STUDY REPORT

SR 202 (2008)

In-situ Measurement of Thermal Resistance for Suspended Timber Floors

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FUNDED BY
THE BUILDING
RESEARCH LEVY
BUILDING RESEARCH

The work reported here was funded by Building Research Levy.

ISSN: 1178-4938

Acknowledgments

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Note

This report is intended to be used by researchers wanting to investigate the in-situ thermal performance of insulation and in particular insulation installed in suspended timber floors. The equipment may also be suitable for measurements involving wall and ceiling systems.

IN-SITU MEASUREMENT OF THERMAL RESISTANCE FOR SUSPENDED TIMBER FLOORS

BRANZ Study Report SR 202 (2008) **Ian Cox-Smith**

Abstract

This report presents an overview of a procedure including measuring equipment that can be used to determine the in-situ thermal performance of suspended timber floor systems which make use of foil, bulk insulation, or a combination of both. Using the developed procedures and equipment the project investigated the thermal performance of a suspended timber floor insulated with foil, including both when the foil was draped over the floor joists and when the foil was installed along the bottom of the joists as in a retrofit situation. For the draped foil case the aim was to measure the performance of a sample of foil that had been installed 15 years ago so that the effects of contamination and/or corrosion of the foil surface could be included in the measurement. The measurements were intended as a demonstration of the technique and equipment and should not be considered as necessarily representing typical performance.

Contents Page

Figures Page

Tables Page

1. INTRODUCTION

The Building Research levy has funded a project to develop test regimes for reflective foil used as floor insulation. The project developed a procedure including measuring equipment that could be used in-situ to determine the 'real life' thermal performance of floor systems using foil, bulk insulation, or a combination of both. Using the developed procedures it investigates the thermal performance of a suspended timber floor insulated with foil, including when the foil is draped over the floor joists and when the foil is installed along the bottom of the joists as in a retrofit situation. For the draped foil case the aim was to measure the performance of a sample of foil that had been installed 15 years ago so that the effects of contamination and/or corrosion of the foil surface could be included in the measurement.

This report provides an overview of the refined technique for in-situ thermal resistance measurement and an analysis of the results for three different types of floor insulation. The report starts with a brief background on the use of the technique at BRANZ and an outline of the project followed by a description of the equipment, its calibration, and its use. Finally an analysis of the results is provided.

2. BACKGROUND

Since the thermal performance of a foil system depends not only on the details of the construction but also on parameters such as ventilation and the condition of the foil surface, it is usually not practical nor even possible to construct a representative test system that would enable reliable laboratory measurements (in an apparatus such as a Guard Hot Box). It is possible with foil systems to use a laboratory based measurement to confirm theoretical predictions for ideal systems where the foil is new and there is no ventilation or moisture to affect the reflective of the foil surface. However, the thermal performance of foil systems in practice needs to be measured in-situ using heat flux transducers (HFTs) and data acquisition in a way that effectively averages the large daily variation in heat flow over a period of a week or more. The technique used for this project is based on a number of previous projects at BRANZ that have involved the use of HFTs and associated data acquisition systems to measure and record heat flow in buildings.

2.1 BRANZ heat flux measurements

BRANZ staff have been using HFTs for field measurements of heat flow since the 1970s when scientist Harry Trethowen developed large panel transducers that were used to investigate the thermal performance of slab-on-grade floors and for a survey of the thermal performance of houses in the 1980s that involved measuring the R-value of walls, floors and ceilings (*A survey of house insulation*, Isaacs, NP and Trethowen HA, Research report R46 BRANZ 1985).

These field measurements had to be conducted during winter to ensure there was sufficient temperature difference across the building components to generate enough heat flow to enable reliable heat flux measurement. One of the findings of the BRANZ *House* insulation survey was that the actual R-values of suspended timber floors insulated with draped foil was on average about 1.3 m^2K/W rather than the theoretical value of 2.6 m^2K/W. Because of the complexity of the radiant heat exchange processes, the dependence on factors that are difficult to quantify, and the generally dynamic nature of the heat flow, the theoretical value requires simplified assumptions to be used. It was therefore no surprise that the measured performance was so different from the theoretical value. The results of the 1980s survey set the Building Code performance requirements for R-values of floors.

2.2 Data acquisition

The use of HFTs requires a data acquisition system to record data at one or two minute intervals for periods of a week or more. Advances in micro-electronics has enabled the relatively large mains powered data aquistion units used to conduct the earlier field measurements to be replaced by tiny battery powered data loggers, whilst at the same time advances in computer software have streamlined and simplified the process of analysing the data. BRANZ staff have developed a series of custom battery data loggers to perform particular measurement tasks including a so-called 'BRANZ micro-volt logger' (µV-logger) that was designed for measuring the micro-volt level signal from both thermocouples and the BRANZ HFTs. The BRANZ micro-volt logger has four input channels – three for thermocouples and one for an HFT and includes a built-in reference junction temperature sensor.

2.3 Practical usage of HFTs for in-situ measurements

Whilst the use of the BRANZ developed HFTs has been an important part of a number of research projects, their use has largely been restricted to hands-on use by BRANZ scientists and technicians. The use has also been restricted to the winter months when there is sufficient heat flow through building envelopes or in specialist applications such as cool stores. Two goals of this project were to simplify the use of the equipment and to develop a so-called 'heating box' to enable measurements over a wider range of ambient conditions.

3. PROJECT OUTLINE

The four components of the project were:

1) Development and upgrade of the data logger and software
2) Upgrade of the HFT and development of the heating box
3) Test sites
4) In-situ measurements.

3.1 Logger and software

Improvements in the capacity and functionality of the electronic components used in the BRANZ loggers, particularly the micro-processor, provided an opportunity to fine-tune the characteristics of the µV-logger to enable it to be used by non-BRANZ technicians and scientists with limited training. This was achieved by simplifying its use in conjunction with the BRANZ HFTs. Although for the current project the equipment was installed and operated by BRANZ staff, the intent was to develop the equipment to the point where the existing database of knowledge on the thermal performance of building components such as suspended floors could be extended by hiring out the equipment.

3.2 HFT and heating box

Along with the need for easier to use equipment was the need to be able to make in-situ measurements during the swing seasons, autumn and spring, and for less dependence on a period of consistently cold weather. This has been achieved by the development of a heating box (discussed below) which is used in conjunction with the existing BRANZ developed HFTs and provides a more consistent and stable temperature difference for heat flux measurement. The heating box is simply an insulated box that surrounds the transducer and provides a higher and more stable interior air temperature against the transducer. Fans inside the box provide both air mixing and heating.

3.3 Test site

Access was granted to a local house (Whitby) with a suspended timber floor insulated with draped foil. The house was constructed in 1990 and the existing draped foil, although relatively shiny on the lower face, had a duller (milky) appearance on the upward-facing surface.

3.4 In-situ measurements

After installing the equipment the heat flow was measured at two locations simultaneously. At the first location two separate tests were carried out: first with the foil as it was; and then re-done but replacing the existing foil with new foil fixed to the bottom of the joists. The foil at the second location was left as it was. Next the retrofitted foil was replaced by bulk insulation of known thermal resistance as a check of the reliability of the measurement method. A heating box on the internal side of the floor component was used to provide more uniform air temperatures and a greater temperature difference between the internal and external environment for the first location. The HFT panel at the second location was used without a heating box because the internal environment (in this case the lounge) was heated sufficiently. Using the two locations provided a means to evaluate the effectiveness of using the heating box.

4. EQUIPMENT AND CALIBRATION

The measurement system consists of six parts:

1) BRANZ developed logger and its calibration
2) Thermocouples for measuring temperature
3) BRANZ developed HFT
4) Calibration of the HFT
5) Heating box for controlling air temperature
6) Using the HFT to determine thermal resistance.

4.1 BRANZ micro-volt logger

a) Specifications

4 channel DC voltage
1 µV sensitivity (0.03 °C for type-T thermocouples)
± 4 µV accuracy (0.1 °C for type-T thermocouples)
± 2048 µV range
± 0.2°C accuracy reference junction temperature
Battery life approximately 1 month
Storage capacity 2 weeks at sampling interval of 1 minute

Operating environment 5–35°C

b) Calibration

The accuracy of measurement of thermal resistance is dependent on the accuracy of the measurement of the millivolt level output from the HFT and the micro-volt level output from the temperature measurement thermocouples. The required calibrations are the amplifier input offset, temperature dependence of the input offset, offset for the reference juction temperature sensor, and the gain for reference junction temperature sensor. The calibrations are conducted using the BRANZ Heat Flow Meter apparatus as a controllable temperature environment and a Fluke Calibrator as a reference source. The calibration constants are stored in the logger along with the raw data and the data is then corrected automatically as it is downloaded from the logger using the BRANZ Logger Download Unit.

4.2 Thermocouples

The temperature difference across the floor is measured using a pair of type-T thermocouples, one measuring the temperature of the surface of the HFT (the surface against the floor) and the other the temperature of the air under the floor adjacent to where the transducer is located. Thermocouples (two for each HFT) are made from a batch of wire for which a sample has been independently calibrated. The wire is run from the logger to the underside of the floor via the nearest window. The wire diameter is small enough to allow the window to be shut.

These field measurements had to be conducted during winter to ensure there was sufficient temperature difference across the building components to generate enough heat flow to enable reliable heat flux measurement.

