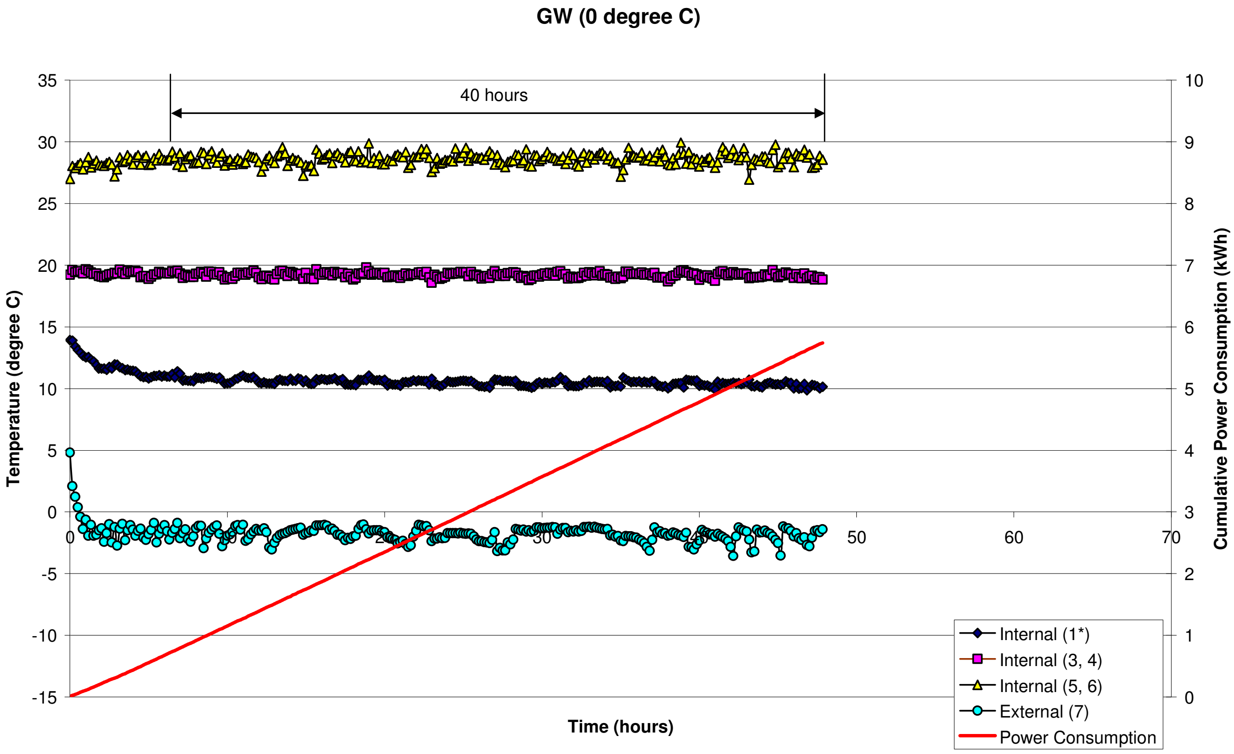
