Bourne Leisure Ltd. Thermal Performance Measurement Report

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1.0 Introduction

1 Bourne Leisure Limited operate a number of caravan holiday parks throughout the UK. As part of their annual hire static caravan fleet renewal programme, Bourne Leisure Limited have developed a detailed specification that the static caravan manufacturers are required to adhere to. For the 2016 hire fleet models, this specification has for the first time incorporated maximum U-values for the external walls, floor and roof of the caravans (see Table 1). As Bourne Leisure Limited have limited experience of specifying maximum U-values for the fabric of their hire fleet caravans, they would like to be able to determine the optimum levels of insulation (and U-values) that should be specified for the main external elements of the fleet hire caravans (external walls, floor and roof) in terms of cost versus performance. In order to determine these optimum levels, Bourne Leisure Limited commissioned Leeds Beckett University to undertake a number of *in situ* measurements of the thermal performance and airtightness of a small number of their new 2016 model fleet hire static caravans. The *in situ* measurements were undertaken to enable the heat loss attributable to each caravan to be disaggregated into its constituent components.

2 This report outlines the results of the various *in situ* measurements undertaken on the caravans and suggests the maximum fabric U-values that should be incorporated within Bourne Leisure's specification for their 2017 hire fleet range.

Element	Target U-value (W/m^2K)
External walls	≤ 0.66
Floor	≤ 0.64
Roof	≤ 0.40
Windows	≤ 1.7

Table 1 Bourne Leisure Limited 2016 hire fleet specification.

2.0 Test caravans

3 The *in situ* measurements were undertaken on five unoccupied Bourne Leisure Limited 2016 hire fleet model static caravans, each one produced by a different caravan manufacturer. The original intention was for all of the tested caravans to be of a similar size. Unfortunately, this was not possible. Therefore, four of the caravans tested were 35 x 12ft models, with the remaining caravan being a 40 x 14ft model. Details of the caravans tested are contained within Table 2. To ensure that the performance of the caravans was representative of the model selected for testing, none of the manufacturers were informed of the particular caravan that was to be used for the testing prior to the commencement of the *in situ* measurements.

4 All of the tested caravans were located next to one another on the Hillcrest touring pitch area of the Reighton Sands site, Reighton, North Yorkshire. The test caravans were orientated north/south (A-frame facing south and master bedroom facing north), to minimise solar gain through the front of the test caravans, and positioned in such a way that they all had as similar, as was practically possible, levels of exposure (see Figure 1).

Caravan	Caravan size
A	40 x 14ft
B	35 x 12ft
C	35 x 12ft
D	35 x 12ft
E	35 x 12ft

Table 2 Details of the tested caravans.

Figure 1 Test caravans located on the Hillcrest touring pitch.

3.0 *In situ* measurements

5 Measurements on the test caravans were undertaken over the period 22nd January 2016 to the 19th February 2016 inclusive. The following *in situ* measurements were undertaken on each of the five 2016 fleet hire model static caravans:

- **Air pressure tests and leakage identification.**
- **Thermal imaging surveys.**
- **CO_2 tracer gas measurements.**
- **Heat flux density measurements.**
- **Whole caravan heat loss (electric coheating) tests.**

6 Details of when each of the above measurements were undertaken is contained within Table 3.

Date	*In situ* measurement
23/01/16 – 02/02/16	Coheating test 1 – all purpose provided ventilation and gas drop outs unsealed.
02/02/16 – 09/02/16	Coheating test 2 – all purpose provided ventilation and gas drop outs sealed.
09/02/16 – 18/02/16	Coheating test 3 – all purpose provided ventilation sealed and gas drop outs unsealed.
29/01/16 – 16/02/16	Heat flux density measurements.
27/01/16 – 19/02/16	CO_2 tracer gas decay measurements.
18/02/16	Air pressurisation tests caravan A and C.
19/02/16	Air pressurisation tests caravan B, D and E.

Table 3 Details of the various *in situ* tests undertaken on the test caravans.

4.0 Test methods

4.1 Air pressure tests and leakage identification.

7 The original intention was to undertake a series of air pressure tests both prior to and immediately following completion of the whole caravan heat loss tests. However, due to the weather conditions experienced during the early stages of the testing programme (high and/or gusting winds), it was

only possible to undertake a series of pressurisation tests once the whole caravan heat loss tests had been completed at the end of the testing period. Three sets of pressurisation tests were undertaken on each test caravan in total. The first set of tests were undertaken with all of the gas drop-out points and purpose provided ventilation openings in each caravan sealed. The second set of tests were undertaken with all of the purpose provided ventilation openings in each caravan sealed and the gas drop out points unsealed. The final set of tests were undertaken with all of the gas drop-out points and purpose provided ventilation openings unsealed. These tests were undertaken to determine the intrinsic airtightness of each test caravan, to approximate the background ventilation heat loss of each test caravan and to enable the amount of purpose provided ventilation in each test caravan to be approximated. Leakage detection, using thermal imaging, was also be undertaken to identify the main air leakage points and paths within each test caravan. All of the pressure tests were performed along the lines of ATTMA Technical Standard L1 testing protocol for building envelopes (dwellings) (ATTMA, 2010). The tests were undertaken using an Energy Conservatory Minneapolis Duct Blaster® System with a DG700 dual-channel pressure gauge (see Figure 2).

Figure 2 Pressurisation test being undertaken on one of the test caravans.

4.2 Thermal imaging surveys

8 Thermal imaging was undertaken at various stages throughout the *in situ* measurement period using a Flir TB620bx Infra-Red Thermal Imaging Camera. Thermal images were captured under two separate conditions. First of all, under a natural pressure differential between the inside and outside of the test caravans. Secondly, during the air pressurisation tests when the test caravans were under depressurisation. The thermal imaging was undertaken to identify any thermal anomalies in the external wall, floor or roof construction of each test caravan, identify appropriate locations for the heat flux plates (HFP's) and to identify any air leakage paths during the air pressure tests.

4.3 CO_2 tracer gas density measurements

9 Although the air pressure tests results provide a measure of the air permeability and/or air leakage rate of the test caravans, the value obtained from undertaking such tests does not represent a real background ventilation rate, as the reported 50Pa artificially induced internal/external pressure differential that is used in the UK when presenting the results is much greater than the internal/external pressure differentials experienced under normal conditions. Under normal conditions, the internal/external pressure differential in buildings is typically around 3 to 6 Pa (Modera *et al.,* 2009). Furthermore, the blower-door test is a single measurement, representing a

particular 'snap-shot' in time. In reality, the background ventilation rate will vary with pressure, temperature and wind conditions, and so is most usefully quoted as an annual average figure.

10 In dwellings, the air leakage rate obtained from a pressure test can be approximated to the natural annual average background ventilation rate by simply dividing the air change rate measured at 50Pa (n_{50}) by 20. This empirical procedure is commonly known as the $n_{50}/20$ *'rule of thumb'*. The origin of this *'rule of thumb'* is usually attributed to Kronvall and Persily (cited by Sherman in 1987) and was originally devised based upon a large number of results obtained from dwellings in North American in the late 1980's. In addition, the '20' devisor was originally applied to air changes per hour (ach^{-1}), rather than permeability in $m^3/(h.m^{2)}$, thus taking better account of the dwellings' geometry.

11 In the UK, the simple '20' divisor has been applied to air permeability ($Q_{50}/20$), rather than air leakage ($n_{50}/20$), to calculate an average annual infiltration (background ventilation) rate for a dwelling. This calculation is contained within the Government's Standard Assessment Procedure (SAP) (BRE, 2012), which forms an integral part of Part L1A of the Building Regulations (NBS, 2013). However, it is not known whether the use of the '20' devisor is applicable to the types of dwellings constructed in the UK. In addition, the consequence of applying this divisor to air permeability, rather than air leakage, is that it favours those dwellings that have a high surface to volume ratio. In other words, for dwellings of similar volume and similar overall levels of airtightness, a much lower background ventilation rate is attributed to narrower, taller dwellings than to a more nearly cubic building. However, as the average dwelling in the UK is a two storey 3 bedroom semi-detached property, which is nearly cubic in form, the difference between using $Q_{50}/20$ or $n_{50}/20$ is marginal.