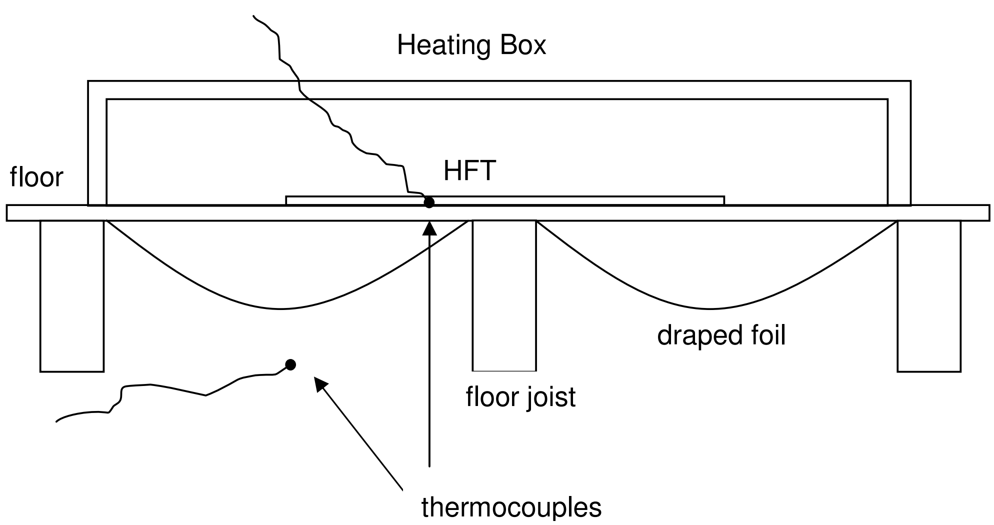

Figure 1: Location of thermocouples

4.3 HFTs

The behaviour, use and performance of the BRANZ HFTs have been described previously in 'Engineeering application of heat flux sensors in buildings – the sensor and its behaviour', BRANZ Reprint No. 46 and 'Measurement errors with surface-mounted heat flux sensors', BRANZ Repirint No. 51. Previously the HFTs were not used in conjunction with a heat box to modify the local interior air temperature.

The BRANZ HFTs are constructed from two 600 x 450 mm sheets of 2.5 mm thick aluminium separated by a 4 mm airspace created using a rim of 4 mm thick balsa wood and small blocks of the balsa in the centre. The low emittance airspace created between the inside faces of the aluminium sheets provides a thermal resistance of approximately 0.1 m^2K/W. Ten pairs of type-T thermocouples are attached to the inside faces of the aluminium sheets and connected in series to give a single output of approximately 10 x 40 = 400 µV/K. A separate single thermocouple is also attached to the inside face of one of the aluminium sheets. The aluminium sheet with the separate thermocouple attached then in practice becomes the face of the HFT that is held against the building component being measured so that the thermocouple is measuring the surface temperature of the building component under test (for this project a carpeted floor)

4.4 Calibration of HFTs

Calibrations are performed with the aid of a LaserComp Fox600 Heat Flow Meter (HFM). The LaserComp HFM is designed for measuring the thermal resistance of insulation samples and has two temperature controlled plates with integral HFTs. Since the HFTs on the LaserComp HFM plates are smaller than the HFT being calibated, there needs to be a buffering material to produce uniform heat flow and to allow it to be controlled to values that are typical of what the HFT will be used to measure in practice.

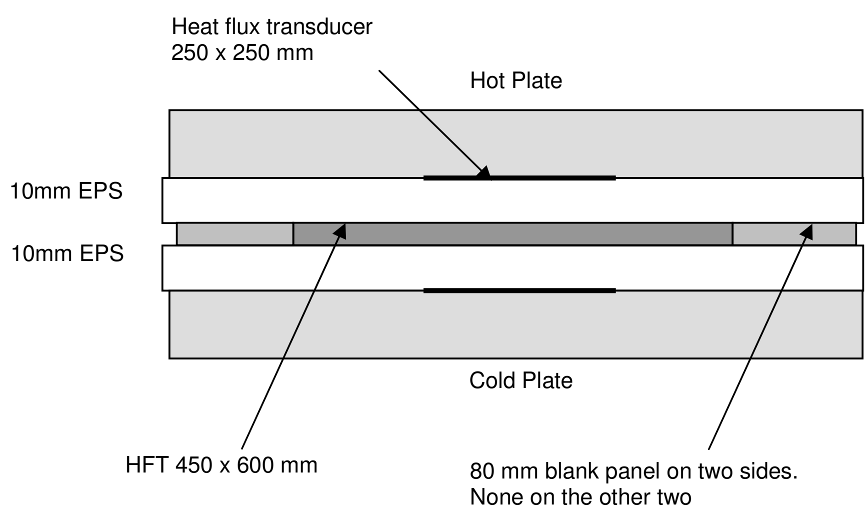

Figure 2: Calibration of HFT using LaserComp Heat Flow Meter

The HFTs output is proportional to the heat flux passing through it but the coefficient varies with temperature and is also slightly dependent on heat flux. The transducer's output coefficient was determined for heat-flux over the range 1.5 to 30 W/m^2. The heat flux was changed by varying the temperature difference between the heat flow meter plates from 1 to 20 K whilst keeping the mean temperature at a constant 20°C. The variation in the coefficent was found to be less than 0.4% and the value of approximately 27 $W/m^2.mV$ is consistent with the estimated thermal resistance of the HFT panels of 0.1 m^2K/W and the ouput from the 10 junction thermophile of 0.4 mV/K.

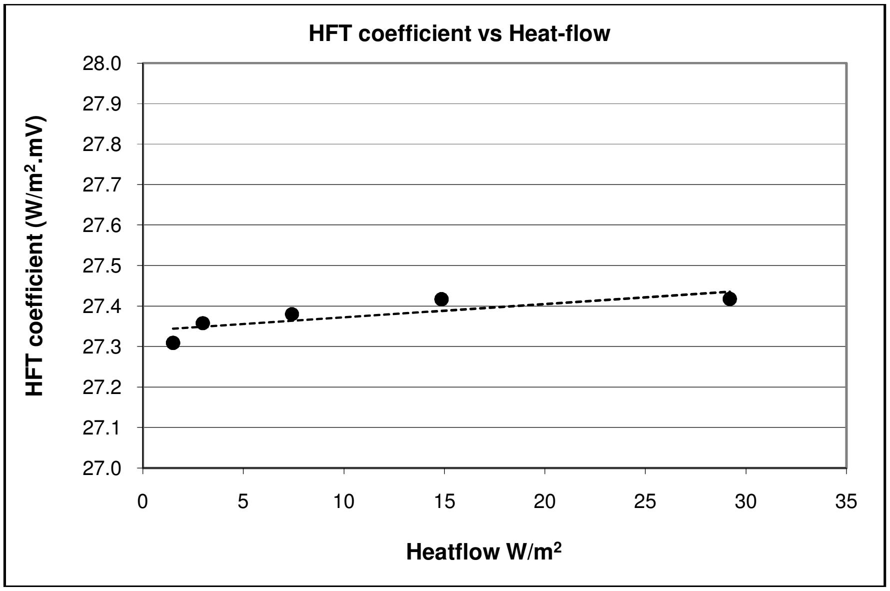

Figure 3: Transducer output coefficient versus heat flow

The dependence of the coefficient on temperature was investigated by varying the mean temperature whilst keeping the heat flux constant. The slope of the graph represents a temperature dependence of 0.25%/°C and is consistent with the temperature dependence of the type-T thermocouple wire that makes up the thermophile. The temperature dependence of the thermal resistance of the HFT panel would be expected to be an order of magniture smaller and therefore not have a significant effect on the coefficient.

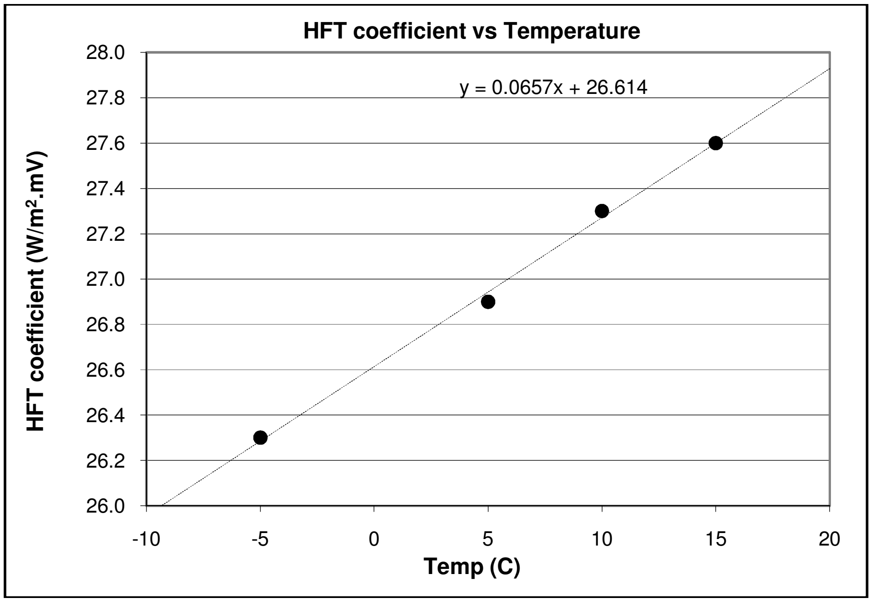

Figure 4: Transducer output coefficient versus temperature

The coefficients for eight of the BRANZ HFT panels were measured using the LaserComp HFM and the results given in the table below. The coefficients for panels 17 and 20 was re-measured to confirm the repeatability of the calibration.

Table 1: Calibration results for BRANZ HFTs

Heat flux sensor	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	Average	Standard Deviation
Heat flow W/m^2	7.370	7.305	7.442	7.312	7.390	7.485	7.365	7.338	7.376	0.062
Heat flux meter output µV	260.7	272.2	270.5	283.4	269.2	279.3	278.0	270.5	273.0	7.1
Meter Coefficient	**28.27**	**26.84**	**27.51**	**25.80**	**27.45**	**26.80**	**26.49**	**27.13**	27.0	0.7
Re-test										
Heat flux meter output µV	261.0			284.5						
Heat flow W/m^2	7.378			7.351						
Meter Coefficient	**28.27**			**25.84**						

4.5 Heating box

Specifications

External dimensions: 1.2 x 1.1 x 0.206 m
Internal dimensions: 1.1 x 1.0 x 0.144 m
Internal volume: 160 litres
Walls 62 mm thick with low emittance faces

Approximate wall thermal resistance: 1.5 m^2K/W @ 25°C
Approximate box conductance: 1.6 W/K
Air movement and heating provided by two 19 W fans
Total weight including fans: 4.5 kg (2 kg walls; 2.5 kg fans)
Approximate heat capacity of box walls: 2300 J/K
Open face area: 1.1 x 1.0 m
Typical time to equilibrium temperature: 2–6 hours

The box is constructed of 50 mm EPS with 6 mm foil-faced foam on both interior and exterior faces. The low emittance surfaces improve the temperature uniformity and the foam provides some additional sound damping for the fan noise.