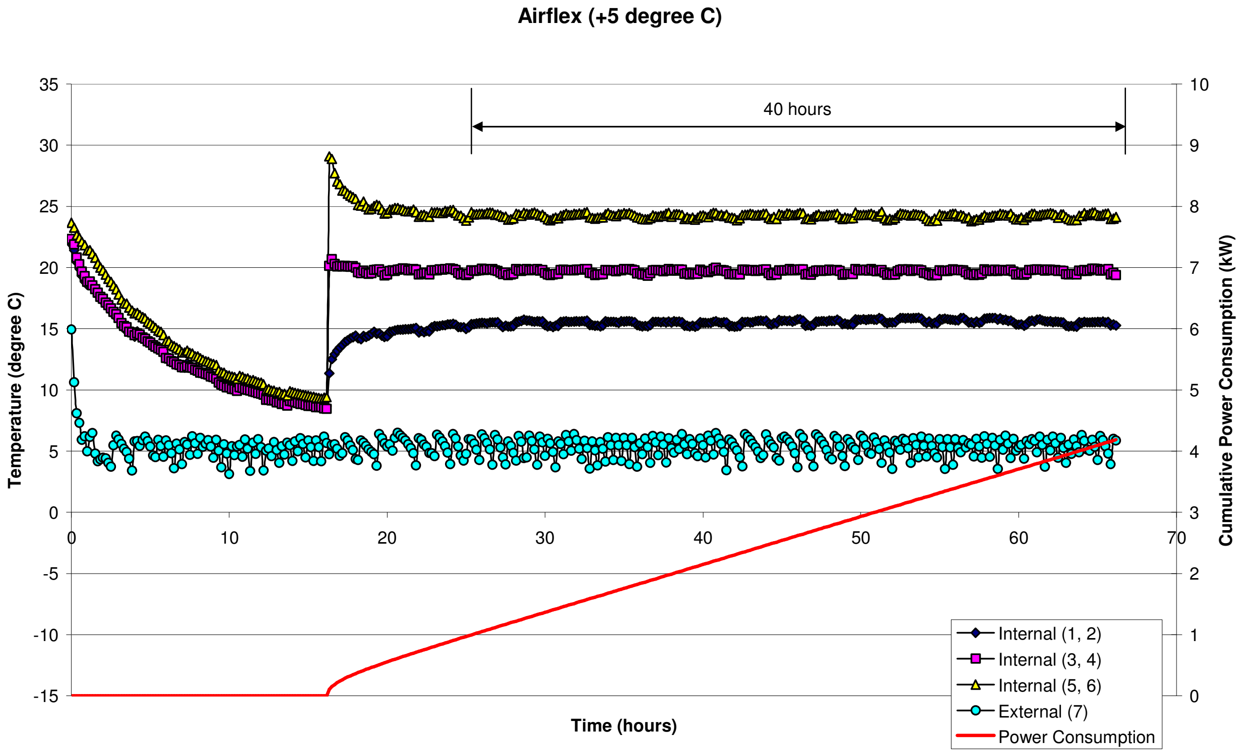