12 In the case of the test caravans, which have a very long and narrow built form, the difference between using $Q_{50}/20$ or $n_{50}/20$ to calculate the background ventilation rate is likely to be significant. Despite this, version 12 of the National Caravan Council (NCC) Energy Efficiency Rating Calculator for Park and Caravan Holiday Homes (NCC, 2016), which is based upon SAP, incorporates the Q50/20 *'rule of thumb'* as opposed the n50/20 *'rule of thumb'*. Additionally, it is also not known whether the use of the '20' devisor in the simple *'rule of thumb'* is appropriate for the test caravans. Given this, a series of CO_2 tracer gas decay measurements were undertaken in test caravans B to E during the three electric coheating test periods. No CO_2 tracer gas decay measurements were undertaken in test caravans A, due to its different size and form factor.

13 The CO_2 tracer gas decay measurements involved artificially introducing short bursts of CO_2 gas (5 minutes in duration) into the open plan living/kitchen area of test caravans B to E at midnight using a simple CO_2 gas dispersal system. The dispersal system comprised a portable CO_2 canister, a solenoid valve, a digital electronic timer and an outlet tube. To aid mixing of the CO_2 gas within the test caravans, the outlet tube from the CO_2 canister was attached to the outer casing of the circulation fan located in the living/kitchen area. This air circulation fan, along with all of the others installed within the test caravans, help ensure that the CO_2 is distributed throughout the caravans. CO_2 sensors located in the living/kitchen area and bedroom 1 were then used to measure the rates of CO_2 decay over time. Background ventilation rates for the living area and bedroom 1 were then determined based upon the period of time taken for the CO_2 concentration to decay to the background level. These were calculated in accordance with the method described within Roulet and Forandini (2002).

14 It should be noted that the air change rates measured using the CO_2 tracer gas decay method are only illustrative and may not necessarily be representative of the background ventilation rate of the test caravans as a whole. The reason being that they have only been undertaken within two of the rooms within the tests caravans, and it may be that the leakage paths and leakage characteristics of these two rooms are not representative of the leakage paths and characteristics of the test caravans as a whole.

4.4 Heat flux density measurements

15 A number of Hukseflux HFP-01 heat flux plates (HFPs) were attached to the internal surfaces of the external walls, floor, roof and window of each test caravan to enable the heat flux density through each element of the fabric to be measured during the electric coheating tests. The heat flux density (measured in W/m^2) was then used in conjunction with the corresponding internal/external air temperature measurements to calculate an *in situ* air-to-air U-value for each HFP location using the average method contained within BS ISO 9869-1: 2014 (BSI, 2014). For a lightweight thermal element, in order to comply with BS ISO 9869-1: 2014, the minimum measurement period is 72 hours and the R-value obtained at the end of the measurement period must not deviate by more than ± 5 % from the value obtained 24 hours previously. The *in situ* air-to-air U-values were

calculated using night-time measurements to reduce the influence of solar radiation, namely from 18:00 – 05:59 inclusive.

16 In total, eight HFP's were installed in the north facing open plan living and kitchen area of each test caravan, six of which were moved to a different location part way through the testing period. Positioning of the HFPs was informed by the thermal imaging survey, with the HFPs being positioned in locations that were considered to be representative of the element being measured and in locations where thermal anomalies, studwork or floor/ceiling joists had been identified. In terms of the thermal anomalies, the anomaly at the external wall coincided with the external aerial mounting point, whilst the anomaly in the ceiling corresponded with a gap or discontinuity in the insulation around the kitchen ceiling mounted extract ventilator.

17 When positioning the HFP's, care was undertaken to ensure that the HFPs were not unduly influenced by excessive air movement and were not located in close proximity to any heat emitters. Details of location of the HFPs within each test caravan are contained within Table 4. The HFPs were fixed to the internal face of the test caravans using adhesive tape and thermal contact paste (Dow Corning 340 Heat Sink Compound). A thin layer of cling film was applied between the thermal contact paste and the internal face of each fabric element to protect the internal finish.

18 The voltage induced by the HFPs was recorded at 1-minute intervals using an Eltek Squirrel 851L data logger. The external ambient air temperatures used in the calculation of the *in situ* U-values were obtained from a Vaisala WXT520 weather transmitter which was mounted on the east facing façade of caravan D (see Figure 3). Ambient internal temperatures were obtained using a TMS Pt100 RTD connected to an Eltek GD52 transmitter. The TMS Pt100 RTD was mounted on a tripod located the centre of the living/kitchen area of each caravan in close proximity to all of the heat flux density measurements. The location of some of the HFP's installed within one of the test caravans is illustrated in Figure 4.

HFP	Location
1	External wall directly between two timber studs.
2	External wall at timber stud.
2a	External wall directly between two timber studs.
3	External wall anomaly.
3a	External wall directly between two timber studs.
4	Ground floor directly between two joists.
5	Ground floor at joist.
5a	Ground floor directly between two joists.
6	Ceiling directly between two roof joists.
6a	Ceiling directly between two roof joists.
7	Ceiling at roof joist.
7a	Ceiling directly between two roof joists.
8	Ceiling anomaly.
8a	Centre of north-facing glazing.

Table 4 Location of the HFPs within each caravan.

Figure 3 Weather station mounted on the East façade of test caravan D.

Figure 4 Location of some of the heat flux plates installed within one of the test caravans.

19 It must be noted that *in situ* effective U-values presented within this report may not be representative of the elements measured as a whole, for the following reasons:

a) Measurement of heat flux density was obtained from only a small proportion of the total surface area of the element being measured in each test caravan.

b) HFP positioning was influenced by the form, internal arrangement, and orientation of each test caravan.

c) A large proportion of the fabric elements have furniture and fittings attached to them, some of which contain unventilated air voids. These voids and the associated furniture and fittings will provide additional thermal resistance, resulting in reduced heat transfer at these points in the construction. For practical reasons, no HFPs have been installed on any of the elements of furniture or fittings, i.e. HFPs were only installed directly onto the external elements.

d) The conditions present during the measurement period, particularly the external climatic conditions, may not be representative of the conditions under which the test caravans are routinely subjected to.

20 The *in situ* U-values of the main elements of the test caravans were measured to enable a comparison to be made between the steady-state U-values specified by the manufacturers, the

steady-state U-values specified for the 2016 hire fleet by Bourne Leisure Limited and the *in situ* U-values obtained in practice.

4.5 Whole caravan heat loss (electric coheating) tests

21 A series of whole caravan heat loss (electric coheating) tests were undertaken in order to determine the steady-state *in situ* aggregate (both fabric and ventilation) heat loss of each test caravan in W/K. These tests involved heating the internal volume of each of the unoccupied caravans electrically to a mean elevated homogeneous internal temperature using thermostatically controlled electric resistance point heaters, and then maintaining this temperature constant for a specified period of time. In addition to the electric resistance point heaters, electrically driven air circulation fans were strategically positioned within each test caravan to ensure that the internal air is adequately mixed and to ensure isothermal conditions existed throughout. The mean elevated internal temperature within each test caravan was set to 20°C. This ensured that the primary direction of the heat flow during the test period was from the inside of the caravan to the outside and that there was a sufficient temperature difference (at least 10K) between the inside and the outside of the caravan (ΔT) throughout the test period. As test caravans B to E are all the same size and all of the test caravans experienced very similar environmental conditions throughout the test, comparison of the data obtained from the test caravans will establish whether any difference in performance exists between each of these caravans.

22 In total, three separate electric coheating tests were undertaken on each test caravan. The first test was undertaken with all of the gas drop out points and purpose provided ventilation openings in each test caravan unsealed. The second set of tests were undertaken with the gas drop out points and all of the purpose provided ventilation openings in each test caravan sealed. The final set of tests were undertaken with all of the gas drop-out points unsealed and purpose provided ventilation openings sealed. Three separate tests were undertaken to enable an estimate of the additional *in situ* heat loss attributable to the purpose provided ventilation and the gas drop out points to be disaggregated from the aggregate heat loss of each test caravan.