Figure 5: Heating box

The table below shows the theoretical temperature difference between the interior and exterior of the heating box when the heat loss through the box walls is in equilibrium with the 38 W input fan power. The temperature difference is expected to be in the range 15 to 20 K. Based on this, for a typical air temperature at floor level of 10–20°C the air temperature in the heat box is expected to be in the range 25–40°C.

Table 2: Estimated temperature elevation inside heating box

Measured R-value W/m.K	Total conductance (box + measurement) W/K	Temperature elevation for equilibrium between heat loss & input fan power K
1.0	2.70	14
1.5	2.33	16
2.0	2.15	18
2.5	2.04	19
3.0	1.97	19
3.5	1.91	20
4.0	1.88	20

4.6 Using the HFT to determine thermal resistance

R-value is determined from accumulative sum of temperature difference and accumulative sum of heat flow:

R-value = $\dfrac{\sum \Delta T}{\sum Q}$

An alternative is to use the sum of squares method:

R-value = $\dfrac{\sum \Delta T^2}{\sum Q.\Delta T}$

The alternative method is only needed when the heat flow through the component under test occurs in both directions making both the sum of temperature and sum of heat flow smaller and therefore making the determination of R-value less accurate.

Provided there is sufficient temperature difference across the component the R-value determined using this method usually converges adequately in about 72 hours and the final R-value is calculated over a total time interval that is a multiple of 24 hours i.e. 72, 96, 120 … hours.

The charts displaying R-value shown below in Section 6 *Results* are plots of accumulative thermal resistance rather than simply the instananeous value. Only the final converged value has any real meaning and the results are analysed as a chart simply because a visual inspection is the easiest way to assess that convergence has occurred.

Principle features for the practical use of HFTs:

- The higher the R-value and the higher the thermal mass, the larger the likely % error in the results
- The higher the R-value and the higher the thermal mass, the longer the measurement takes
- Five days is a practical minimum measurement period but the results should still be examined after five days to decide if the measurement needs to proceed for a longer period
- The mean temperature difference between indoor and outdoor needs to be above 4 K to avoid large measurement uncertainty
- Temperature reversals and associated inward heat flows can result in unreliable measurements if they form a significant fraction of the total test period
- Accuracies of about 10% are achievable if there is sufficient temperature difference
- It is important to maintain good contact between the HFT and component being measured.

5. TEST SITE

The test site consisted of two areas of a residential floor, the first being in a spare bedroom and the second in the lounge. At both locations there was carpet on the floor, the floor joists (200 mm) were spaced at approximately 600 mm centres, and the transducers were placed so that they spanned across a joist. The measurements therefore were correctly weighting the frame at a ratio of one joist per 600 mm length of the HFT. The transducers were located so that dwangs were not included in the measurement. The depth of the foil drape was approximately 100 mm at the centre of the drape.

The subfloor clearance was 0.5 to 1.0 m and the floor was constructed with the floor joists cantilevered 0.3 m out over the perimter wall (fibre-cement) and with the perimeter area of the draped foil fully exposed and not protected by the subfloor. The style of construction of the floor probably means the natural ventilation of the subfloor space (and the airspace between the foil and the underside of the 20 mm thick particle board floor) was probably higher than for other styles of construction but it is none-the-less a common type of construction. A relatively high ventilation rate is expected to have a significant impact on the thermal resistance for the floor.

The HFT in the lounge was placed under a settee so that it was out of the way of the occupants. Since this room was heated periodically during the day and for five to six hours every evening, the tranducer was not used in conjuction with a heating box. Also the style of heater (wood burner) meant residual heating occurred for a period after the occupants had gone to bed.

The HFT in the spare bedroom was placed under a double bed and the heating box was required because the room was only indirectly heated.

6. RESULTS

Table 3 summarises the results for the six sets of measurements.

Table 3: Summary of results

	Foil draped		**Foil along joists**		**Rigid fibrous polyester**
Location	1	2	1	2	1
Heating box	Yes	No	Yes	No	Yes
Test period (days)	8	8	20	20	16
Subfloor temperatures (°C)	9 – 16	9 – 16	7 – 18	7 – 18	10 – 19
Carpet temperatures (°C)	25 – 30	13 – 17	25 – 31	12 – 18	33 – 39
Temperature difference (K)	12 – 18	0 – 7	12 – 22	-1 – 7	18 – 25
Average temperature difference (K)	14	3	16	3	22
Heat flow (W/m^2)	13 - 14	2 – 5	12.5 – 15	1 – 5	9.5 – 11.5
Accumulative R-value (m^{2}K/W)	1.10	1.05	1.25	1.55	2.05
R-value range assuming 10% uncertainty in the measurement	1.0 – 1.2	0.95 –1.15	1.1 – 1.4	1.4 – 1.7	1.85 – 2.25

The charts below show the accumulative R-value for the six sets of measurements. Charts for subfloor air temperature, carpet surface temperature, temperature difference, heat flow, and instantaneous R-value are included in Appendix A.

Previous studies have estimated the uncertainty in determining thermal resistance using the HFTs as 10% including calibration errors and uncertainties associated with installation and in-use conditions. The estimation of the uncertainty was based on an assumption that the average temperature difference is at least 10 K. If the temperature difference is less than 10 K the method becomes less reliable and repeat measurements are needed to provide confidence in the results.

For the measurements at location 2 where there was no heat box the average temperature difference was only 3 K and the plots of accumulative R-value show a less well defined convergence compared with the results for location 1.

6.1 Foil draped

6.1.1 Location 1 using heating box

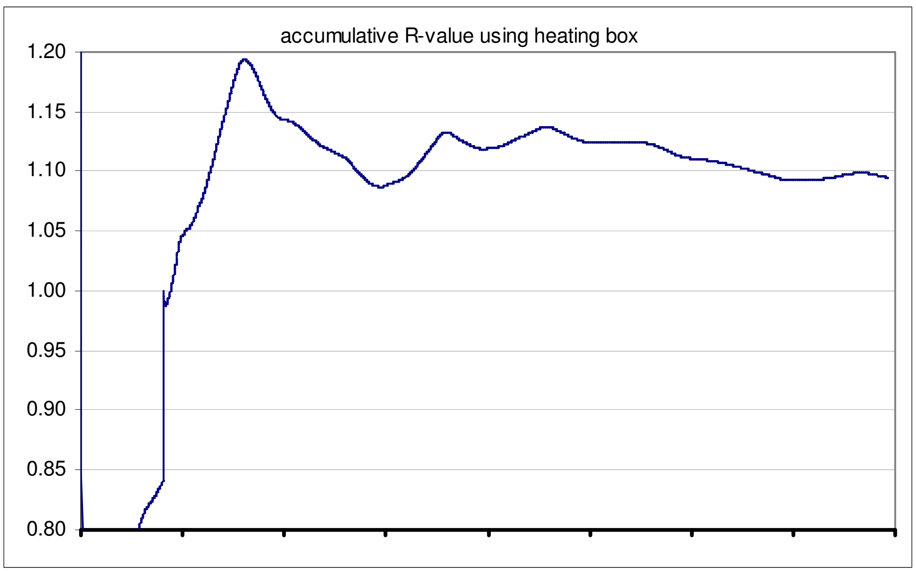

Figure 6: Foil draped – accumulative R-value using heating box (x-axis units = days, y-axis units = m^2K/W)

6.1.2 Location 2 using room heating

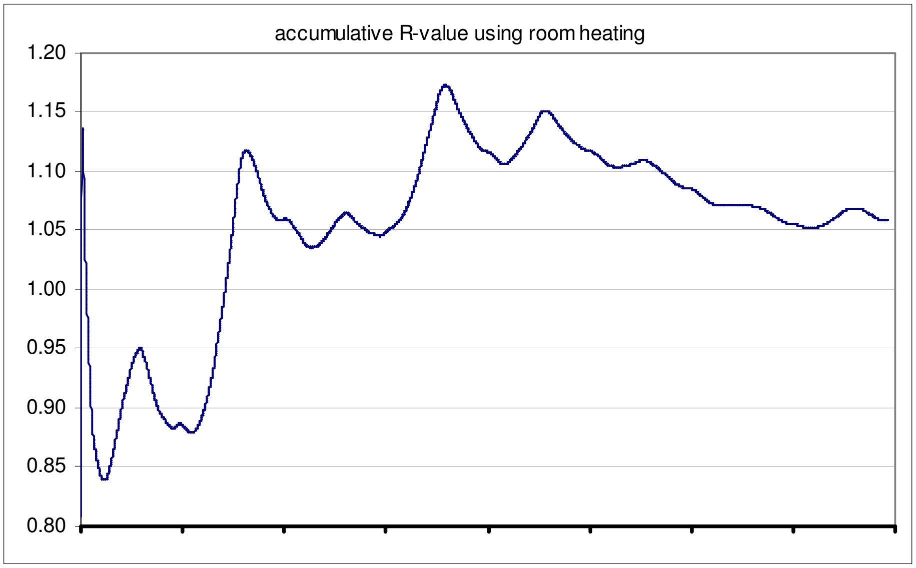

Figure 7: **Foil draped – accumulative R-value using room heating (x-axis units = days, y-axis units = m^2K/W)**

