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Test Report

UKAS TESTING 0002

Measurements to determine the effect of air infiltration on the U-value of a Mineral Wool Best Practice roof structure

FOR	EURIMA Avenue Louise 375, Box 4 B-1050 Brussels Belgium In association with the Mineral Wool Insulation Manufacturers Association For the attention of Mr Alain Herssens (EURIMA) & Mr Stephen Wise (Knauf)
IDENTIFICATION	NPL Quote numbers: 2013030359, 2013110262 and 2013120162. NPL ID number R155 was assigned to the Mineral Wool Best Practice roof structure . NPL ID number LA621 assigned to the two layers of 90 mm thick Knauf Earthwool SK Frametherm Roll 35. NPL ID number LA622 to the 50 mm thick Knauf Earthwool Building slab RS45.
BASIS OF TEST	The NPL Rotatable Wall Guarded Hot Box whose calibration is traceable to National Standards and using the measurement procedures defined in the European Standard BS EN ISO 8990 was used to measure the heat transfer through the system. Additional equipment was installed in the test elements to enable a variable air flow to be produced through the roof cavity and to measure the air velocity in the roof cavity that was produced.
UNCERTAINTY	The overall expanded uncertainty is estimated to be within ± 6.5 %, based on a standard uncertainty multiplied by a coverage factor k = 2, providing a coverage probability of approximately 95 %. The uncertainty evaluation has been carried out in accordance with UKAS requirements.

Reference PP31/2013030359/2

Date of issue: 21 October 2014

Signed: (Authorised Signatory)

Checked by:

Name: Ray Williams for Managing Director

1 OVERVIEW OF MEASUREMENTS

a) These measurements were carried out in an attempt to quantify the effect of passing air through the cavity created just under the tile layer of a roof structure (which in this roof structure was a simple sheet of plywood). The roof structure was installed in the NPL Rotatable Wall Guarded Hot Box Apparatus and its thermal transmittance measured with three different, measured, air flows established through that cavity.

b) The air flow through the cavity was achieved by sucking air from the cold chamber of the hot box apparatus through the roof cavity at different rates. This was achieved by using a small, DC fan fixed to an aperture near the top of the "tile" layer in each half of the roof. The air was drawn through a 30 mm gap that was left at the bottom of the tile layer. This is shown in Figure 1.

c) The measurements were carried out with the test roof mounted at 45 degrees to the horizontal. The cold chamber was above the warm chamber.

d) The air velocity in the roof cavity was measured using six air flow velocity sensors. Three air flow sensors were installed in each half of each roof, either side of the central rafter. See Figure 3.

e) Four additional thermocouples (to those normally used to measure U-values) were installed inside each roof structure during these measurements to detect any effect of the various air flow regimes on the temperature profile across the roof.

f) Six calibrated heat flux transducers were fixed to the warm surface of the roof structure and their outputs logged during the measurements as a check on the heat flow through the structure as an additional way of measuring the effect of air movement through the structure.

g) The thermal transmittance of the roof structure was measured with i) three air flow rates through the roof cavity, ii) with no air flow through the roof cavity and the slot at the bottom of the tile layer blocked off and iii) with the maximum air flow through the roof cavity and with four off, 6 mm diameter holes drilled through the plasterboard of the structure. The holes were to replicate the effect of accidental breaks in the plasterboard that sometimes occurs around light fittings etc.

1 DESCRIPTION OF THE TEST ELEMENT

The roof structure under investigation during this series of measurements was referred to as a Best Practice Mineral Wool roof structure. The cross section drawing in Figure 2 shows the make-up of this test structure. The details of the rafters and the positions of the air velocity sensors are shown in the front elevation drawing in Figure 3. To replicate the likely practice in a real roof, the insulation was installed in pieces with butt joints between those pieces. The position of those joints and the positions of the additional thermocouples are shown in Figure 4. The insulation and roofing underlay used in this structure were:

- 2 layers of Knauf Earthwool 90 mm Frame Therm Roll 35
- 1 layer of Knauf Earthwool Building Slab RS45 50 mm thick
- Glidevale Protect VP 400 Roofing underlay & DAFA Difoil Vapour barrier.

Figure 1 Sketch showing positions of the fans and the rafters

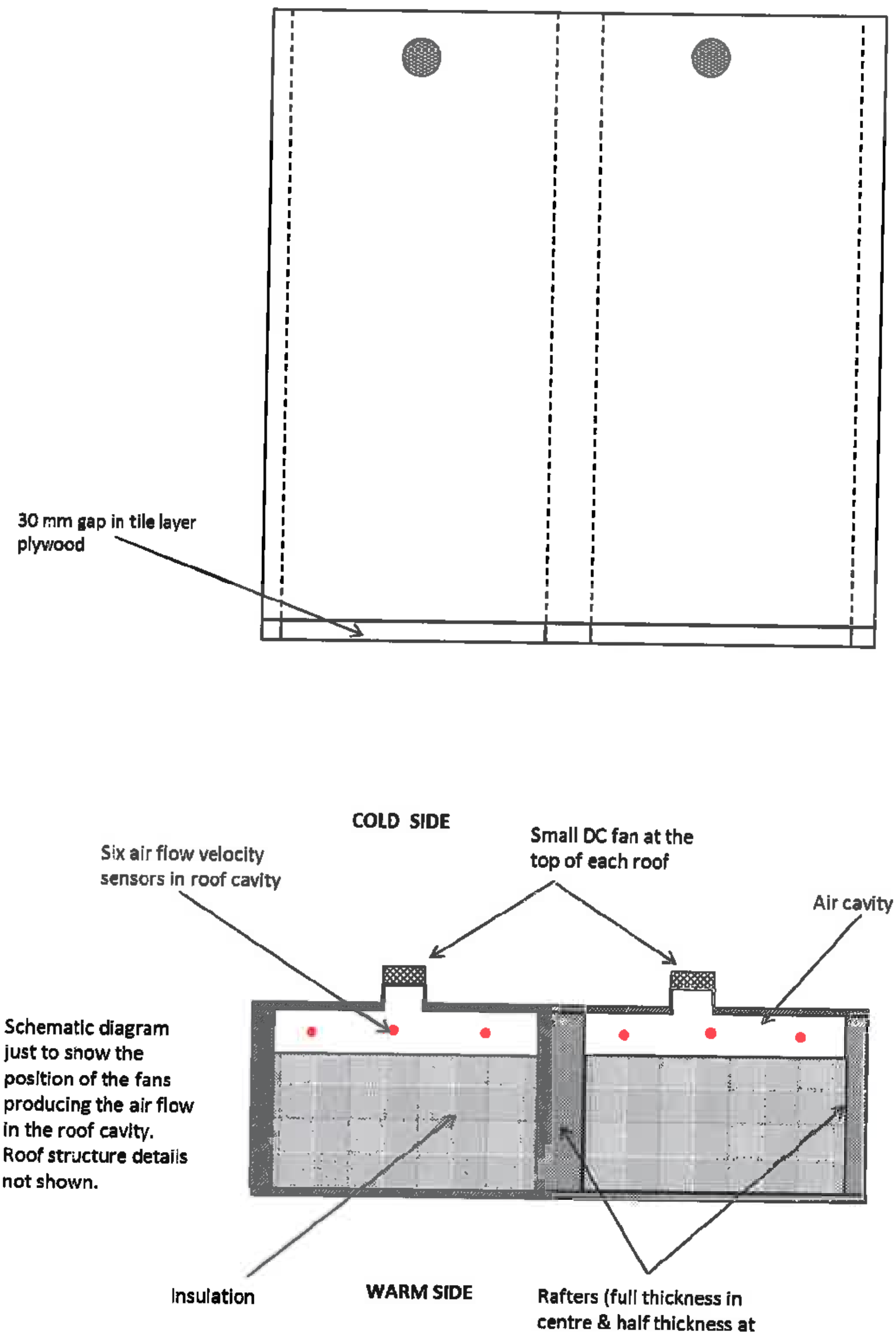

Figure 2 Cross section drawing of the Best Practice Mineral Wool roof structure.