23 All of the whole caravan heat loss tests were undertaken based upon a modified version of the Leeds Beckett University (formerly Leeds Metropolitan University) whole house heat loss test method (coheating) protocol (see Johnston, Miles-Shenton, Farmer & Wingfield, 2013). The coheating test method was modified to account for the short time period that was available to the research team to undertake each separate electric coheating test (approximately 1 week per test). Typically, electric coheating tests in dwellings are undertaken over a period of between 7 to 21 days and are based upon 24 hour daily average data. Generally speaking, longer testing periods are preferred, as this enables the multiple linear regression analysis procedure to more confidently account for thermal mass effects, the influence of solar radiation and the effect of wind speed on the heat loss coefficient (HLC). As the test caravans are of lightweight construction and consequently have very low thermal mass, it is reasonable to assume that an electric coheating test could be undertaken over a shorter time period than that normally associated with typical dwellings. However, if daily average data is used in the analysis, the shorter time period precludes an accurate estimation of the contribution of solar radiation on the heating power input to the caravan using multiple regression analysis. Thus, the data that has been used in the estimation of the HLC is from a time period thought not to be influenced by direct or previously stored solar radiation, namely 18:00 – 05:59 inclusive. In addition, the data points used in an electric coheating multiple regression analysis are usually based upon 24 hour daily average data. However, due to the limited time period associated with each test and the fact that any thermal lag between a change in ΔT and the resultant change in heating power is likely to be minimal (due to the low thermal mass of the caravans), the electric coheating data was aggregated into hourly mean time intervals for the analysis.

24 An illustration of some of the electric coheating equipment installed within one of the test caravans is contained within Figure 5.

Figure 5 Electric coheating test equipment installed within one of the test caravans.

5.0 Results

5.1 Air pressure tests and leakage identification

***Based upon a pressurisation test result undertaken by the manufacturer.** .

25 Table 8 also includes the corresponding back calculated design air leakage rate for each test caravan based upon the design air permeability value inserted within the NCC Energy Efficiency Rating Calculator. These air leakage rates have been included to illustrate the size of the difference that can exist between these two values.

Caravan	Mean air permeability ($m^3/(h.m^2)$ @ 50Pa)	Mean air leakage rate (ach^{-1} @ 50Pa)	Correlation coefficient (r^2)
A	7.7	11.8	0.996
B	6.3	10.4	0.998
C	5.2	8.4	0.996
D*	9.1	14.2	
E	7.9	12.9	0.998

*Based upon a spot 50Pa pressure test as the seal below the fridge was compromised during the original test.

Table 5 Air pressure test results (gas drop-out points and purpose provided ventilation openings sealed).

Caravan	Mean air permeability ($m^3/(h.m^2)$ @ 50Pa)	Mean air leakage rate (ach^{-1} @ 50Pa)	Correlation coefficient (r^2)
A	8.2	12.6	0.999
B*	6.8	11.3	n/a
C*	9.1	15.6	n/a
D*	9.8	15.3	n/a
E*	8.3	13.6	n/a

*Based upon a spot 50Pa pressure test.

Table 6 Air pressure test results (gas drop-out points unsealed and purpose provided ventilation openings sealed).

Caravan	Mean air permeability ($m^3/h/m^2$ @ 50Pa)	Mean air leakage rate (ach^{-1} @ 50Pa)	Correlation coefficient (r^2)
A	11.9	18.3	0.997
B	13.8	22.9	1.000
C	10.9	17.6	0.997
D	13.2	20.5	0.994
E	12.1	20.1	0.998

Table 7 Air pressure test results (gas drop-out points and purpose provided ventilation openings unsealed).

Caravan	Mean air permeability ($m^3/h/m^2$ @ 50Pa)	Back calculated mean air leakage rate (ach^{-1} @ 50Pa)
A	11.5*	17.7
B	15.0	25.0
C	15.0	24.3
D	3.0*	4.7
E	6.0*	9.8

*****Based upon a pressurisation test result undertaken by the manufacturer. .

Table 8 NCC Calculator air permeability values for each test caravan.

26 A comparison between the mean air permeability and mean air leakage rate of the test caravans is illustrated in Figure 6 and Figure 7.

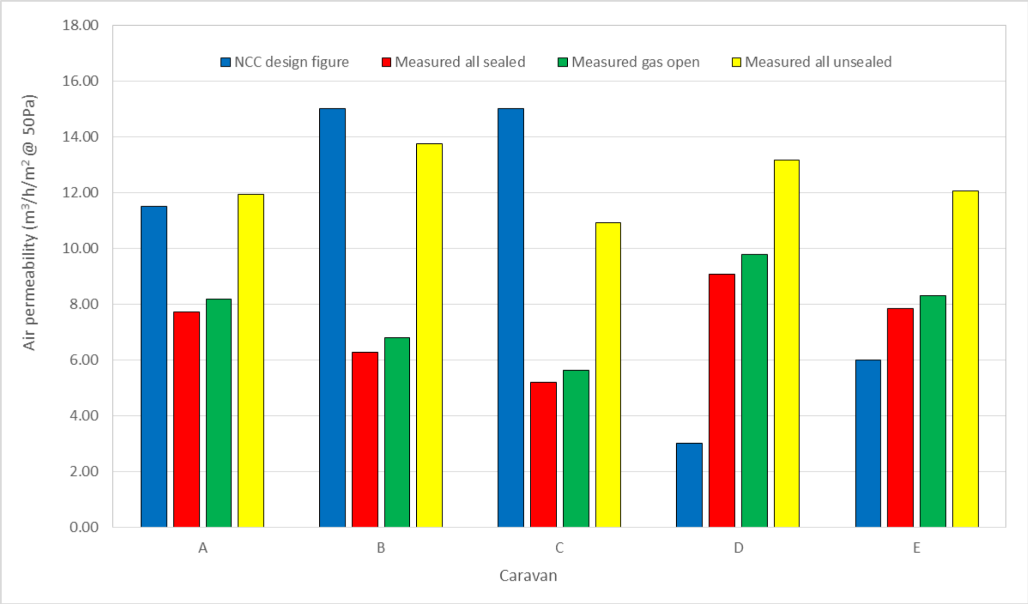


Figure 6 Comparison between the measured and design air permeability values for the test caravans.

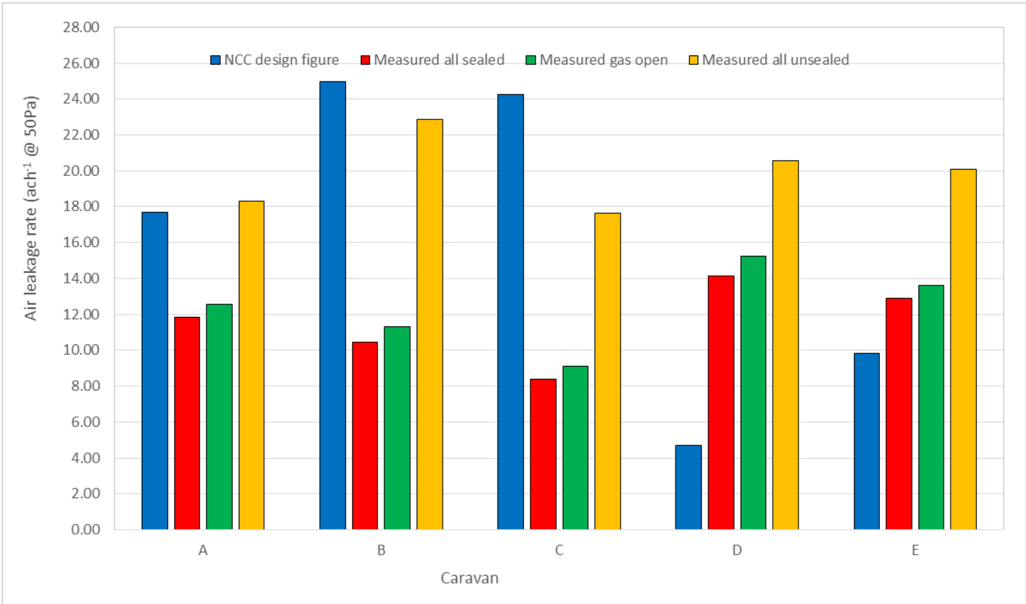


Figure 7 Comparison between the measured and design air leakage rates for the test caravans.

27 For caravans, A, B and C, the measured air permeability values obtained when all of the purpose provided ventilation and gas drop out points are sealed are significantly lower than the design intent. For caravans B and C, this can be attributed to the fact that the manufacturers of these caravans claimed that no airtightness test had been undertaken on a suitably tested caravan within the NCC Energy Efficiency Calculator, so the air permeability figure used for the design intent was the default value of 15 $m^3/(h.m^2)$ @ 50Pa. The default figure contained within the NCC Energy Efficiency Calculator is artificially high to encourage manufacturers to undertake a pressurisation test on their caravans.