6.2 Foil across bottom of joists

6.2.1 Location 1 using heating box

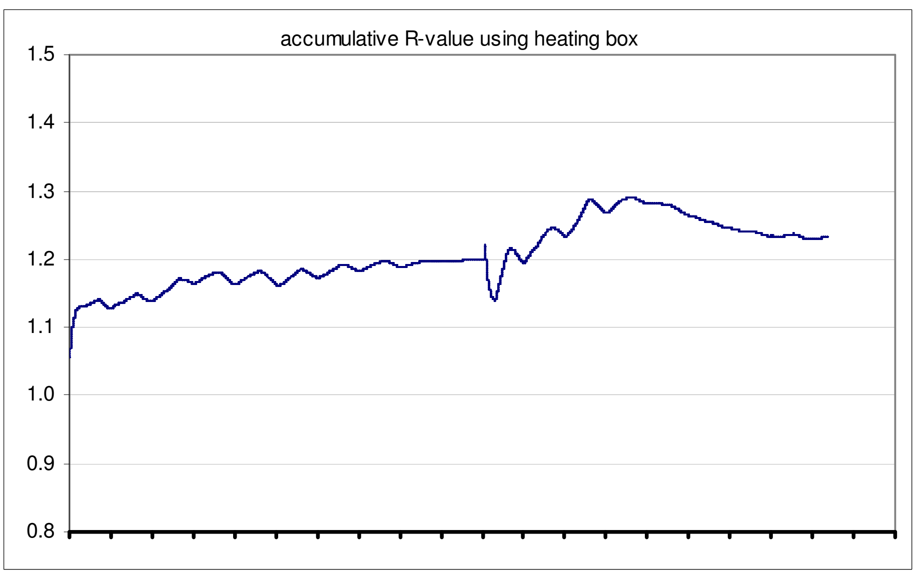

Figure 8: **Foil across bottom of joists – accumulative R-value using heating box (x-axis units = days, y-axis units = m^2K/W)**

6.2.2 Location 1 using heating box after removing and re-installing equipment

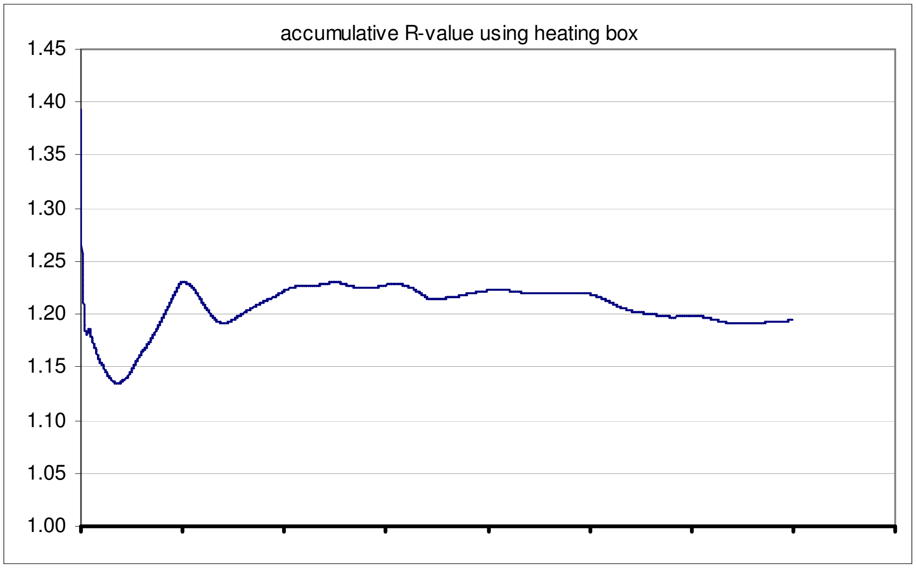

Figure 9: **Foil across bottom of joists – accumulative R-value using heating box – after re-installation of measurement equipment (x-axis units = days, y-axis units = m^2K/W)**

6.2.3 Location 2 using room heating

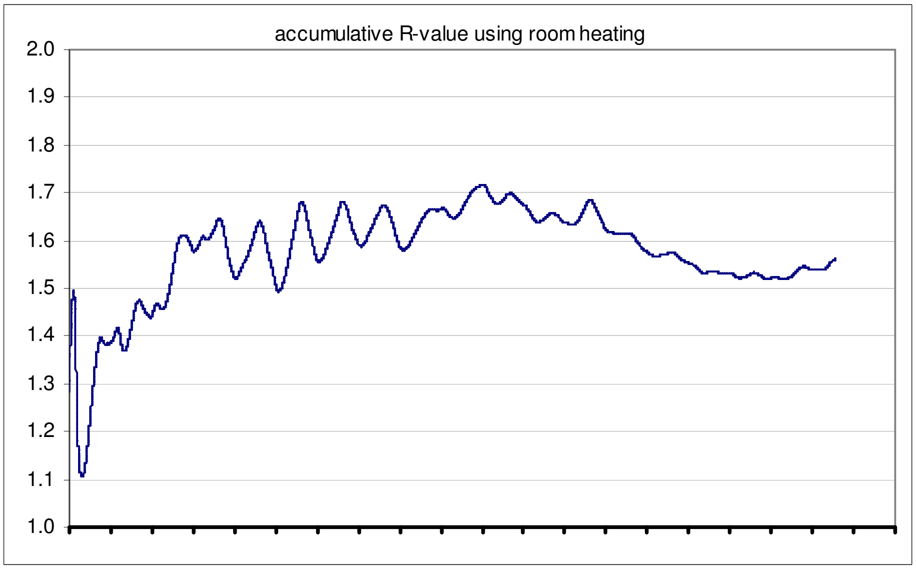

Figure 10: **Foil across bottom of joists – accumulative R-value using room heating (x-axis units = days, y-axis units = m^2K/W)**

6.3 R-1.5 Rigid fibrous polyester – insulation against

6.3.1 Location 1 using heating box

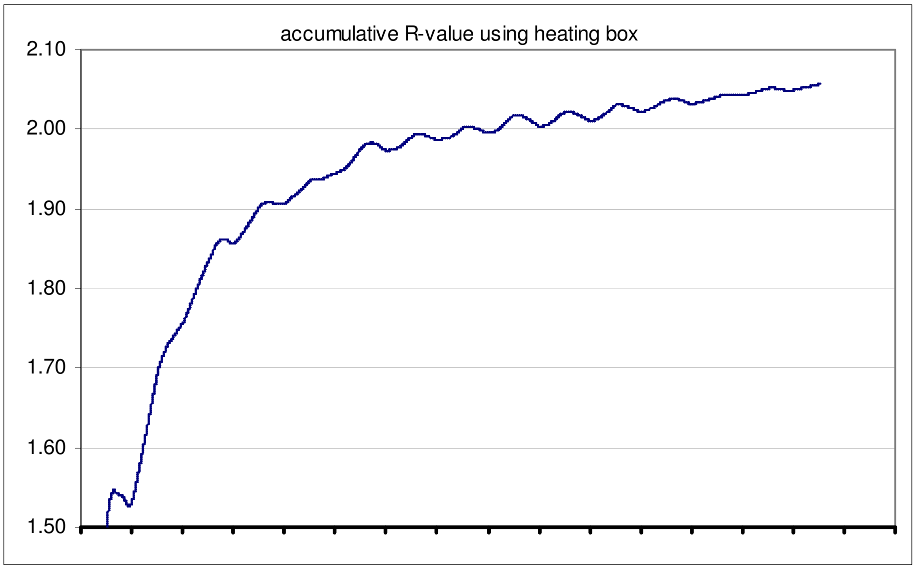

Figure 11: Fibrous polyester insulation – accumulative R-value using heating box (x-axis units = days, y-axis units = m^2K/W)

7. DISCUSSION

Thermal modelling demonstrates that the technique we have developed is relatively insensitive to differences in temperature between the inside of the heating box and the surrounding air for typical bulk insulation materials. However, when foil surfaces and associated airspaces are incorporated into the construction then there is a greater potential for convective and radiant heat exchange imbalances to impact on the results. This impact is likely to be greater when the temperature difference between the inside and outside of the heating box is large or when the air temperature surrounding the heating box is non-uniform. From this study we were not able to determine the sensitivity of the equipment but the measured thermal resistance for the foil cases for this project were consistent with the earlier BRANZ in-situ survey of construction R-values and there is reasonable agreement between the results using the heating box and the results with only room heating.

Testing of sensitivity to temperature difference between the inside and outside of the heating box would require a series of tests during relative repetitive ambient temperature conditions where the room temperature is shifted through a range of set-points. The solution if the current equipment design does exhibit significant dependence to this is to increase the size of the heating box to provide a larger guard area around the HFT.

Similarly, only practical experience with the equipment will enable a determination of the maximum and minimum values of thermal resistance that can be reliably measured.

8. CONCLUSIONS AND RECOMMENDATIONS

The project has successfully developed an update to the BRANZ in-situ thermal resistance measurement equipment that will enable field measurements of thermal resistance over a wider range of ambient temperatures conditions. It will also require less involvement by BRANZ personnel in the actual installation and operation of the equipment and in most cases will enable measurements to be made in much shorter periods of time. A key aspect is a successful measurement will be less dependent on waiting for stable cold ambient conditions.

As was expected the thermal performance of the high density bulk insulation material was more stable and closer to the theoretical calculations based on the measured thermal resistance for the material. In the case of the foil systems the thermal performance was dynamic and with an average thermal resistance similar to that measured previously in a field survey. The dynamic nature of foil R-values is not widely understood in the industry and this measurement technique can provide a way of effectively showing the variable R-value.

Since the typical age of the foil in the earlier measurements was three or four years compared with the 12 years of the draped foil, the conclusion in this particular case is that most of the changes in the reflectivity of foil surface due to contamination and ageing has probably occurred within a few years after installation. The fact that new foil installed along the bottom of the joists did not significantly improve the thermal resistance suggests that at least the thermal performance is being dominated by some other aspect other than the reflectivity of the foil surfaces. Two likely aspects are ventilation and moisture.

It is recommended that BRANZ personnel continue to be involved in field measurements using the equipment until there is a more thorough understanding of the limitations and accuracy of the equipment. In particular the equipment needs to be trialled over a wider range of both ambient and interior temperatures.