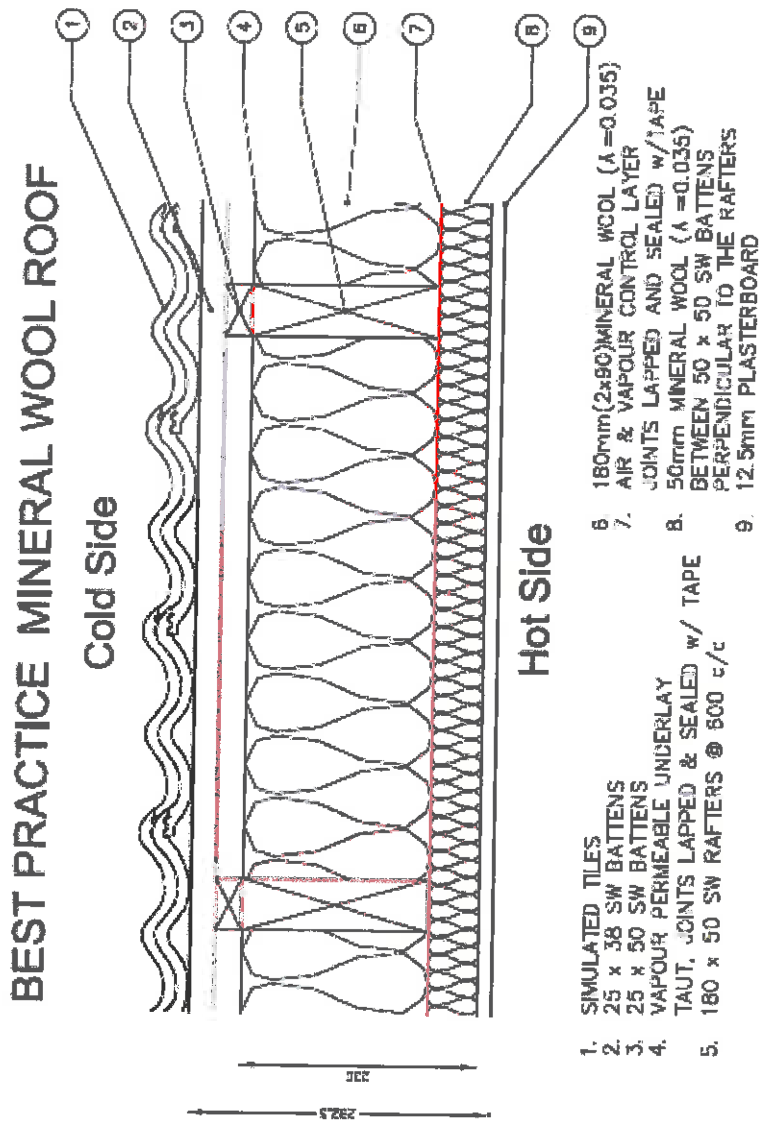

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Figure 3 Sketch showing the position of the air flow velocity sensors and 6 mm diameter holes drilled through just the plaster board

Positions of the air velocity sensors marked by their identity code eg 1A & 2A

Positions of the 6 mm diameter holes drilled through the plaster board only marked by "O"