28 For caravan A, the measured figure obtained during the air pressure test was significantly lower than the measured value inserted into the NCC Energy Efficiency Calculator (7.7 as opposed to 11.5 $m^3/(h.m^2)$ @ 50Pa. The reason for this is not known, but may be attributable to the manufacturer testing a different variant of the same model of caravan and using this test result in the NCC calculator. For caravans D and E, the opposite is true, with the measured air permeability values being significantly greater than the design intent. In the case of caravan D, the measured air permeability is over 300% greater than the design intent value; this represents a significant

performance gap. In caravan E, the discrepancy between the measured and design air permeability values was much smaller, with the measured air permeability being just over 30% greater than the design intent air permeability. However, this still represents a significant performance gap. The reasons why there are such large discrepancies between the air permeability results claimed by the manufacturers of caravan D and E and the results obtained by the Leeds Beckett University testing team are not known, as the air permeability results for these two caravans have not been made available as part of this project. Part of the reason for the discrepancy in air permeability may be attributable to the fact that the NCC Energy Efficiency Calculator does allow the manufacturers to use an air permeability test result that has been obtained from a different caravan as long as it is of the same construction. However, they do ask that the manufacturer tests a caravan that is likely to be the worst case scenario for a particular construction, which is generally the smallest model built using that construction. Although this may explain some of the difference in the air permeability results, it is unlikely to explain the large difference in measured air permeability for caravan D.

29 The results contained within Figure 4 and Figure 6 also illustrate the air permeability and leakage rate increasing from one test to the next, as the gas drop out points and then the purpose provided ventilation openings are unsealed. This is to be expected. On average, the air permeability increased by 7% when the gas drop out points were unsealed and then by a further 60% when all of the purpose provided ventilation openings were unsealed.

30 The results also illustrate that all of the tests caravans do vary in terms of their air permeability. The air permeability measured with all of the purpose provided ventilation openings and gas drop out points sealed varied from just over 5 $m^3/(h.m^2)$ @ 50 Pa for caravan C to just over 9 $m^3/(h.m^2)$ @ 50 Pa for caravan D. On average, the air permeability of the test caravans was just over 7 $m^3/(h.m^2)$ @ 50 Pa. This level of air permeability is lower than the minimum standard of 10 $m^3/(h.m^2)$ @ 50 Pa that is contained within Part L1A of the Building Regulations (NBS, 2013) and is comparable to that achieved in new build housing in the UK. Interestingly, all of the test caravans achieved significantly lower levels of air permeability than the default value of 15 $m^3/(h.m^2)$ @ 50 Pa contained within the NCC Energy Efficiency Calculator.

31 In terms of air leakage identification, in the main, all of the test caravans displayed a number of very similar and significant air leakage points and pathways. The main difference between the test caravans being the degree through which air leakage occurred at these points and pathways. The main areas of air leakage were detected during depressurisation using thermal imaging. An advantage of using thermal imaging for leakage detection is that it indicates not only direct infiltration into the caravans, but also where indirect air leakage is occurring, such as air leakage through and between layers and voids in the construction. The main areas of air leakage identified within the caravans were as follows:

- Around sockets located on the external wall (see Figure 8).
- Around the ceiling mounting extract grilles (see Figure 9).
- Around the wall-mounted extract fans and grilles (see Figure 10)
- At the ceiling ridge junction (see Figure 11).
- Around the consumer unit (see Figure 12).
- Around the boiler flue (see Figure 13).
- Around the water pipes, gas pipes and condensate drain at the boiler (see Figure 14).
- Around the central heating pipes where they penetrate the ground floor (see Figure 15).
- Around the gas pipes to the cooker (see Figure 16).
- Around the waste and water pipes under the kitchen units (see Figure 17).
- Around the toilet waste pipe (see Figure 18).
- Beneath the shower tray (see Figure 19).
- At the external wall/ceiling junction and at external wall corners (see Figure 20). This was particularly obvious in caravan D (see Figure 21).
- Around the window frames (see Figure 22).

32 In addition, there were a much smaller number of areas of air leakage identified that were specific to particular test caravans. These were as follows:

- At the shower tray/floor junction in caravan B (see Figure 23).
- At the external wall/floor junction in the master bedroom of caravan A and E (see Figure 24).
- Beneath the carpet in the master bedroom of caravan B (see Figure 25).
- Around the front door of caravan C (see Figure 26).

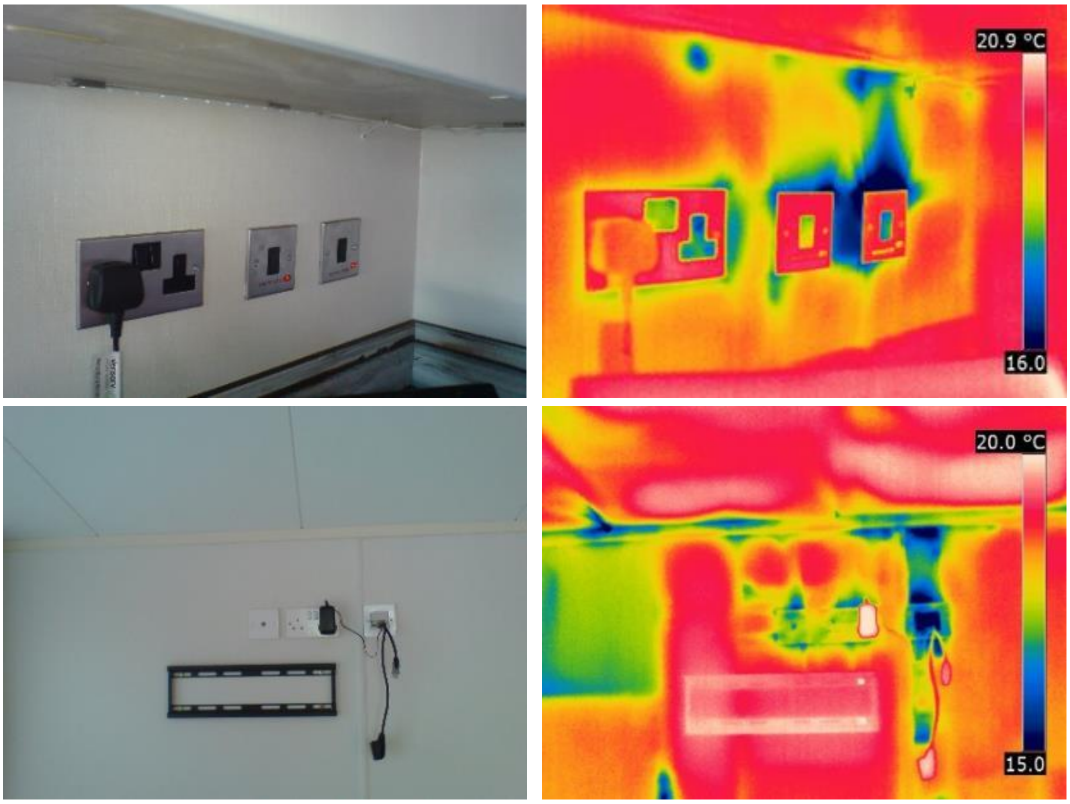


Figure 8 Air leakage around external wall sockets.