Appendix

A.1 Foil draped

(a) Location 1 using heating box

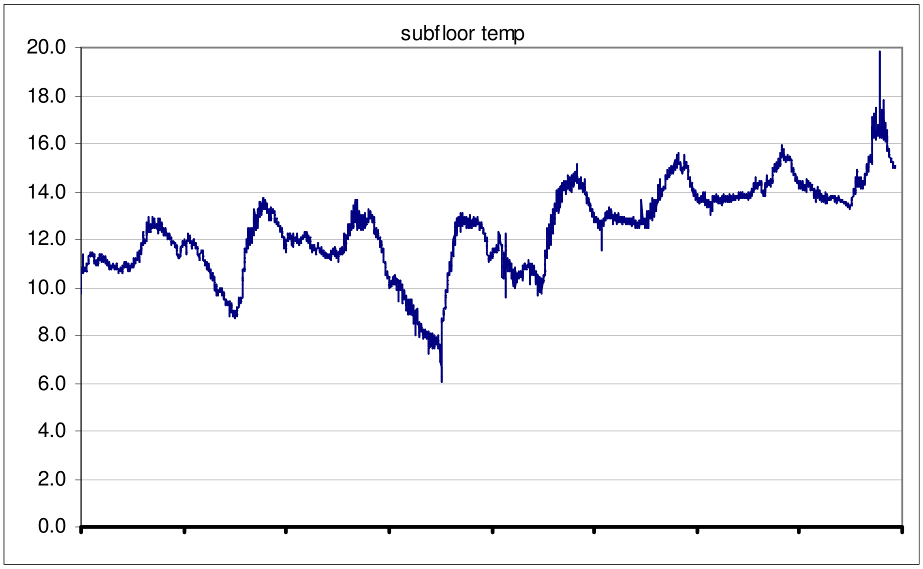

Figure 12: Foil draped – using heating box – subfloor temperature (x-axis units = days, y-axis units = °C)

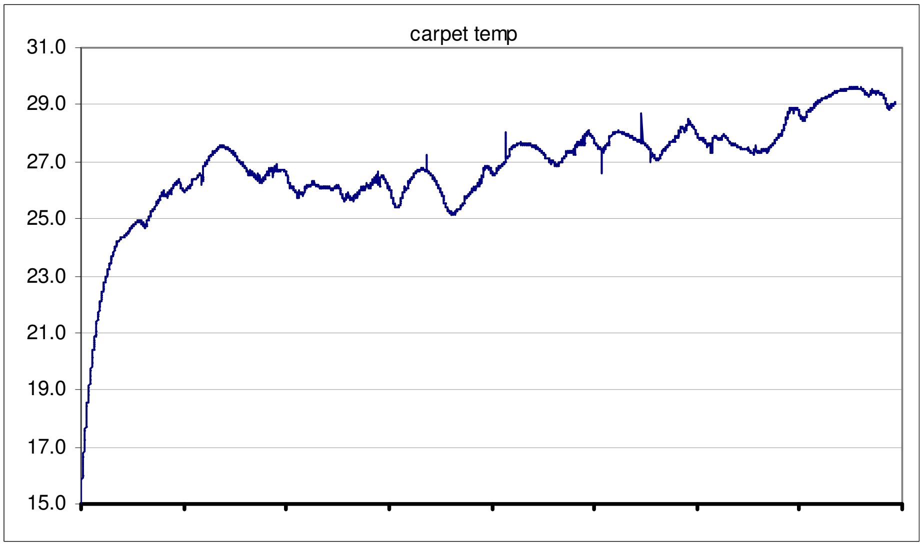

Figure 13: Foil draped – using heating box – carpet temperature (x-axis units = days, y-axis units = °C)

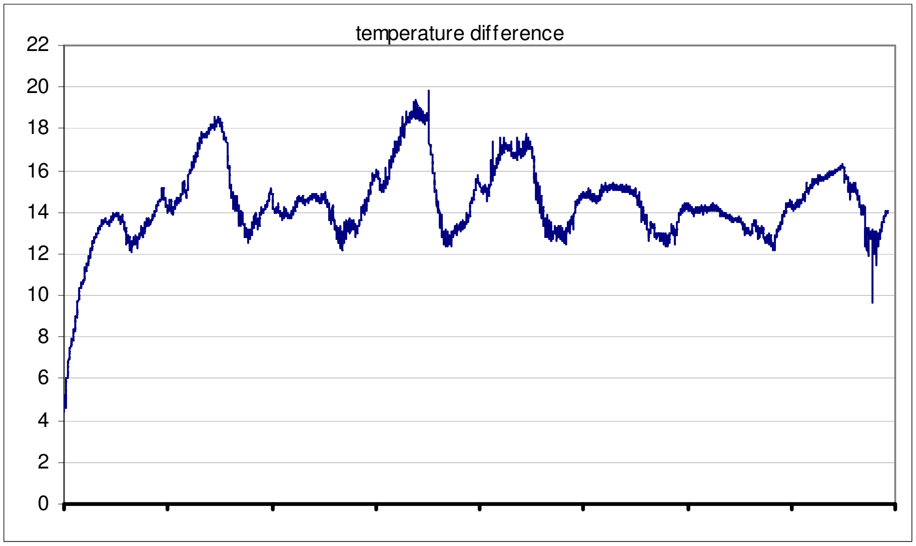

Figure 14: Foil draped – using heating box – temperature difference between subfloor and carpet (x-axis units = days, y-axis units = °C)

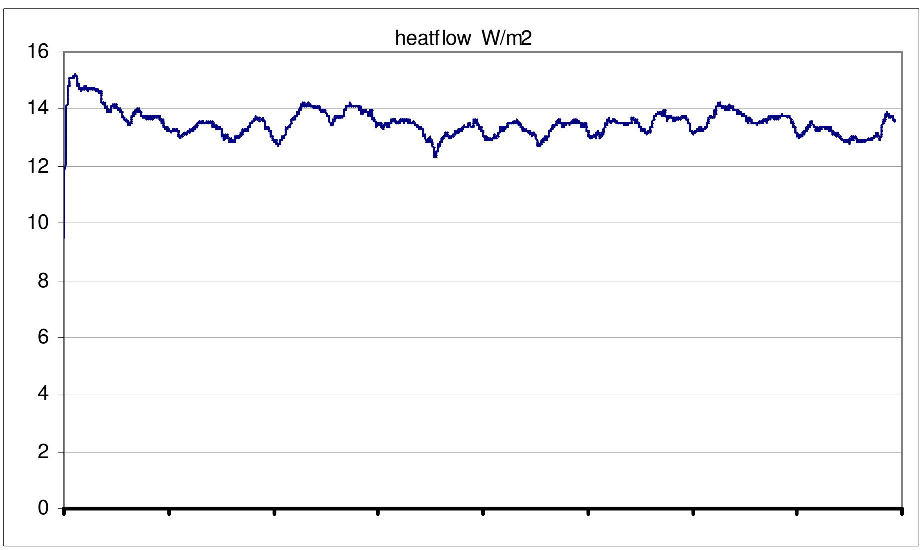

Figure 15: Foil draped – using heating box – heat flow (x-axis units = days, y-axis units = W/m^2)

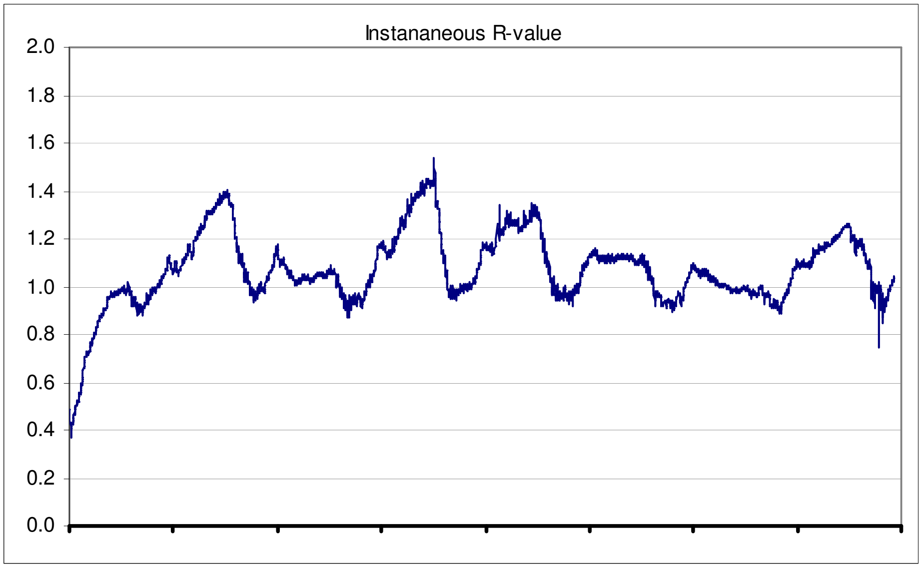

Figure 16: Foil draped – using heating box – instantaneous R-value (x-axis units = days, y-axis units = m^2K/W)

(b) Location 2 using room heating

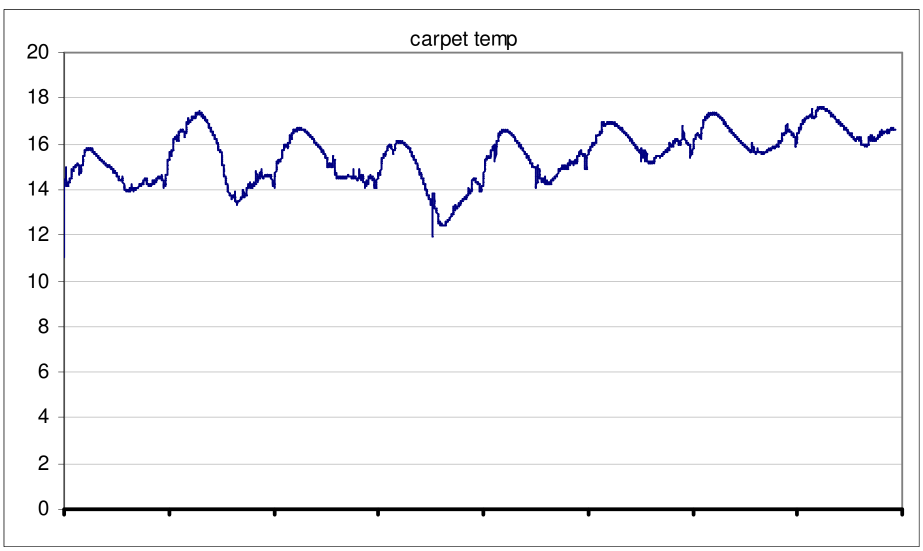

Figure 17: Foil draped – using room heating – carpet temperature (x-axis units = days, y-axis units = °C)