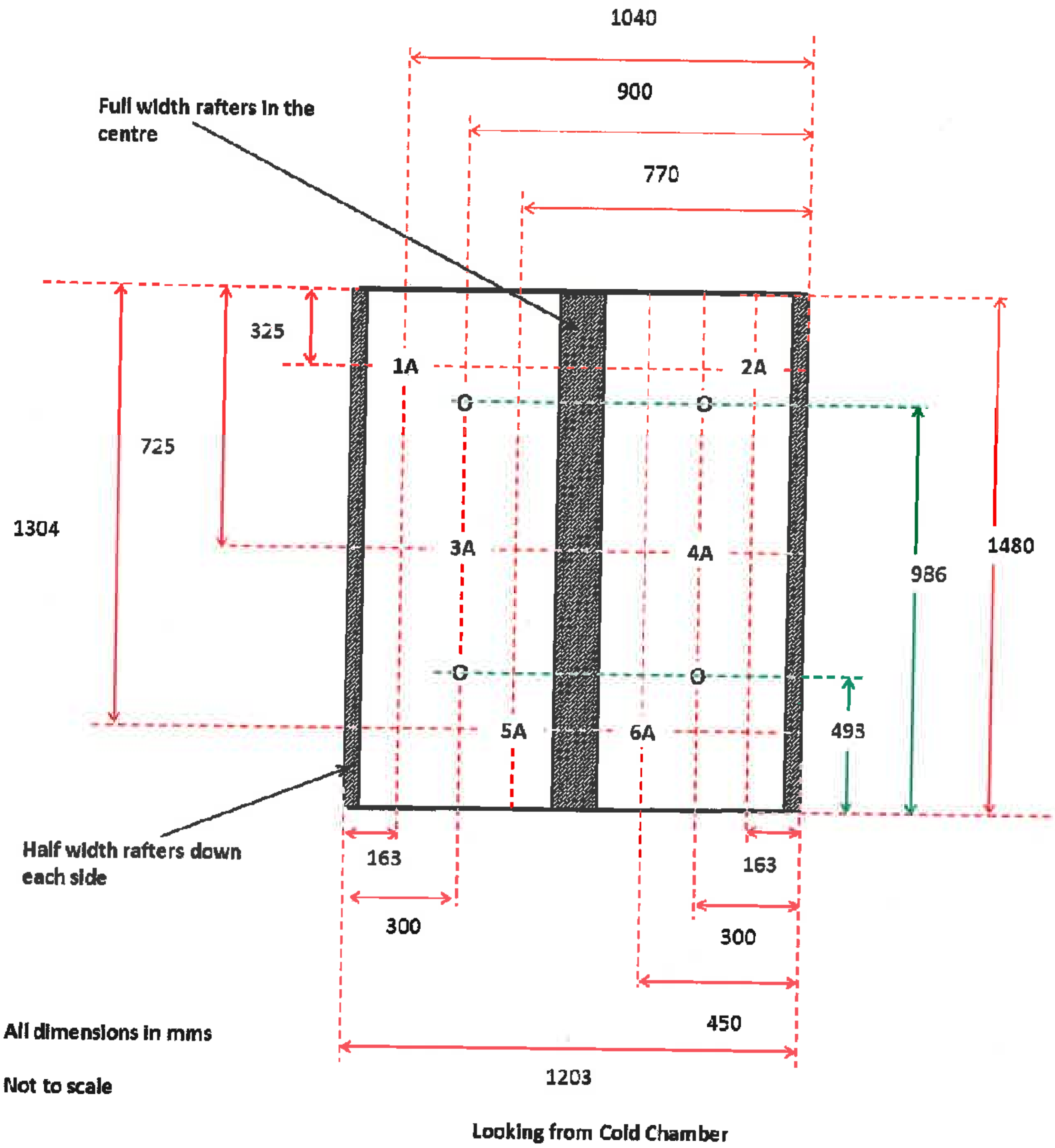

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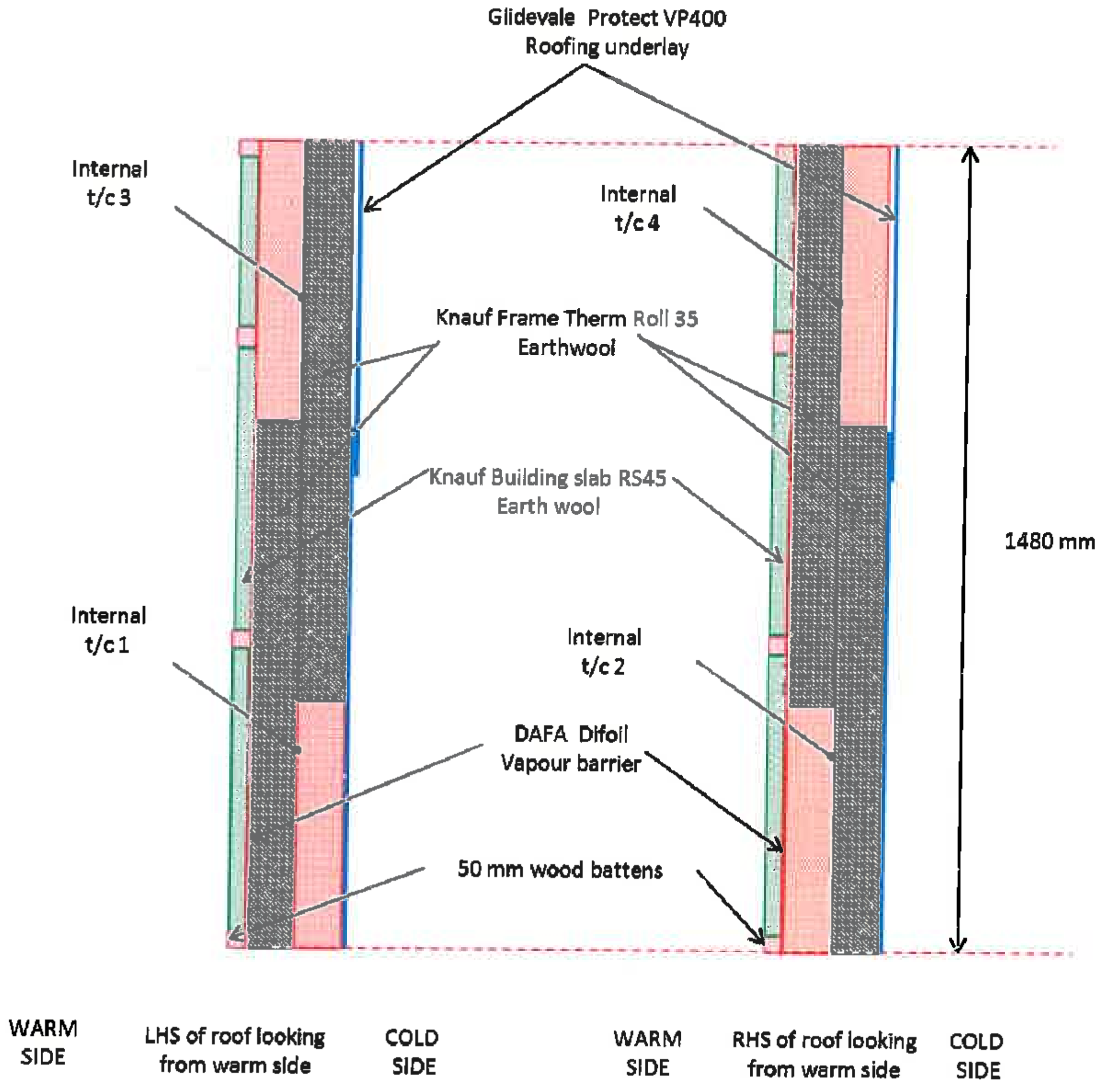
Figure 4   Sketch showing the position of the additional (internal) thermocouples.



Vertical axis approximately to scale

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2 THE APPARATUS

Hot box apparatus

Details of the additional equipment used in these measurements are given in Table 1.