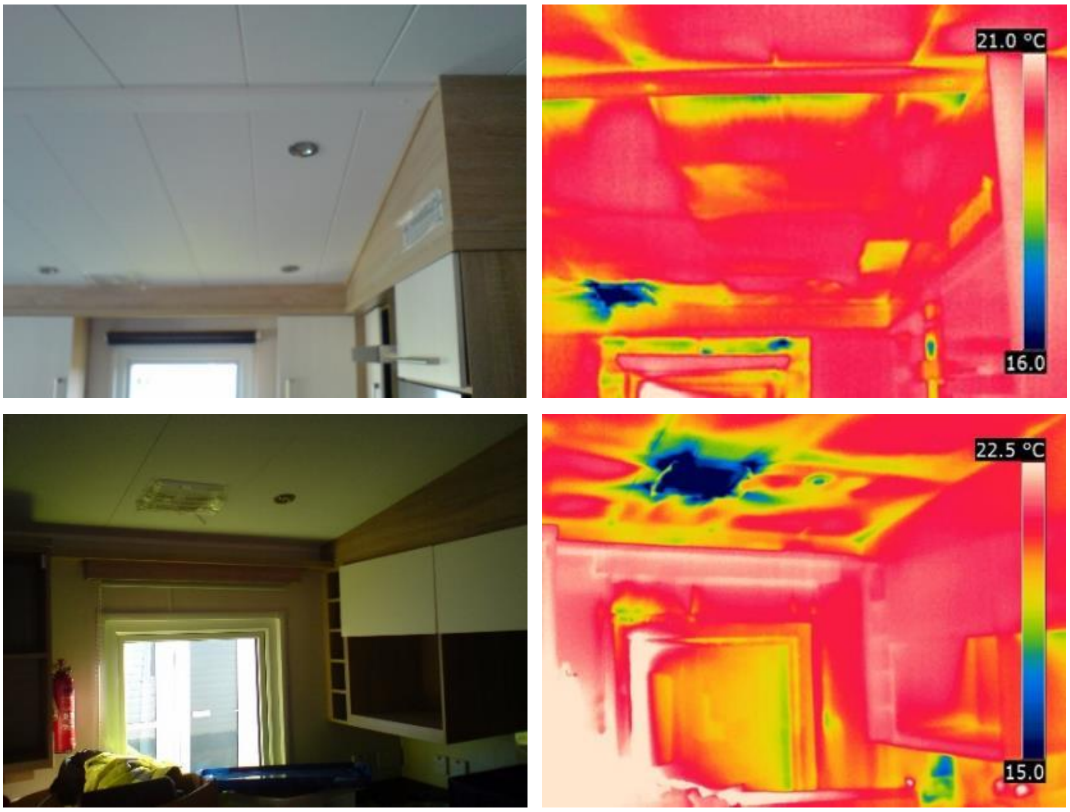


Figure 9 Air leakage around ceiling mounted extract grilles.

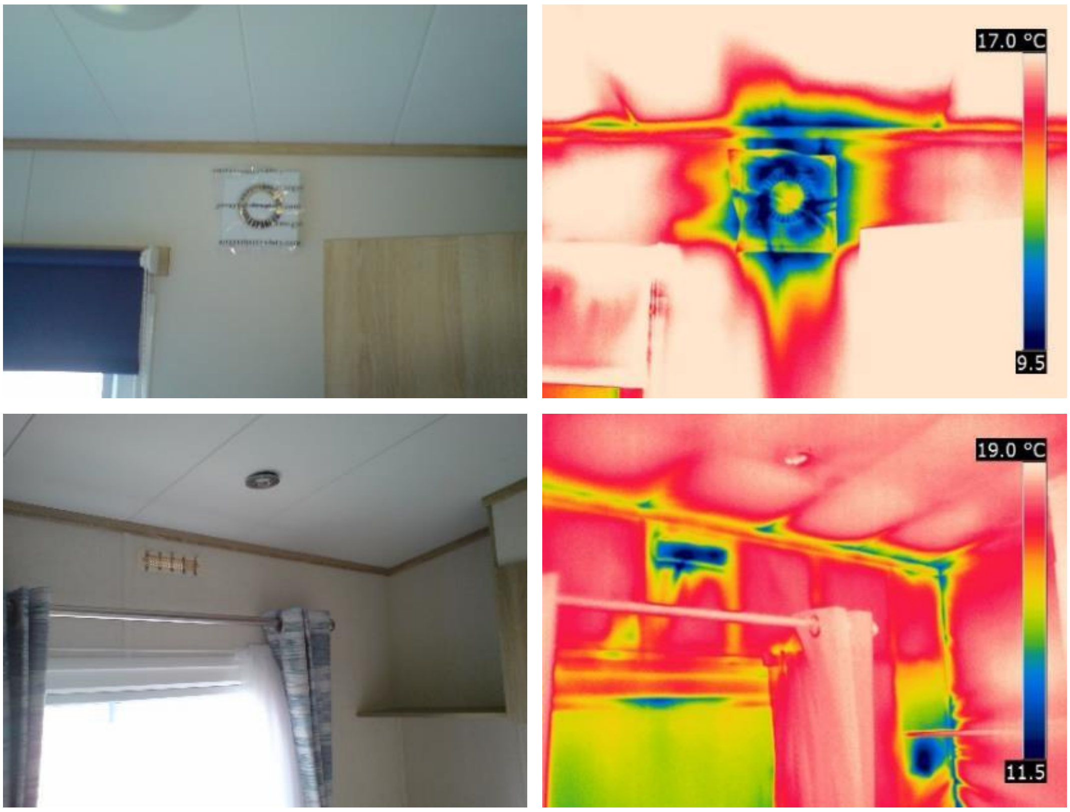


Figure 10 Air leakage around wall mounted extract fans (top) and grilles (bottom).

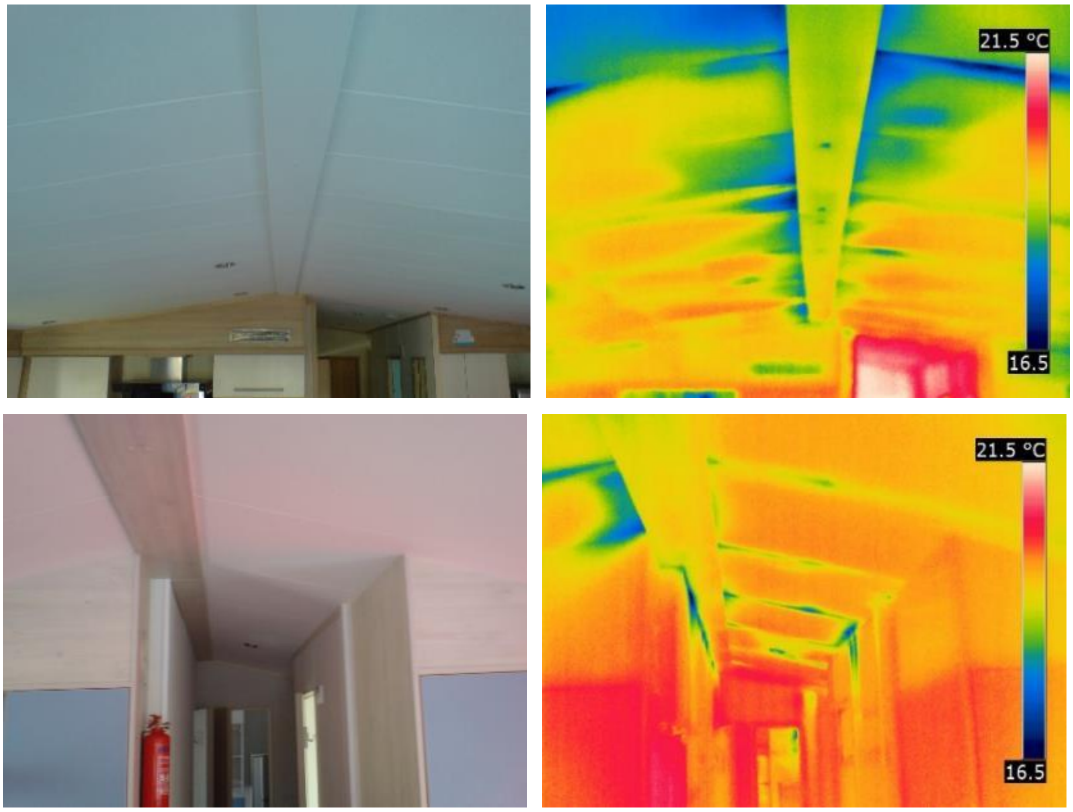


Figure 11 Air leakage at the ceiling ridge junction.

Figure 12 Air leakage around the consumer unit.