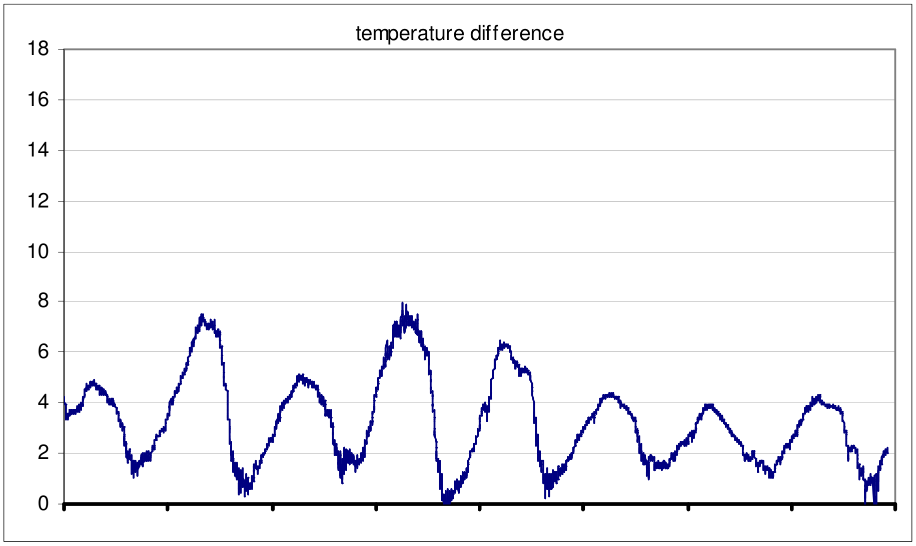

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Figure 18: Foil draped – using room heating – temperature difference between subfloor and carpet (x-axis units = days, y-axis units = °C)

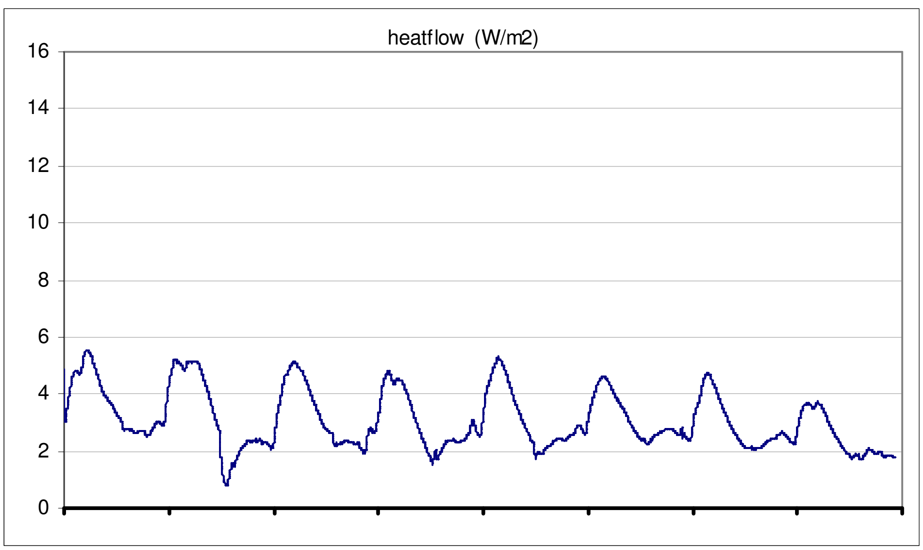

Figure 19: Foil draped – using room heating – heat flow (x-axis units = days, y-axis units = W/m^2)

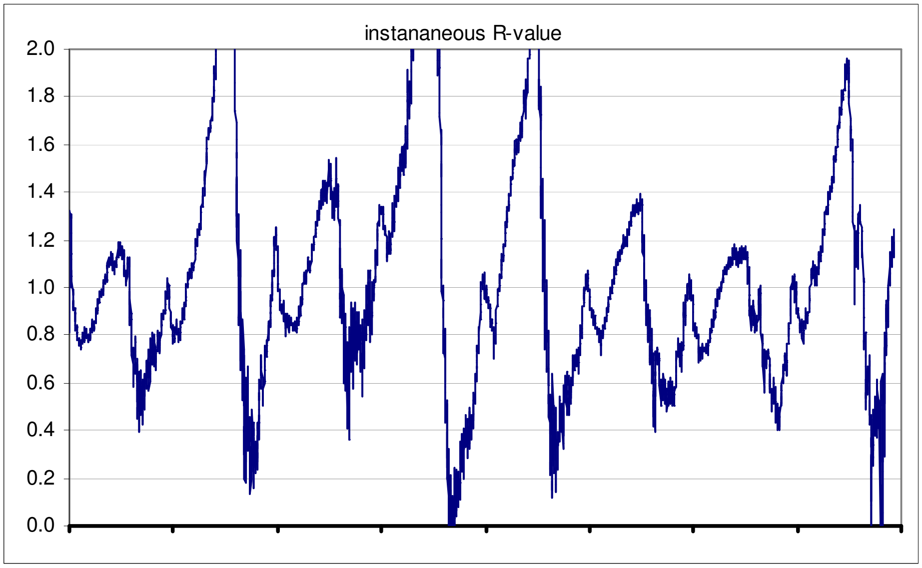

Figure 20: Foil draped – using room heating – instantaneous R-value (x-axis units = days, y-axis units = m²K/W)

A.2 Foil across bottom of joists

(a) Location 1 using heating box

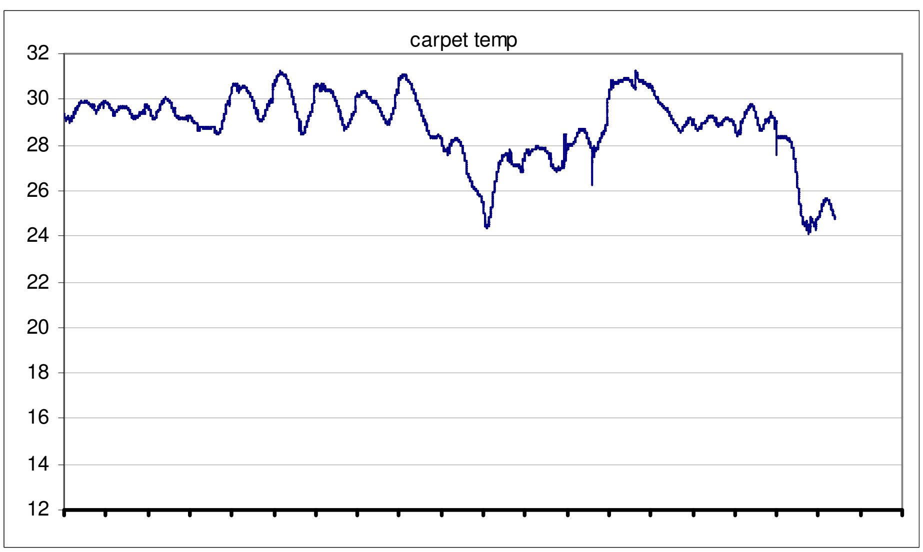

Figure 21: Foil across bottom of joists – using heating box – carpet temperature (x-axis units = days, y-axis units = °C)

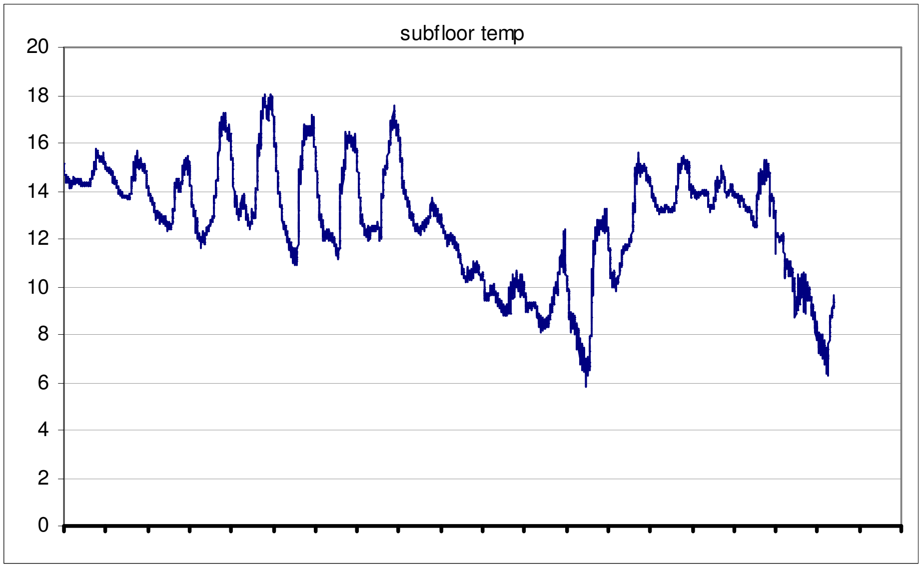

Figure 22: Foil across bottom of joists – using heating box – subfloor temperature (x-axis units = days, y-axis units = °C)

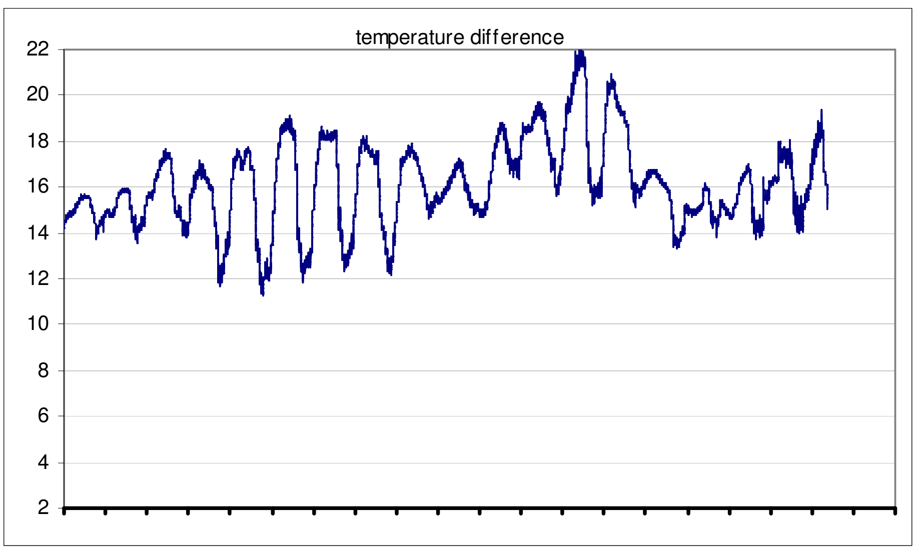

Figure 23: Foil across bottom of joists – using heating box – temperature difference between subfloor and carpet (x-axis units = days, y-axis units = °C)