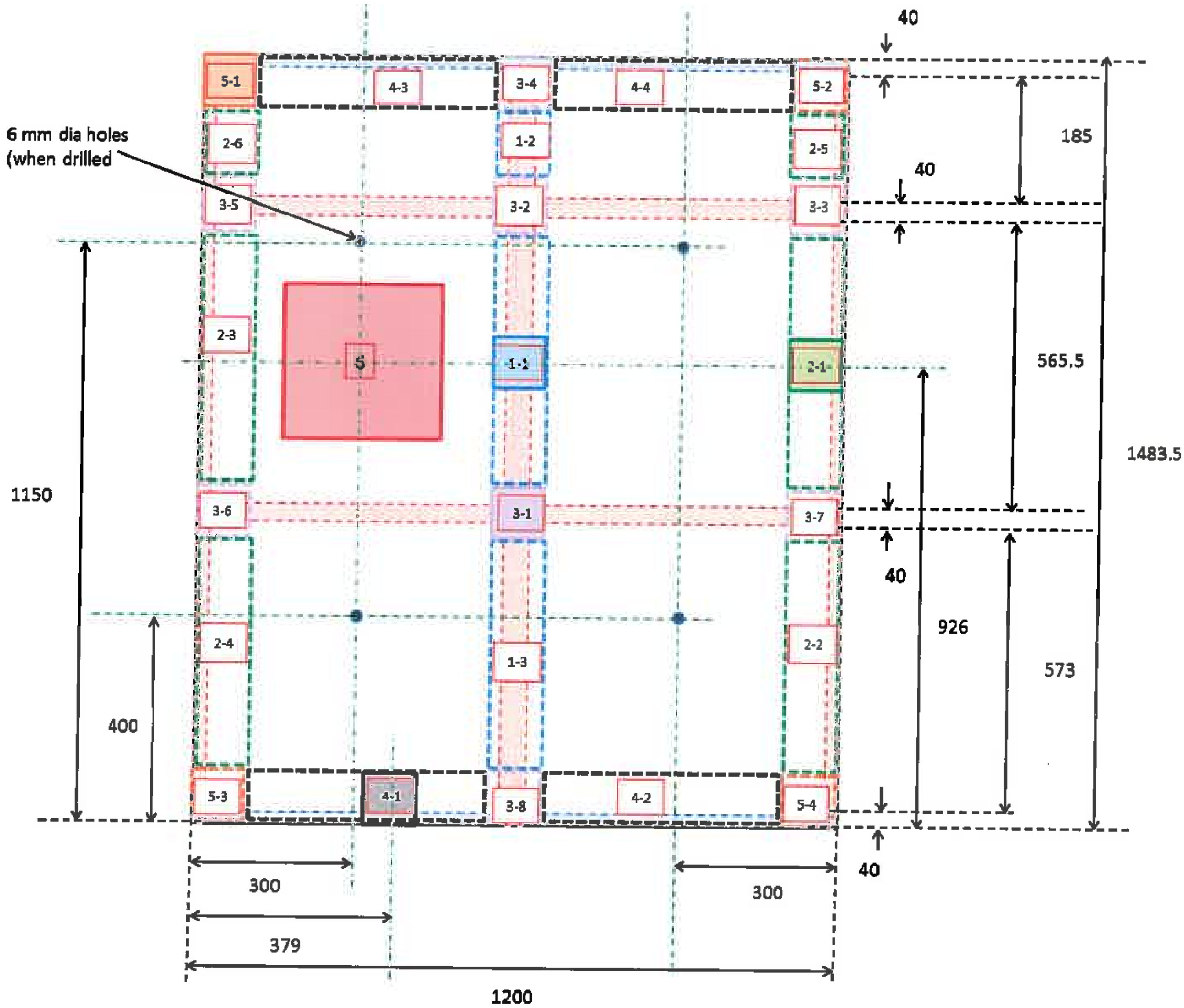
Table 1 Additional equipment used

Equipment	**Specification**
12 Volt DC fan Sunon PMD 1209PMB1-A(2)	120 ft^3/min and Static pressure 0.73 inch H_2O. 92 mm x 92 mm x 38 mm
TPI Air velocity sensors model 8455	Accuracy ± 2% reading & ± 0.5% FSD
Sequoia heat flux transducers (HFM) 5 off 100 mm x 100 mm 1 off 300 mm x 300 mm	• Thin foil flexible heat flux sensors consist of a thermoelectrical panel laminated between flexible heterogeneous plastic layers. • No temperature dependence: in the range –200°C-+200°C • The thickness of 0.4 mm, guarantees minimal disturbance and so there is no need for guard plates. • The HFMs were all individually calibrated in the NPL's standard guarded hot plate apparatus. (± 1% heat flux) • The HFMs were sprayed matt black to help match the surface emissivity with that of the rest of the wall.

These measurements were made in the NPL Rotatable Wall Guarded Hot Box, described in NPL Report CBTLM 25. Where relevant, the equipment and measurement procedures are in accordance with the requirements of BS EN ISO 8990:1996. The main features of the equipment are summarised below:

- The interior dimensions of the hot box are 2.4 m x 2.4 m.
- All surfaces "seen" by the test element are matt black.
- There are twenty five air temperature sensors, 75 mm from the holder panel face, positioned at the centres of squares of equal areas in front of the specimen in both the hot and cold boxes.
- The specimens were tested whilst mounted at 45 degrees to the horizontal - with the cold chamber above the warm chamber.

Figure 5 Positions of the HFMs and the areas that that they were assigned to represent



Heat-flow meter apparatus

- Conforms to EN 12667:2001 and EN 12939:2000.
- UKAS accredited test service (UKAS 0002).
- Accredited under 89/106/EEC: Construction Products, Notification id: 1146
- Registered laboratory in CEN Keymark scheme for Thermal Insulation.

3 MEASUREMENT PROCEDURES

The hot box U-value measurement procedure used was essentially an air-to-air method. Thermocouples were also mounted on the hot and cold surfaces of the specimen to facilitate calculation of the environmental temperatures, as specified in BS EN ISO 8990. The test element is mounted in an expanded polystyrene surround panel. The heat flow through this surround panel was calculated from its thermal conductivity and the surface temperature difference across it. The thermal conductivity of the EPS material was measured in the NPL guarded hot plate facility.
The steady state thermal transmittance values quoted are the mean of five sets of readings taken at two-hourly intervals. Equilibrium is assumed when the maximum difference between the five thermal transmittance values is less than approximately 2%.

In addition to the normal hot box measurements the six HFMs were fixed to the warm surface of the roof structure to enable an area weighted mean density of heat flow rate to be measured separately to the normal hot box measurements. These were used to try to quantify the effect of air flowing from the warm chamber through the test element the result of drilling holes in the warm surface. Previous measurements of that type had shown that the normal hot box measurements did not capture the thermal results of that heat transfer mechanism. The positions of the HFMs are shown in Figure 5 which also shows the areas that each HFM was considered to be representative of.

4 RESULTS

Hot box results
It should be noted that only the results of the U-value measurements are covered by the UKAS accreditation.

The following results are given in this report:

i. The air flow velocities recorded by the six air velocity sensors from the start of each measurement run to approximately the end of the eight hour period used to calculate the final values (Figures 6 to 9)

ii. The temperatures recorded by the internal thermocouples during the eight hour period used to calculate the final values (Table 2).

iii. The measured thermal transmittance of the roof structure for each configuration derived from the hot box heat flux and the area weighted mean outputs of the six HFMs are shown in Table 3. This table also shows the U-value of the structure with no air flow through the cavity modelled using the 2D FEA software THERM.

iv. The main measured parameters for each configuration are given in Tables 5 to 9.

Results of the thermal resistance measurements of the insulation materials used.

The thermal resistance of two layers of the 90 mm thick mineral wool were measured, in a 610 mm HFM apparatus, as one test sample (to replicate its use in the roof structure). It was measured at 180 mm thickness the nominal thickness in the test structure. The thermal resistance of the 50 mm thick mineral wool was measured separately. The results of these measurements are shown in Table 4.

5 OBSERVATIONS

a) This structure showed no significant effect on the U-value of passing air flow of different velocities through the roof cavity (see Table 3). The average U-value of the roof with air flow through the cavity was not significantly different from the U-value of the roof with a sealed air cavity. If the air cavity was completely vented the U-value should have increased about 4%.

b) There was, however, an increase in the temperatures recorded by the internal thermocouples 3 and 4 when the holes were drilled in the warm side plasterboard. This small increase in temperature was unexpected and appears to indicate that warm air is being sucked through the roof structure – not cold air being blown through the structure. The average internal temperatures over the logging period are shown in Table 2 and the changes highlighted in the graph in Figure 10. This increase in temperature could be caused by: a) the effective thermal resistance of the insulation decreasing as air passes through it; b) by the sensible heat transfer – with the warm air by-passing some of the insulation; c) possible leakage of air past the vapour barrier. Any of these mechanisms would result in more heat transfer through the structure and therefore should have produced a higher "effective" U-value.

c) The measured base level U-value was about 10% lower than that modelled using THERM (2D FEA) . This discrepancy was not the result of the mineral wool having a lower thermal conductivity than it's nominal value which as can be seen from measured thermal resistance measurements in Table 4 was very close to its declared value.

d) The air flow produced by the small DC fans, controlled by constant voltage power supplies, was more variable over time than anticipated. This is shown in the air velocity vs time graphs given in Figures 6, 7. 8 and 9. It is assumed that the changes in air velocity are caused by the geometry of the air cavity formed by the vapour barrier and the outer skin changing with time.

e) The air flow in the cold chamber is about 3.5 m/s in an upward direction. This air flow influenced the air velocity recorded by the two bottom air flow velocity sensors more than those mounted in the centre and top of the cavity.

f) The small decrease in the measured U-value that occurred on drilling the holes in the plasterboard was also unexpected – see point b) above. It is not considered credible that the U-value actually decreased and so other explanations have to be sought. As already noted, the increase in temperature of some of the internal thermocouples indicate that the effect of drilling 4 x 6 mm diameter holes in the plasterboard was to cause air to be sucked from the warm chamber, through the test roof, into the cold chamber (not blown from the cold chamber into the warm chamber as anticipated). Two possible causes of this effect have been identified to date; these are:

a) The release of latent heat of condensation.