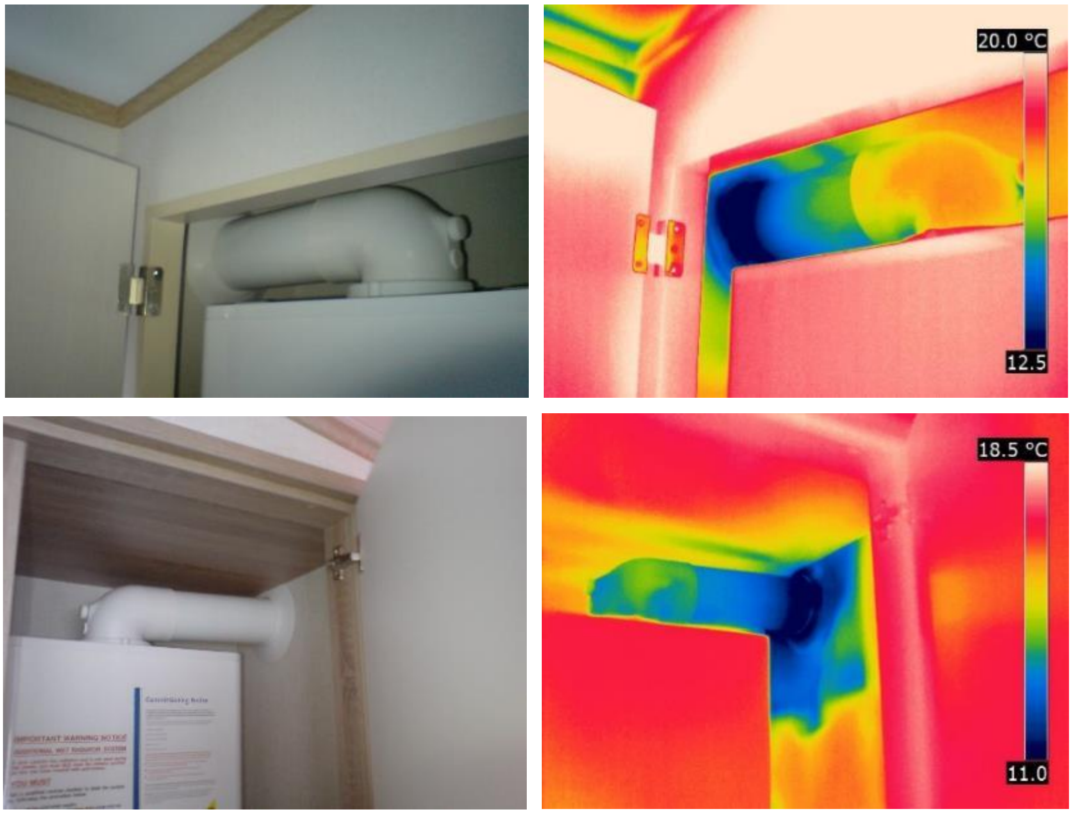


Figure 13 Air leakage around the boiler flue.

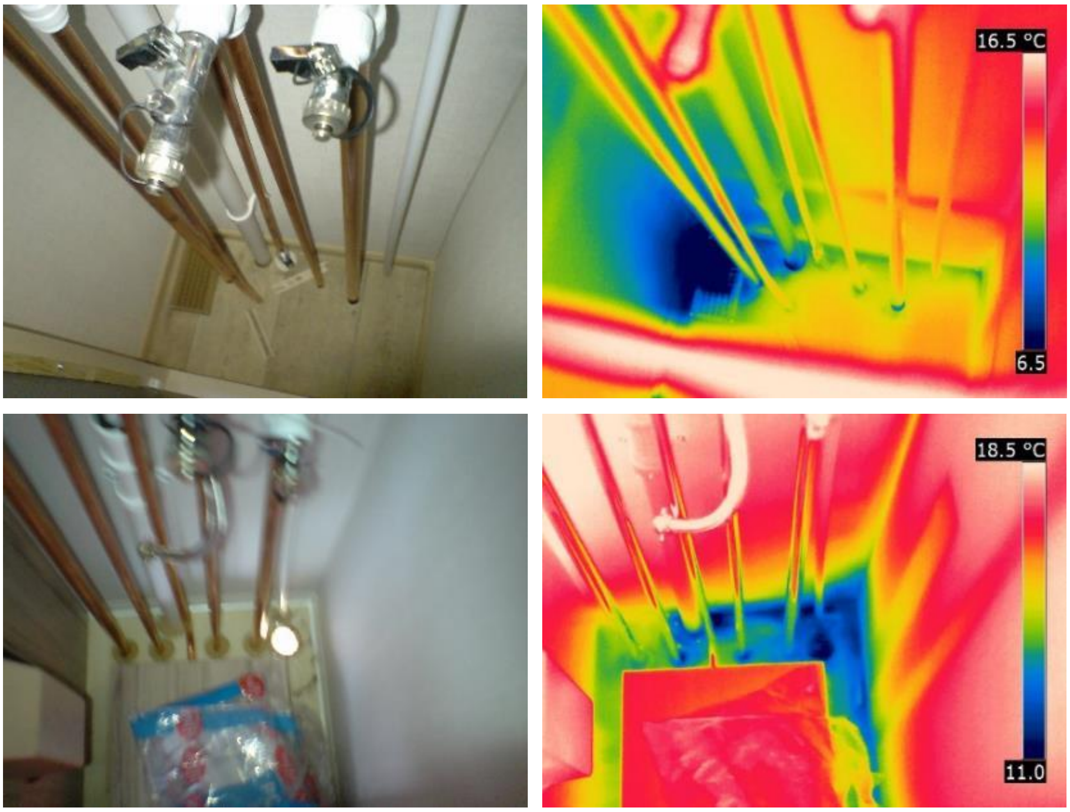


Figure 14 Air leakage around the water pipes, gas pipes and condensate drain at the boiler.

Figure 15 Air leakage around the central heating pipes where they penetrate through the ground floor.

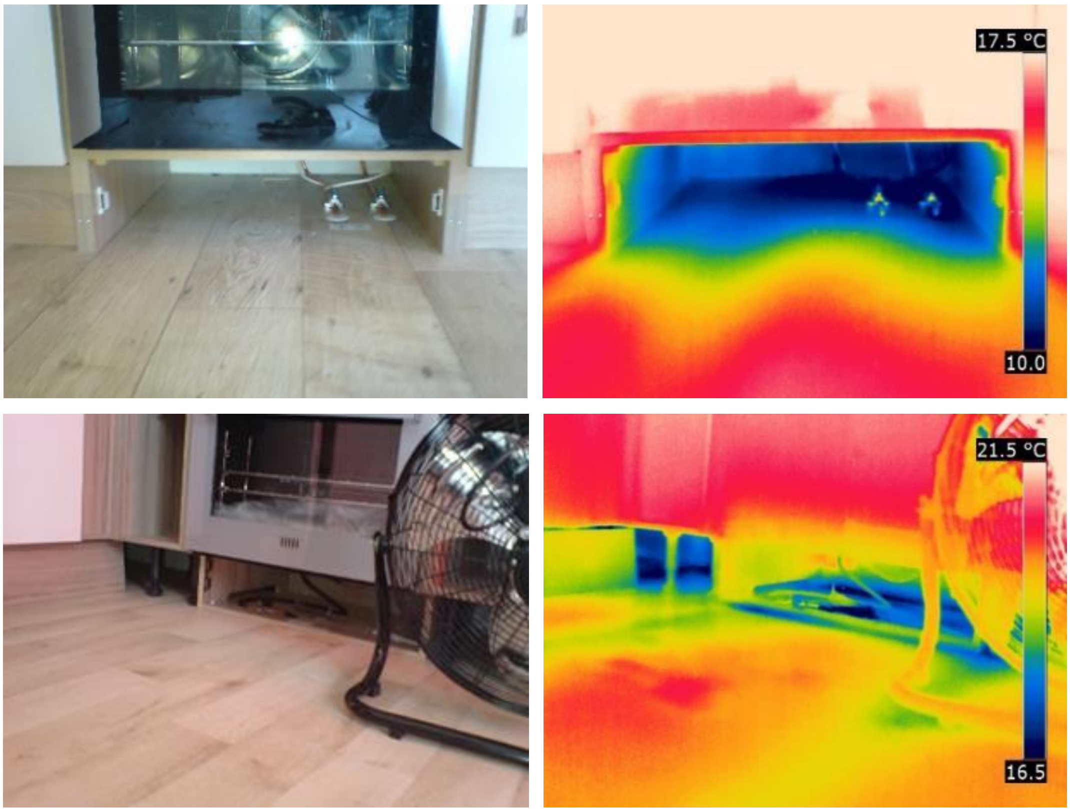


Figure 16 Air leakage around the gas pipes to the cooker.