Fig. 12 Temperature profiles at 0°C



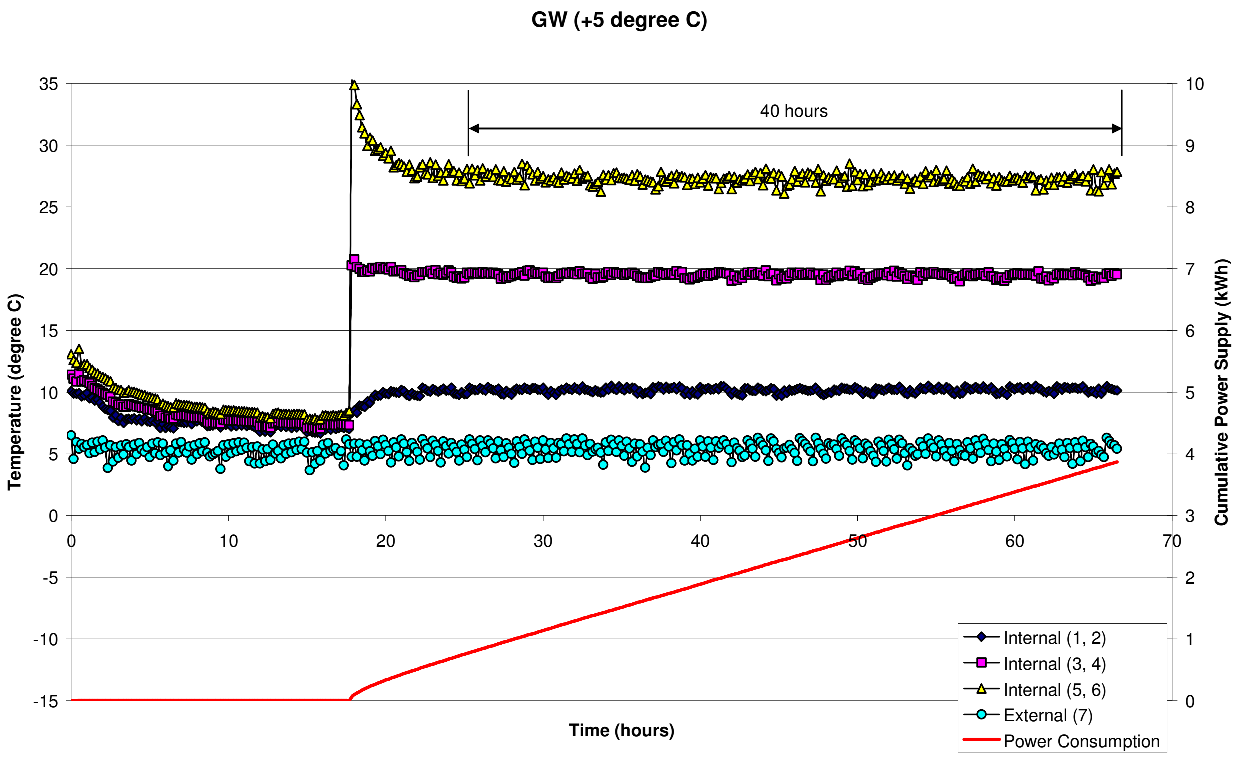


Fig. 13 Temperature profiles at +5°C

5.2 Analysis of data

Referring to Figs. 11-13, a similar trend is evident in all profiles. In the early stages of testing, the external temperature in the environmental chamber is allowed to stabilise. The heaters are then switched on in the enclosure. The power consumption steadily increases as energy input is required to maintain a target temperature of 21°C.

The profiles from the internal gauges in Figs. 11-13 are predominantly horizontal indicating that a steady state is reached. It is clear, however, that the temperature profiles in the Airflex insulated roof are closer together indicating a lower temperature variation between the floor and apex of the roof as opposed to the Glass wool insulated roof (the reflective material is more efficient in circulating heat within the enclosure). In addition, the profile of thermocouples 'Internal (3, 4)' in all tests unsurprisingly exhibits a temperature close to 21°C as the thermocouples are at a similar height in relation to the heater thermostat (Fig. 7).

Since the consumption of power is used to assess the performance of the insulation materials, a steady state period of 40 hours is used throughout in the analysis to eliminate the effects of the initial settling period experienced by all materials. This period is taken as the final 40 hours of testing when a steady state has materialised.

The data presented in Table 1 gives a comparison of the performance of the insulation materials. The data is used to calculate the apparent heat required to maintain the internal temperature at 21°C, taking into account differences such as internal air volume and measured average internal and external temperatures. The apparent specific heat required to maintain the internal temperature is calculated from the specific heat capacity equation as follows:

$$c = \frac{Q}{(m)(\Delta T)} \qquad \text{Equation 1}$$

where c is the apparent specific heat required to maintain the internal temperature at 21°C (kJ/kg°C), Q is the cumulative heat input of the heater (kJ), m is the mass of air (kg) and ΔT is the temperature gradient (°C).