The air in the warm chamber is at 22 °C and has a Relative Humidity (RH) of approximately 51%. The dew point of this air is 11.5 °C and the tile membrane surface temperature will be approximately 2 °C. Water will, therefore, condense out of the warm air throughout the structure and at the tile membrane which will release the latent heat of condensation. To check if such a supposition is credible, the rate of condensation required to produce the "missing power" has been calculated. The weight of water that could be condensed has been determined by calculating the difference between the moisture content of air at 22 °C and 51% RH and air at 2 °C and 100% RH. From this figure, the air velocity through the four, 6 mm diameter holes required to produce that rate of condensation has been calculated. Finally the total volume of condensed water, over the typical three day test period, has been estimated. These data are given in the table below which shows that the release of the latent heat of condensation from an air stream flowing at 0.148 m/s through the four holes would be enough to produce additional power. The air flow in the warm chamber is 0.29 m/s and with the additional suction effect of the air flow in the air cavity, such an air flow rate through the holes is quite possible. It is therefore credible that the additional power required to produce the observed reduction in U-value could be generated by condensation.

This effect could be eradicated by drying out the air in the warm chamber before closing up the apparatus (by flushing with compressed air which is very dry and then putting desiccant in the chamber to ensure a very low RH of the warm chamber air.

Test ID	Roof description	Power 2 m/s air no hole	Power 2 m/s air 4 off holes	Additional power required	Condensed mass of water / sec required	Mass of water condensed from 1 m^3 of air at 22 °C & 51% RH - to 2 °C & 100% RH	Volume of air needed per second	Velocity of air thro' holes	Velocity of air in warm chamber	Dewpoint of air @ 22 °C & 51% RH	Amount of condensed water in 3 days
		Watts	Watts	Watts	g/s	g	m^3/s	m/s	m/s	°C	litres
R155	Best Practice MW	5.033	4.821	0.212	0.00008648	5.16	0.00001676	0.148	0.29	11.5	0.022

b) The air replacing that being pulled through the roof is heated by one of the apparatus guard systems

The air being pulled from the warm chamber, through the roof structure, has to be replaced and another explanation for the observed decrease in U-value is that the air being drawn into the warm chamber is being heated by one of the guarding systems used in the NPL hot box apparatus. The result of this is that the total power into the hot box was no longer simply that produced by the warm chamber heater. This would result in the measured U-value appearing to go down because the power through the test structure was actually higher than being measured.

If this mechanism was the cause of the apparent decrease in U-value that was observed when air flow through the structure (from warm chamber to cold chamber) was facilitated by drilling the holes in the plasterboard, it is difficult to think of a methodology that could be employed with a guarded hot box that would enable that thermal effect to be quantified. In that case, another methodology would have to be employed, comprising measuring the U-value of a roof structure unit that was perfectly sealed at its warm and cold surfaces and then take that unit to a window air infiltration measurement facility (BS EN 1026) and measure the air infiltration for different tile systems and warm side permeability (holes). The various air flow rates through the roof can then be translated into heat transfer by a suitable calculation. The net heat transfer could then be calculated and an "effective" U-value derived.

g) The addition of the six calibrated HFMs was an attempt to measure the power through the test element independently of the hot box power monitoring system. This approach, however, was not successful as the measured U-value derived from the HFM outputs also appeared to go down. Both of the suggested mechanisms for producing the additional power that are given above, however, would bypass the HFMs.

Figure 6 R155A – Air velocities

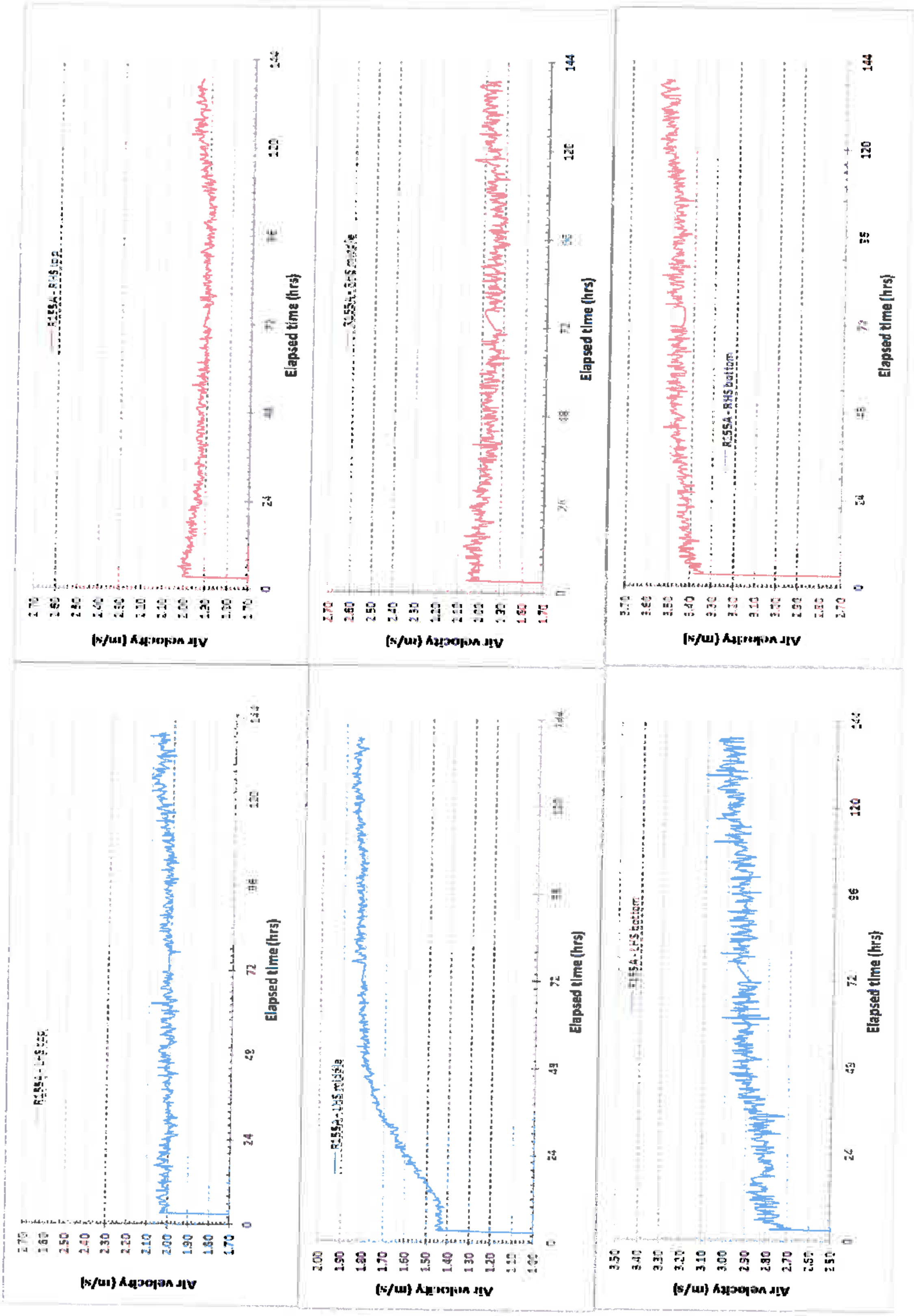


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Figure 7 R155B – Air velocities