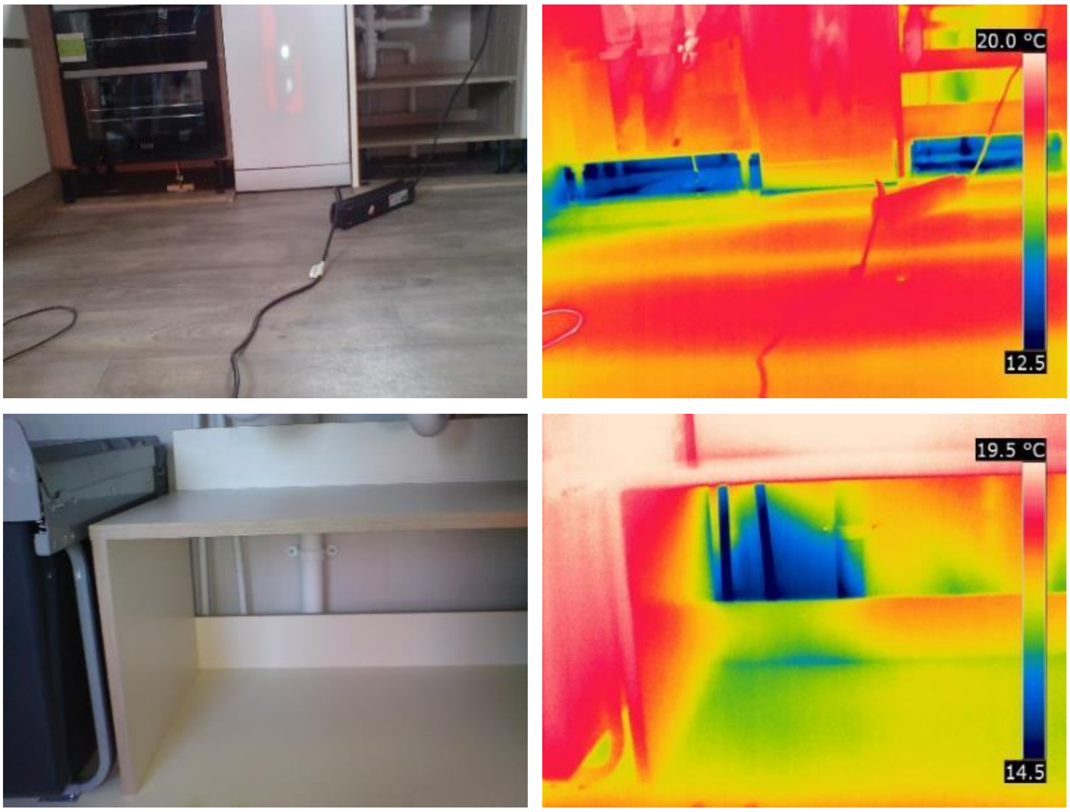


Figure 17 Air leakage around waste and water pipes under the kitchen units.

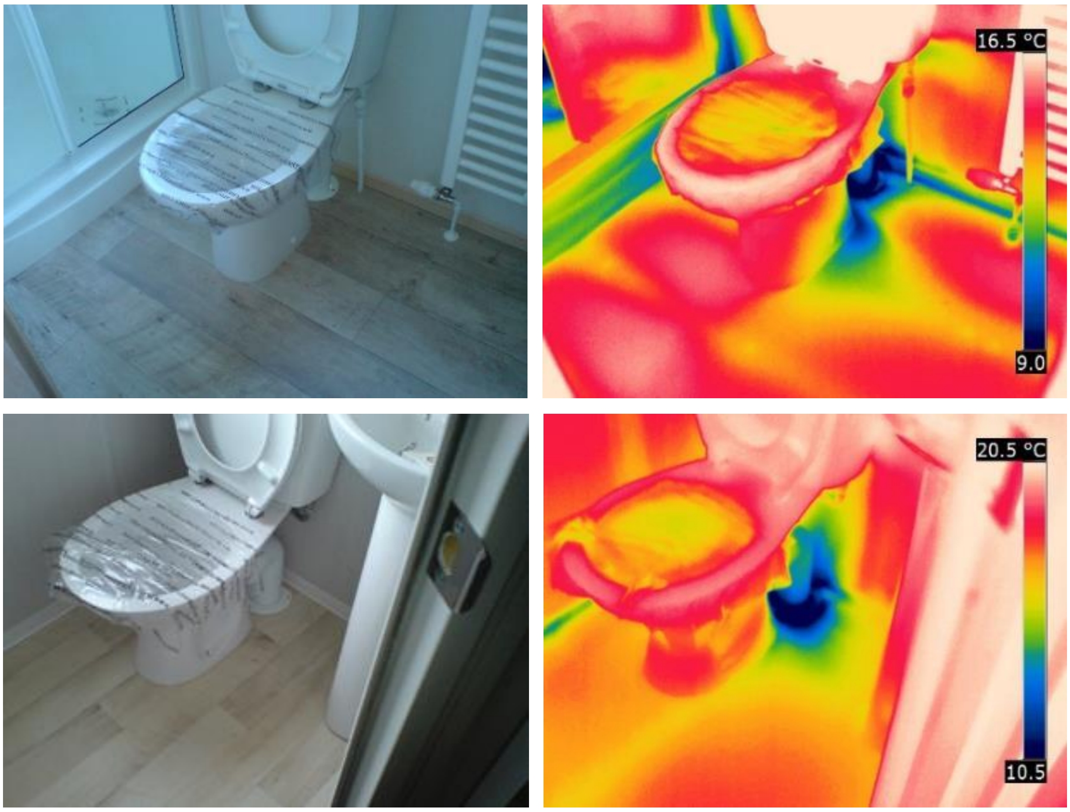


Figure 18 Around the toilet waste pipe.

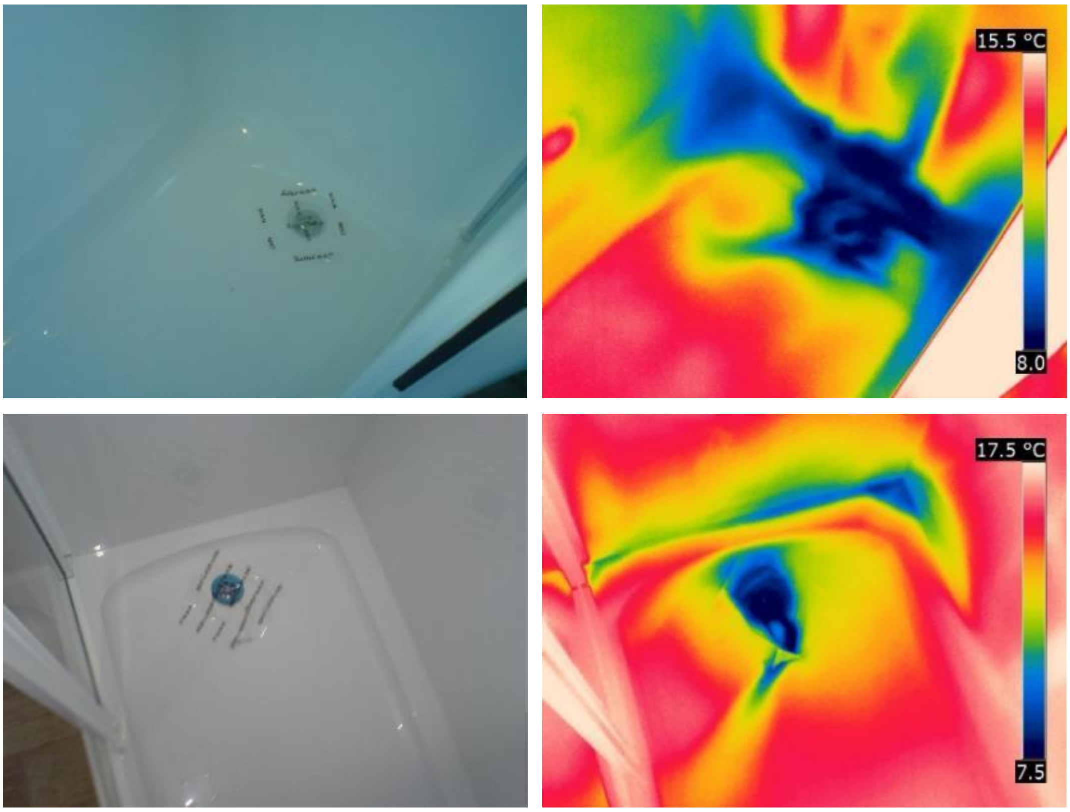


Figure 19 Air leakage from service penetrations beneath the shower tray.