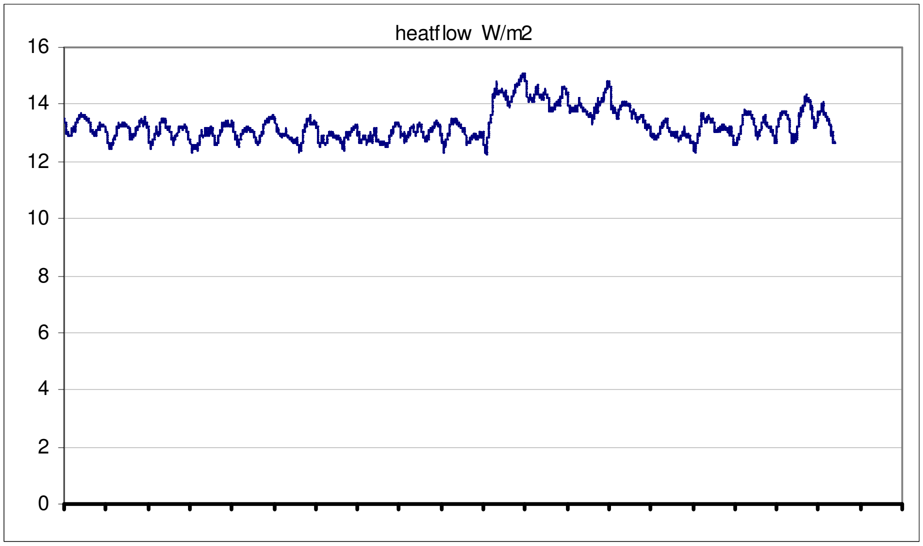

Figure 24: Foil across bottom of joists – using heating box – heat flow (x-axis units = days, y-axis units = W/m^2)

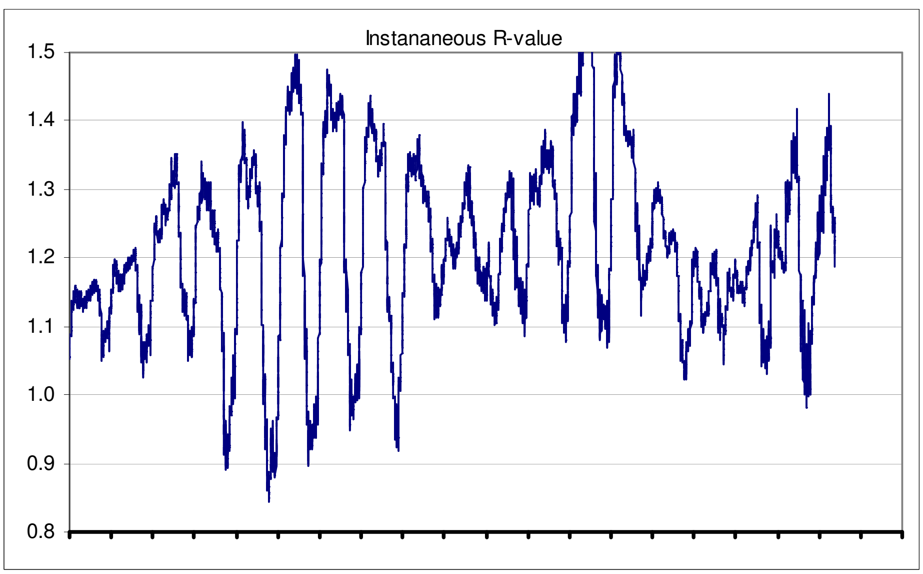

Figure 25: Foil across bottom of joists – using heating box – instantaneous R-value (x-axis units = days, y-axis units = m^{2}K/W)

(b) Location 2 using room heating

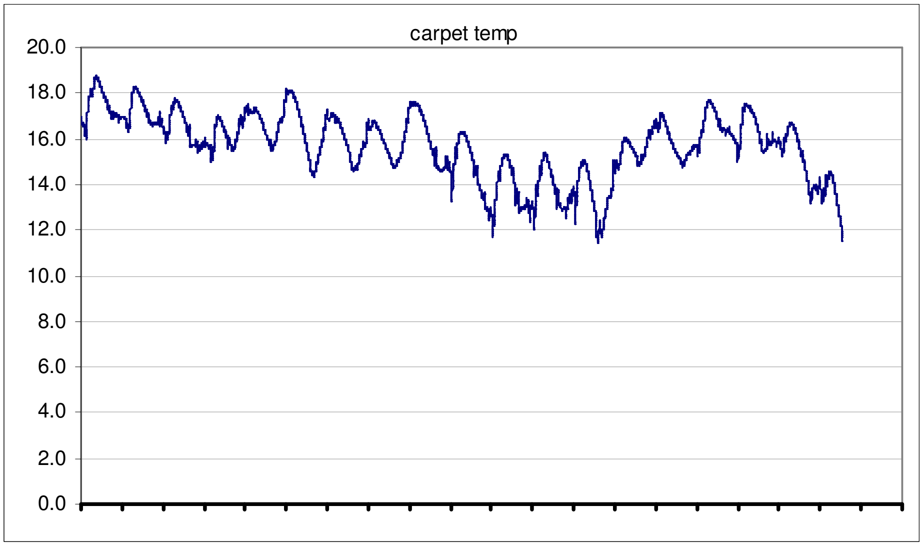

Figure 26: Foil across bottom of joists – using room heating – carpet temperature (x-axis units = days, y-axis units = °C)

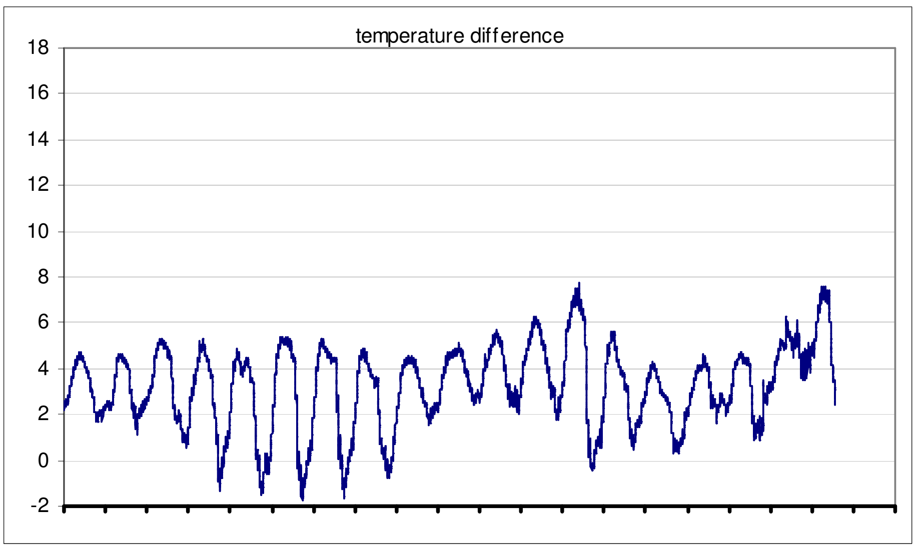

Figure 27: Foil across bottom of joists – using room heating – temperature difference between subfloor and carpet (x-axis units = days, y-axis units = °C)

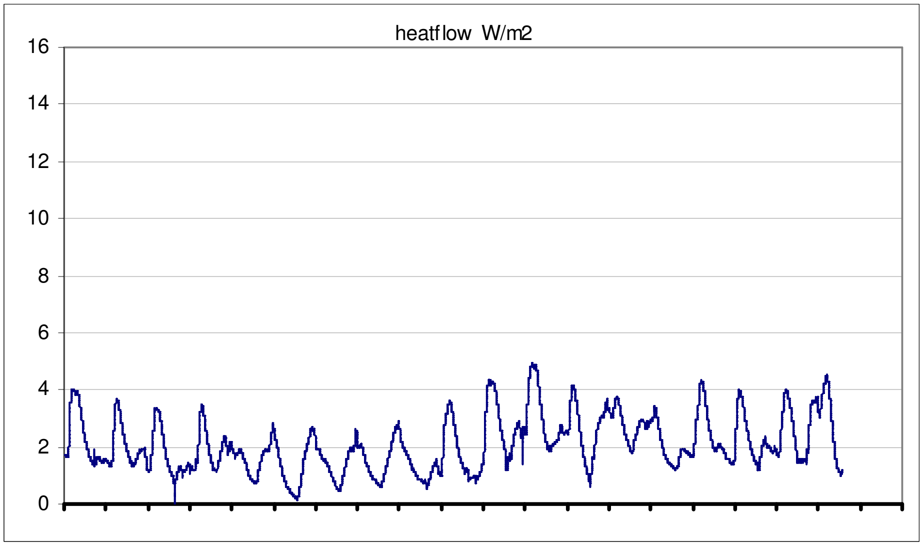

Figure 28: Foil across bottom of joists – using room heating – heat flow (x-axis units = days, y-axis units = W/m^2)