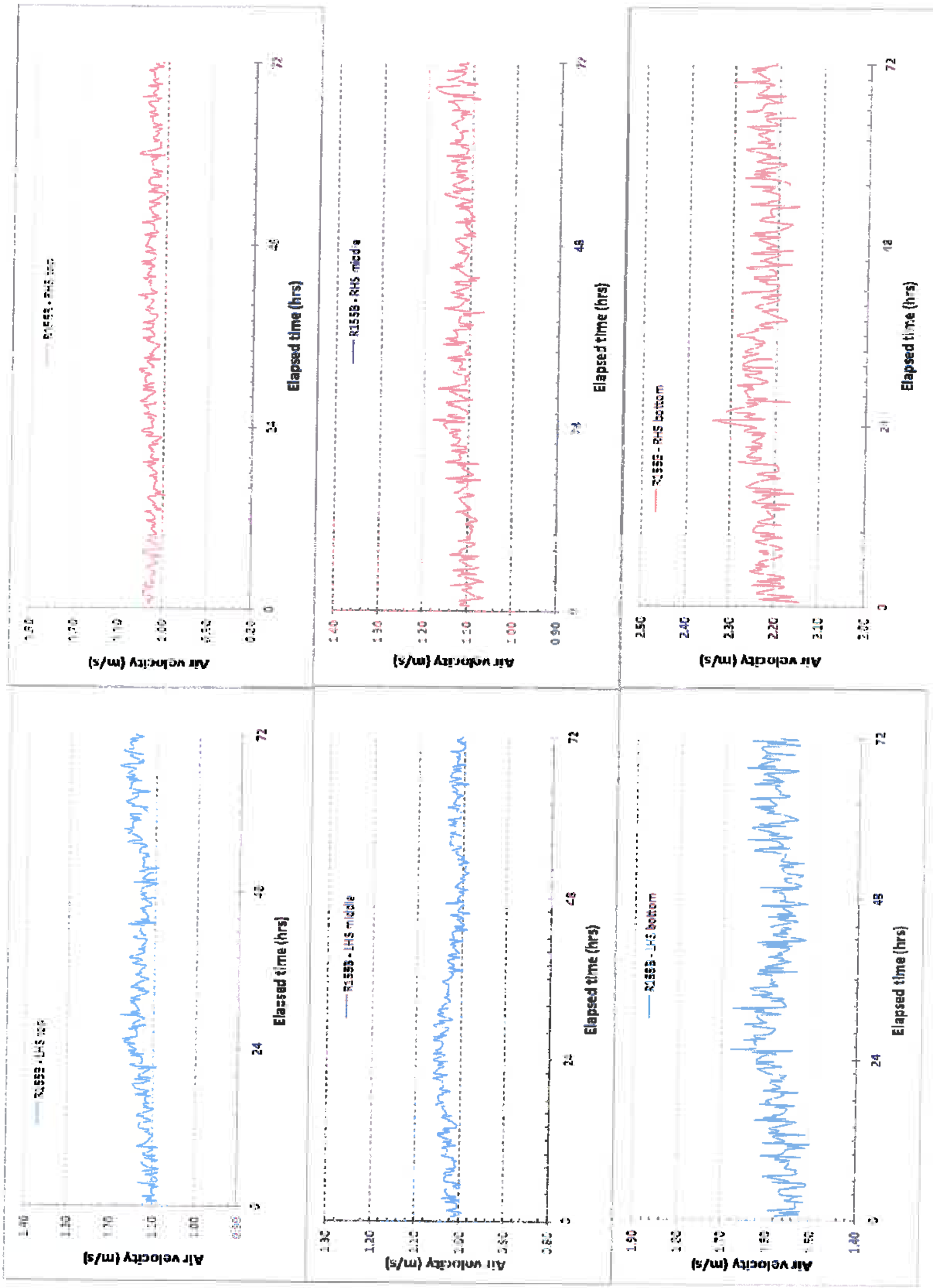

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Figure 8 R154C – Air velocities

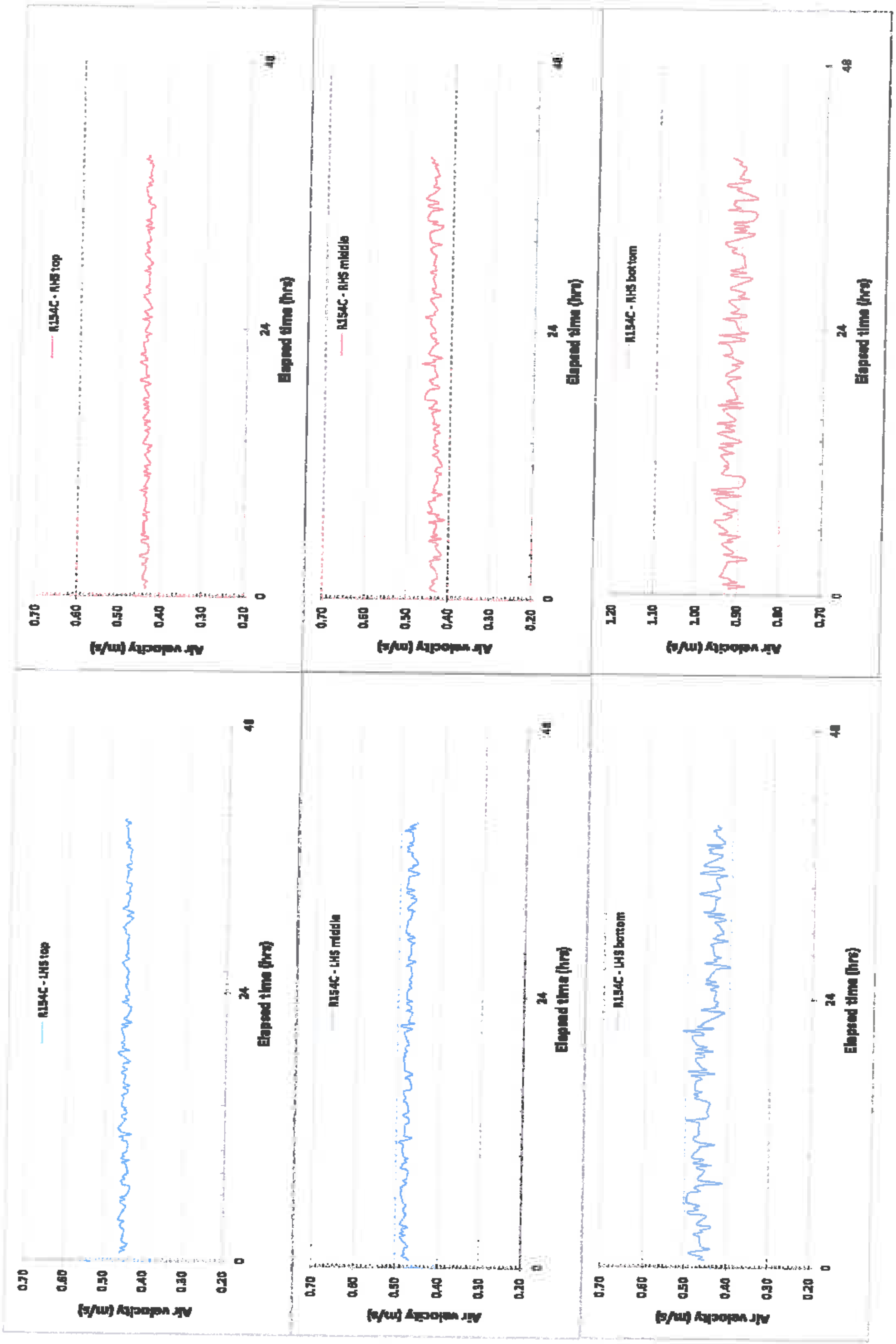

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Figure 9 R154E – Air velocities