Col. 1 shows the materials under consideration and col. 2 gives the target external temperatures of -5°C, 0°C and +5°C. The actual average external temperatures over the 40 hour monitoring period are given in col. 3 (taken from 'External (7)', Figs. 11-13), and the average internal temperature is shown in col. 4. Since the temperature within the respective roof increases from the base to the apex as shown in Figs. 11-13, the internal average temperature is obtained through a process of integration to account for the variation in increasing temperature and decreasing volume along the height of the roof. Col. 4 also shows that the Airflex insulated roof maintained a higher average internal temperature at each of the target internal temperatures of -5°C, 0°C and +5°C. Col. 5 gives the internal and external temperature gradient (col. 4 - col. 3). The power consumed within the 40 hour analysis period is given in cols. 6 and 7 respectively for each test (from 'Power Consumption' in Figs. 11-13) and the total power consumed in kW over this 40 hour period is given in col. 8 (col. 7 - col. 6). The power consumed in col. 8 is converted to kJ in col. 9 (col. 8 x 3.6 e10^6). A constant density of 1.204 kg/m^3 is assumed for the air inside the enclosure (col. 10) and the volume of airspace is estimated in col. 11 (the thicker Glasswool insulation leads to a reduction in the volume of air inside the enclosure). The resulting mass of air in the enclosure is shown in col. 12. The apparent specific heat, c, required to maintain the target temperature of 21°C inside the enclosure is given in col. 13 and is calculated from Equation 1. The percentage difference in specific heat is shown in col. 14 and indicates that the performance of the Airflex insulation material is 44.5%, 40.1% and 43.7% more efficient than the Glasswool when tested at -5°C, 0°C and +5°C external temperature respectively.

5.3 Discussion

Referring to the total power consumption data in col. 8 (Table 1), the Airflex and Glasswool exhibit similar consumptions at the 0 and +5°C tests whereas the Airflex is more efficient at the -5˚C test. However, when the difference in internal and external temperatures is taken into account (col. 5) along with the difference in internal volumes (col. 11), the analysis shows that the apparent specific heat required to maintain the internal temperature at 21˚C is lower for the Airflex material (col. 13).

Table 1 Analysis of data

1	2	3	4	5	6	7	8	9	10	11	12	13	14
	Target External Temp	Average External Temp	Average Internal Temp	ΔT	Power	Power	Total Power	Total Power	Density of Air	Volume of Air	Mass of Air	Apparent Specific Heat, c*	% diff
												Eq. 1	
		°C	°C	°C	kWh	kWh	kWh	kJ	kg/m^3	m^3	kg	kJ/kg°C	
Airflex	-5	-8.54	16.35	24.89	1.238	7.475	6.237	22453	1.204	1.21	1.457	619	44.5
	0	-1.73	18.15	19.88	0.962	5.627	4.665	16794	1.204	1.21	1.457	580	40.1
	5	5.29	18.11	12.82	1.143	4.185	3.042	10951	1.204	1.21	1.457	586	43.7
GW	-5	-9.17	13.05	22.22	1.852	9.144	7.292	26251	1.204	0.88	1.060	1115	
	0	-1.85	15.18	17.03	0.89	5.743	4.853	17471	1.204	0.88	1.060	968	
	5	5.39	15.30	9.91	0.829	3.869	3.04	10944	1.204	0.88	1.060	1042	

** These are relative values given by a common monitoring system. They should not be used to compare the performance of materials of different manufacturers given elsewhere*

In addition, the apparent specific heat calculated for the Airflex at -5, 0 and +5˚C is within 7% (580-619 kJ/kg°C) indicating that the insulant performed consistently irrespective of the external temperature. This value is more variable in the Glasswool tests (968-1115 kJ/kg°C) giving a maximum variation of 15%.

6 Conclusions

The following conclusions are based on the results and analysis of the tests conducted to evaluate the performance of Airflex in relation to Glasswool as an insulation material in simulated roof spaces:

- Less heat is required in the Airflex insulated enclosures to maintain a target temperature of 21ºC when variations in the temperature gradient and volume of airspace within the enclosure are taken into account.
- Airflex is 44.5%, 40.1% and 43.7% more efficient than the Glasswool when tested at -5°C, 0°C and +5°C external temperature respectively.
- The technique used to join the Airflex at bends needs further consideration as the joint had failed in one of the preliminary tests.
- In the absence of a standard thermal conductivity test for reflective insulants, the effective thermal resistance for Airflex in this comparative test, whilst not directly measured or calculated, is considered to be at least equal to the thermal resistance of the Glasswool (5.0 m^2K/W) as a result of the relative performances observed in this study.