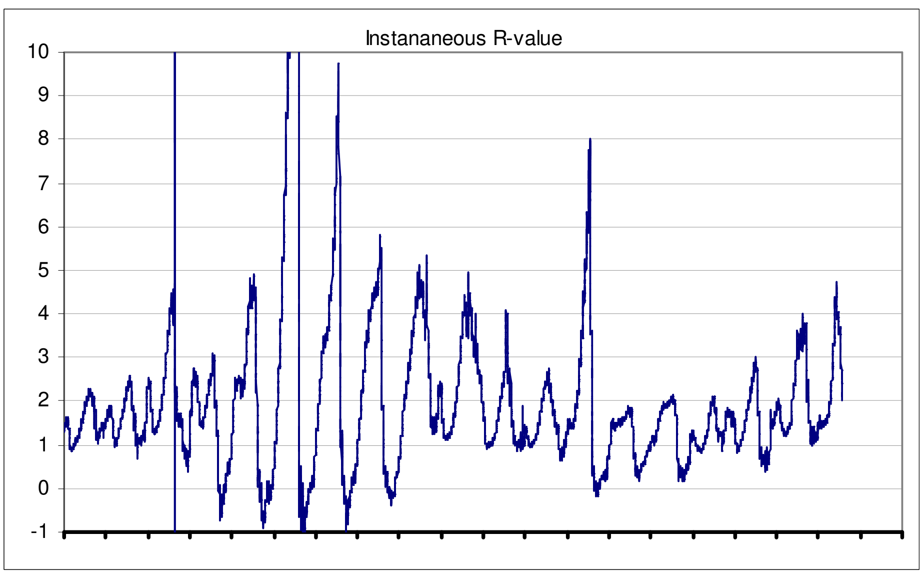

Figure 29: Foil across bottom of joists – using room heating – instantaneous R-value (x-axis units = days, y-axis units = m^{2}K/W)

A3. R-1.5 Rigid fibrous polyester – insulation against

(a) Location 1 using heating box

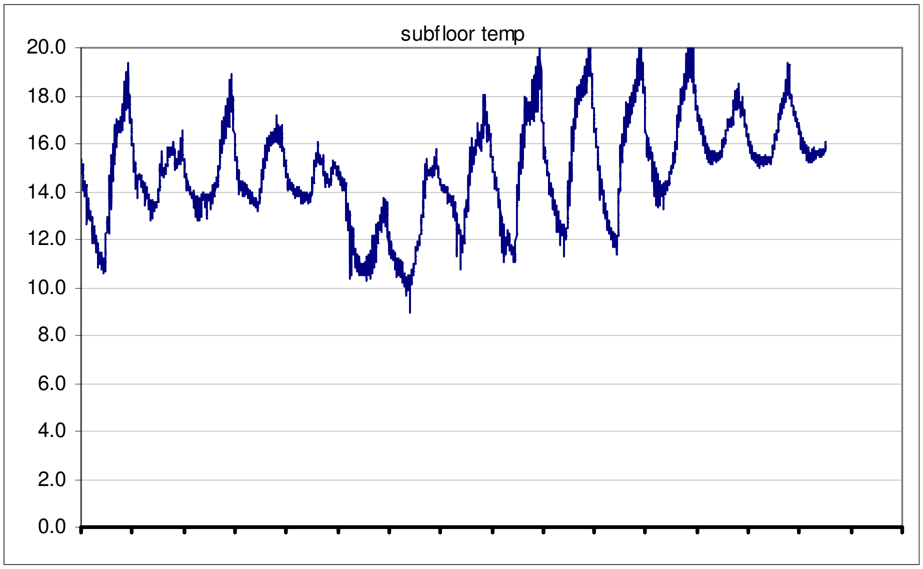

Figure 30: Fibrous polyester insulation – using heating box – subfloor temperature (x-axis units = days, y-axis units = °C)

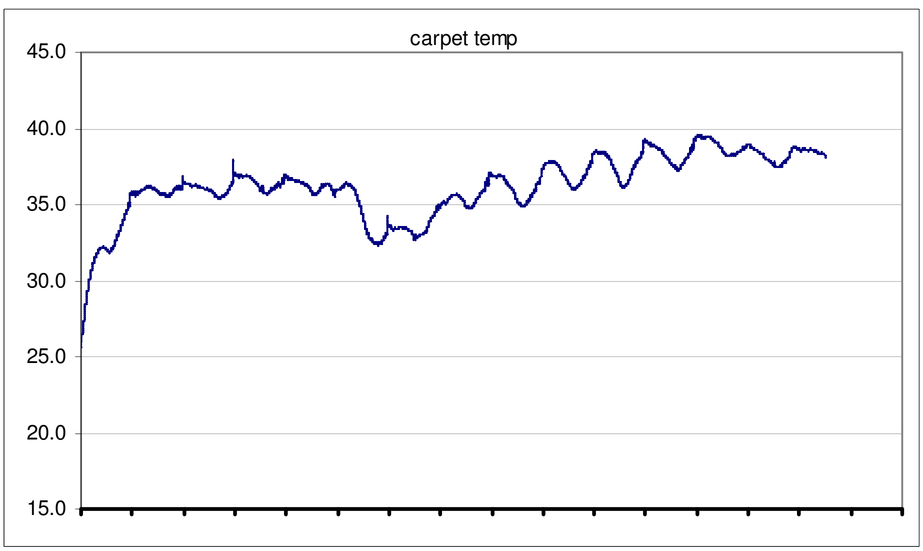

Figure 31: Fibrous polyester insulation – using heating box – carpet temperature (x-axis units = days, y-axis units = °C)

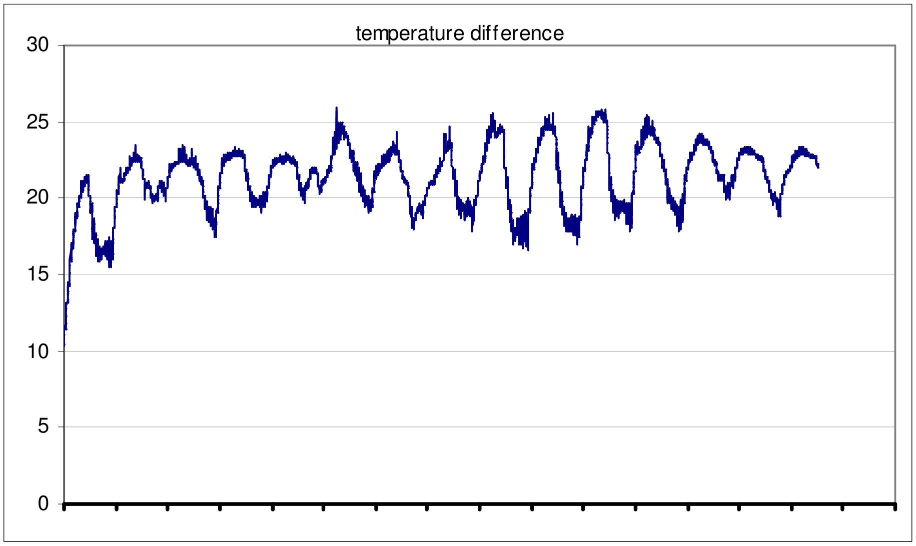

Figure 32: Foil fibrous polyester insulation – using heating box – temperature difference between subfloor and carpet (x-axis units = days, y-axis units = °C)

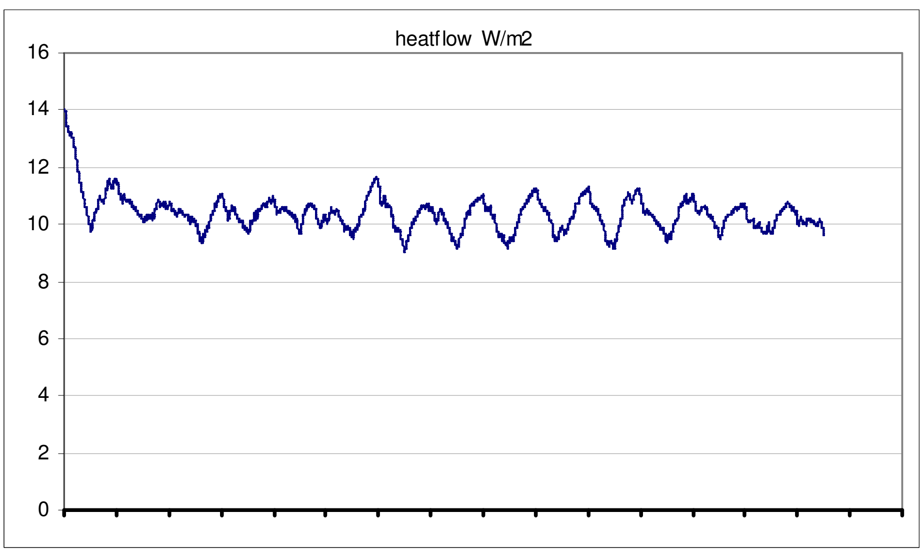

Figure 33: Fibrous polyester insulation – using heating box – heat flow (x-axis units = days, y-axis units = W/m^2)

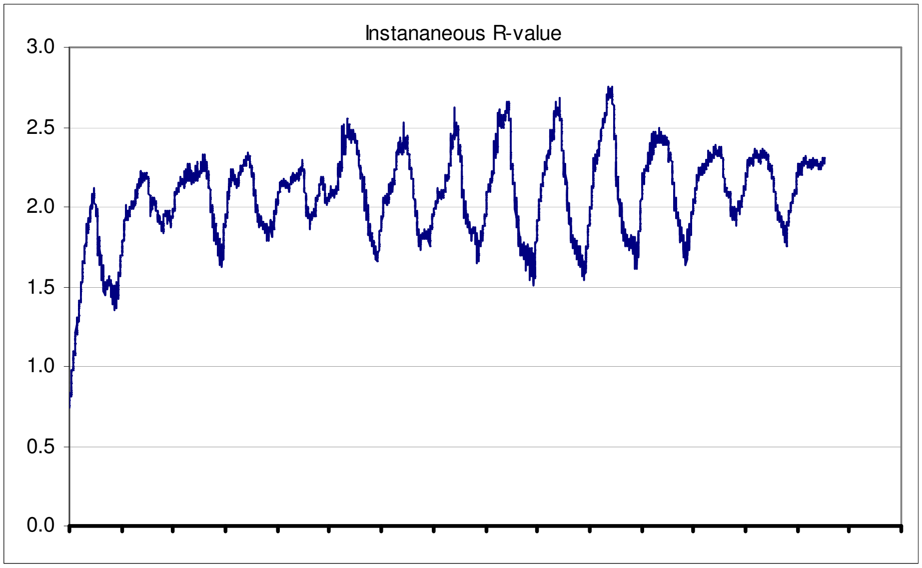

Figure 34: Fibrous polyester insulation – using heating box – instantaneous R-value (x-axis units = days, y-axis units = m^2K/W)