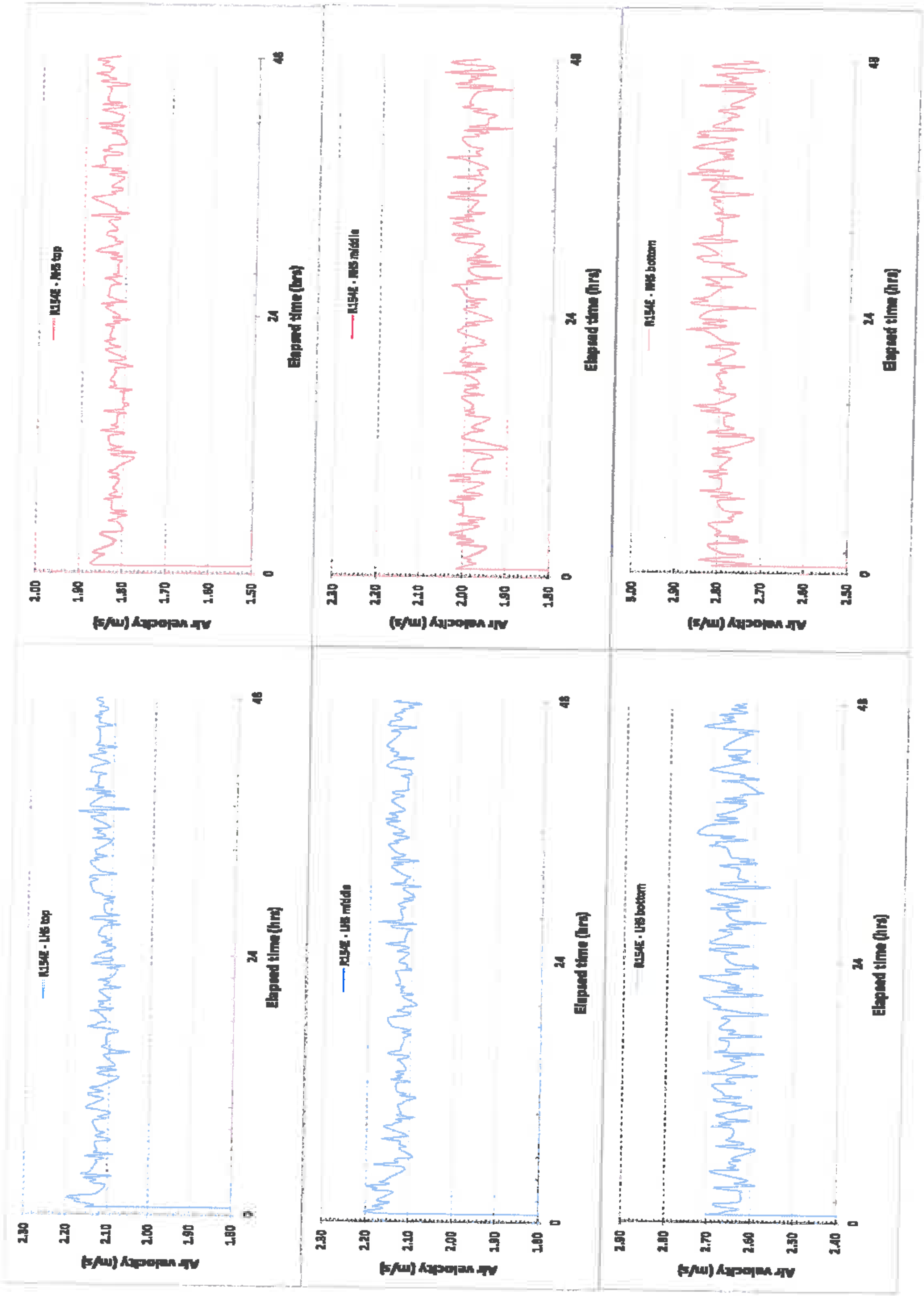

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Table 2 R155 – Internal roof temperatures (see Figure 4 for thermocouple positions)

R155A	Nominal 2 m/s air flow & no holes		
AVERAGE INTERNAL t/C TEMPS OVER SCANNED PERIOD			
Internal t/c 1	Internal t/c 2	Internal t/c 3	Internal t/c 4
9.65	9.76	10.66	10.47

R155B	Nominal 1 m/s air flow & no holes		
AVERAGE INTERNAL t/C TEMPS OVER SCANNED PERIOD			
Internal t/c 1	Internal t/c 2	Internal t/c 3	Internal t/c 4
9.59	9.78	10.43	10.08

R155C	Nominal 0.5 m/s air flow & no holes		
AVERAGE INTERNAL t/C TEMPS OVER SCANNED PERIOD			
Internal t/c 1	Internal t/c 2	Internal t/c 3	Internal t/c 4
9.61	9.83	10.35	9.94

R155D	Nominal 2 m/s air flow & 4 x 6 mm dia holes		
AVERAGE INTERNAL t/C TEMPS OVER SCANNED PERIOD			
Internal t/c 1	Internal t/c 2	Internal t/c 3	Internal t/c 4
10.20	10.08	12.25	11.39

R155E	No air flow & no holes		
AVERAGE INTERNAL t/C TEMPS OVER SCANNED PERIOD			
Internal t/c 1	Internal t/c 2	Internal t/c 3	Internal t/c 4
10.12	10.28	10.74	10.28

Figure 10 The internal temperatures plotted for the different air flow conditions.

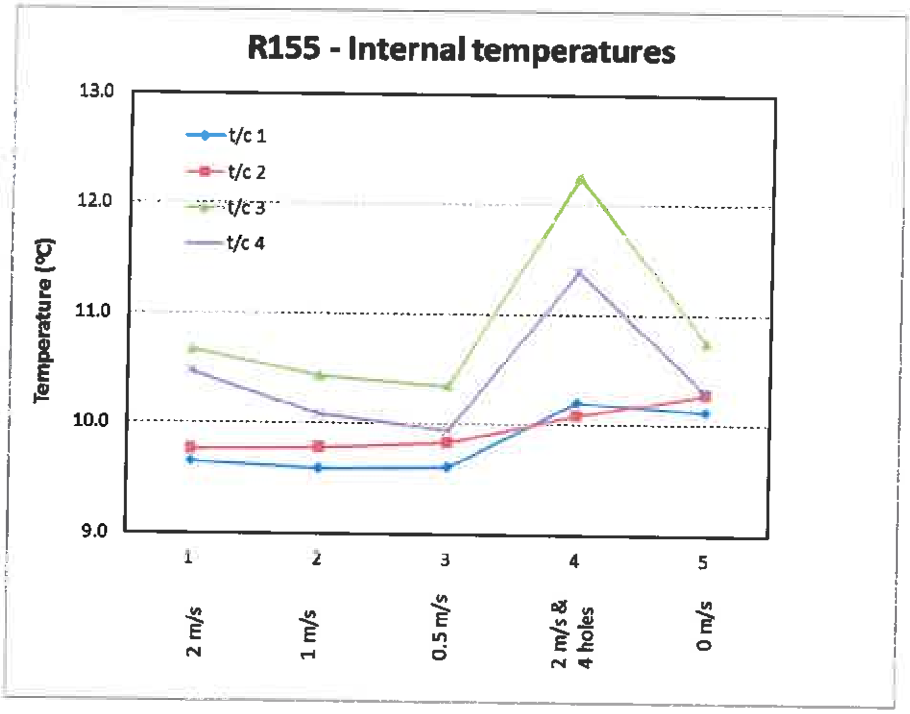

Table 3 Summary of measured and calculated U-values

Axis label	DATE	RUN ID	Cavity air flow m/s	No. of 6 mm dia holes in warm face	Thermal transmittance (Hot box heat flux) W/m^2.K	Thermal transmittance - area weighted mean HFM heat flux W/m^2.K	Thermal transmittance - modelled (THERM - 2D FEA) W/m^2.K	Thermal transmittance - lower limit (No cold bridging) W/m^2.K
R155A - Best Practice wool - 2 m/s & no holes	11/11/13	R155A	2	None	0.14	0.15		
R155B - Best Practice wool - 1 m/s & no holes	14/11/13	R155B	1	None	0.14	0.15		
R154C - Best Practice wool - 0.5 m/s & no holes	17/11/13	R155C	0.5	None	0.14	0.15		
R155E - Best Practice wool - 0 m/s & no holes	24/11/13	R155E	0	Blocked	0.14	0.14	0.15	0.14
R155D - Best Practice wool - 2 m/s & 4 x 6 mm dia holes in plasterboard	22/11/13	R155D	2	4	0.13	0.12		

Table 4 Thermal resistance / thermal conductivity results.

NPL ID number	Hot box test element number	Material description	Thickness (mm)	Density (kg/m^3)	Measured thermal resistance (m^2.K/W)	Calculated thermal conductivity (W/m.K)
LA621	R155	Knauf Earthwool 90mm 2407396 SK Frametherm Roll 35 (Two layers)	179.98	21.7	5.304	0.0339
LA622	R155	Knauf Earthwool 50mm 2411327 Building Slab RS45	49.99	38.6	1.453	0.0344

Table 5 R155A Measured hot box parameters

Experimental parameters for R155A

R155A			
Best Practice Mineral Wool Roof with nominal 2 m/s air flow through roof cavity			
Test element dimensions			
Height		1.480	m
Width		1.203	m
Thickness		250	mm
Measured values			
Mean warm air temperature		22.24	°C
Mean warm baffle temperature		22.07	°C
Mean warm surface temperature		21.71	°C
Mean cold air temperature		1.89	°C
Mean cold baffle temperature		1.99	°C
Mean cold surface temperature		1.91	°C
Power to hot box		13.975	W
Air flow rate in the cold box		3.37	m/s
Air flow rate in the hot box		0.29	m/s
Air flow rate through the roof cavity (min / max)	1.67	2.96	m/s
Calculated values			
Heat flux density through test element		2.827	W/m²
Warm side environmental temperature		22.12	°C
Cold side environmental temperature		1.89	°C
Environmental temperature difference		20.23	°C
Environmental temperature mean		12.01	°C
Hot surface resistance		0.146	(m²·K)/W
Cold surface resistance		0.008	(m²·K)/W
Measured thermal transmittance test element		**0.140**	**W/(m²·K)**

Table 6 R155B Measured hot box parameters

Experimental parameters for R155B

R155B			
Best Practice Mineral Wool Roof with nominal 1 m/s air flow through roof cavity			
Test element dimensions			
Height		1.480	m
Width		1.203	m
Thickness		250	mm
Measured values			
Mean warm air temperature		22.11	°C
Mean warm baffle temperature		21.93	°C
Mean warm surface temperature		21.56	°C
Mean cold air temperature		1.88	°C
Mean cold baffle temperature		1.96	°C
Mean cold surface temperature		1.90	°C
Power to hot box		13.733	W
Air flow rate in the cold box		3.32	m/s
Air flow rate in the hot box		0.29	m/s
Air flow rate through the roof cavity (min / max)	0.99	2.31	m/s
Calculated values			
Heat flux density through test element		2.721	W/m²
Warm side environmental temperature		21.98	°C
Cold side environmental temperature		1.88	°C
Environmental temperature difference		20.09	°C
Environmental temperature mean		11.93	°C
Hot surface resistance		0.151	(m²·K)/W
Cold surface resistance		0.005	(m²·K)/W
Measured thermal transmittance test element		**0.135**	**W/(m²·K)**

Table 7 R155C Measured hot box parameters

Experimental parameters for R155C

R155C			
Best Practice Mineral Wool Roof with nominal 0.5 m/s air flow through roof cavity			
Test element dimensions			
Height		1.480	m
Width		1.203	m
Thickness		250	mm
Measured values			
Mean warm air temperature		22.09	°C
Mean warm baffle temperature		21.91	°C
Mean warm surface temperature		21.54	°C
Mean cold air temperature		1.84	°C
Mean cold baffle temperature		1.93	°C
Mean cold surface temperature		1.89	°C
Power to hot box		13.794	W
Air flow rate in the cold box		3.45	m/s
Air flow rate in the hot box		0.29	m/s
Air flow rate through the roof cavity (min / max)	0.42	1.41	m/s
Calculated values			
Heat flux density through test element		2.753	W/m²
Warm side environmental temperature		21.95	°C
Cold side environmental temperature		1.85	°C
Environmental temperature difference		20.11	°C
Environmental temperature mean		11.90	°C
Hot surface resistance		0.149	(m²·K)/W
Cold surface resistance		0.016	(m²·K)/W
Measured thermal transmittance test element		**0.137**	**W/(m²·K)**

Table 8 R155D Measured hot box parameters

R155D			
Best Practice Mineral Wool Roof with nominal 2 m/s air flow through roof cavity & 4 x 6 mm dia holes			
Test element dimensions			
Height		1.480	m
Width		1.203	m
Thickness		250	mm
Measured values			
Mean warm air temperature		22.14	°C
Mean warm baffle temperature		21.97	°C
Mean warm surface temperature		21.65	°C
Mean cold air temperature		1.94	°C
Mean cold baffle temperature		2.03	°C
Mean cold surface temperature		1.97	°C
Power to hot box		13.698	W
Air flow rate in the cold box		3.21	m/s
Air flow rate in the hot box		0.29	m/s
Air flow rate through the roof cavity (min / max)	1.71	3.57	m/s
Calculated values			
Heat flux density through test element		2.708	W/m^2
Warm side environmental temperature		22.02	°C
Cold side environmental temperature		1.93	°C
Environmental temperature difference		20.09	°C
Environmental temperature mean		11.98	°C
Hot surface resistance		0.137	$(m^2 \cdot K)/W$
Cold surface resistance		0.014	$(m^2 \cdot K)/W$
Measured thermal transmittance test element		**0.135**	**$W/(m^2 \cdot K)$**

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Table 9 R155E Measured hot box parameters

R155E Best Practice Mineral Wool Roof with no air flow through roof cavity & all apertures blocked			
Test element dimensions			
Height		1.480	m
Width		1.203	m
Thickness		250	mm
Measured values			
Mean warm air temperature		22.16	°C
Mean warm baffle temperature		21.98	°C
Mean warm surface temperature		21.64	°C
Mean cold air temperature		1.87	°C
Mean cold baffle temperature		1.95	°C
Mean cold surface temperature		2.00	°C
Power to hot box		14.042	W
Air flow rate in the cold box		3.71	m/s
Air flow rate in the hot box		0.30	m/s
Air flow rate through the roof cavity (min / max)	0	0	m/s
Calculated values			
Heat flux density through test element		2.822	W/m²
Warm side environmental temperature		22.04	°C
Cold side environmental temperature		1.87	°C
Environmental temperature difference		20.16	°C
Environmental temperature mean		11.95	°C
Hot surface resistance		0.142	(m²·K)/W
Cold surface resistance		0.046	(m²·K)/W
Measured thermal transmittance test element		**0.140**	**W/(m²·K)**

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