Figure 20 Air leakage at the external wall/ceiling junction (top and bottom) and at external wall corners (top).

Figure 21 Air leakage at the external wall/ceiling junction in caravan D.

Figure 22 Air leakage around the window frames.

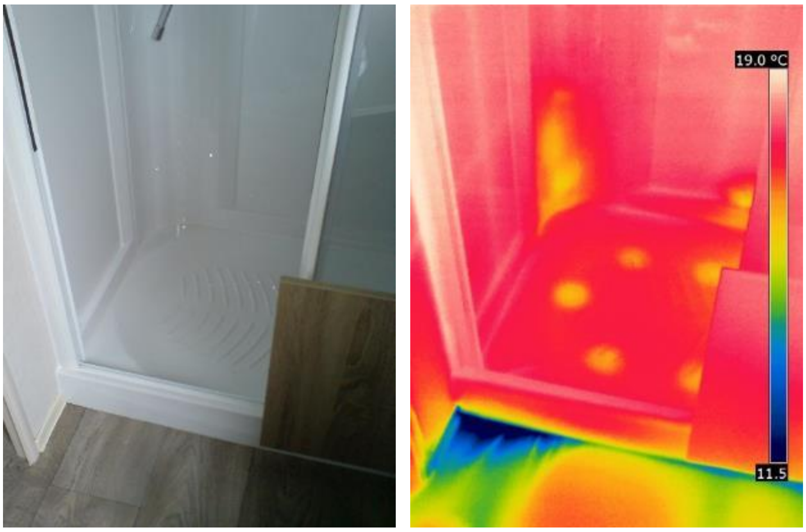


Figure 23 Air leakage at the shower tray/floor junction in caravan B.

Figure 24 A leakage at the external wall/floor junction in the master bedroom of caravan A (top) and caravan E (bottom).

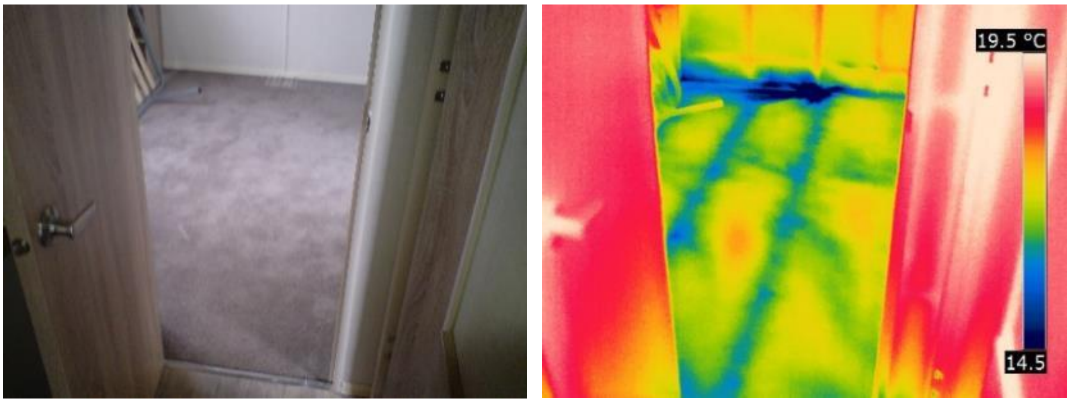


Figure 25 Air leakage resulting in the carpet lifting under depressurisation in the master bedroom of caravan B.

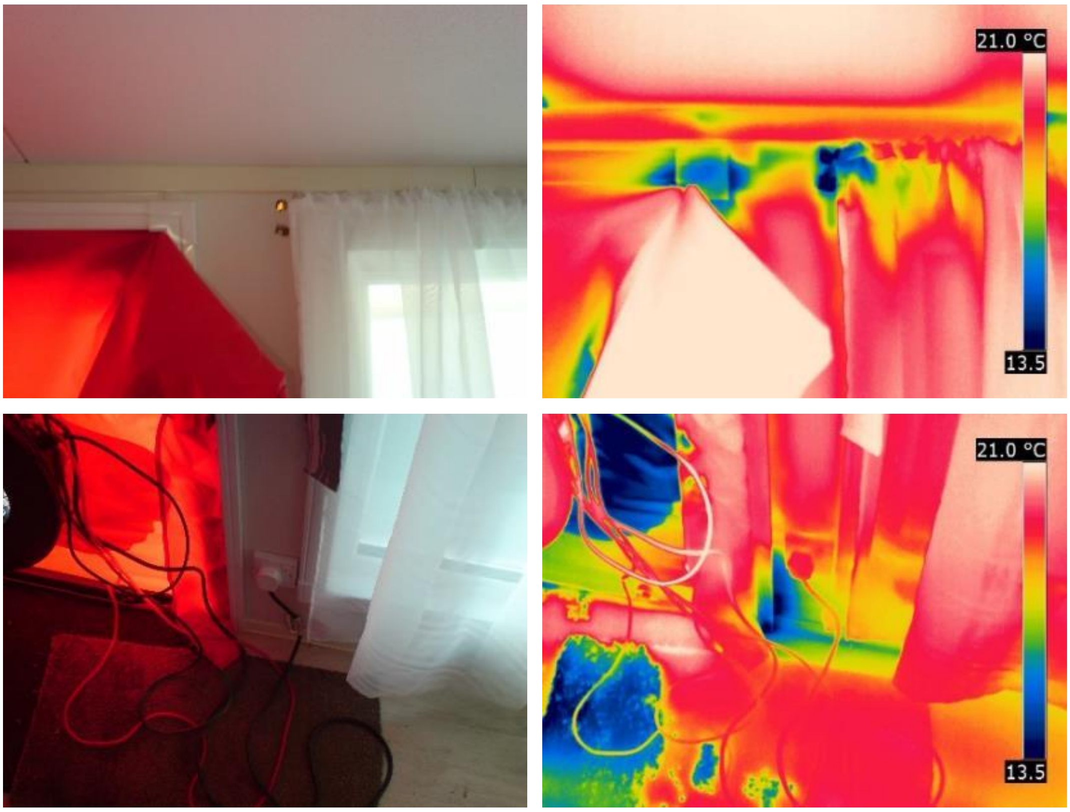


Figure 26 Air leakage around the front door of caravan C.

33 Further details regarding the leakage detection can be found within Appendix A.

5.2 Thermal imaging surveys

34 As the materials used to construct the test caravans are highly reflective and have a low emissivity (Versasteel roof tiles and PVUE external wall cladding), it was only possible to undertake a very limited number of external thermal images of the caravans[1]. Therefore, the majority of the thermal images undertaken during the surveys were undertaken from the inside of the caravan during the day.

35 The thermal imaging surveys revealed a number of significant areas of thermal bridging that tended to be common across the majority of the test caravans. These were as follows:

- At the ground floor joists where the joists penetrate through the insulation layer (see Figure 27). In caravan D, the steel chassis members are clearly visible in relation to the timber joists (see Figure 28). A number of the fixings are also visible in some of the test caravans (see Figure 29).
- At the vertical and horizontal studs used to construct the framing for the external wall where they penetrated through the insulation layer (see Figure 30). It is interesting to note that there are no horizontal farming members used in the construction of the external walls in caravan E (see Figure 31).
- At the roof joists and noggins where they penetrated the insulation layer (see Figure 32).
- Around the purpose provided extract grille located in the kitchen/living area, due to a lack of continuity in the insulation layer (see Figure 33).
- Around ceiling and external wall mounted vents, due to a lack of continuity in the insulation layer (see Figure 34).
- Around spotlights, due to a lack of continuity in the insulation layer (see Figure 35).
- Around wall and light switches, particularly where there were cable runs, due a lack of continuity in the insulation layer (see Figure 36).

[1] Due to the lower and variable emissivity of the materials constituting the external facades and the changing environmental conditions, the external thermal images can easily be misinterpreted.

- Around the external aerial mounting point on the external wall, due to a lack of continuity in the insulation layer (see Figure 37).

36 In addition, there were a much smaller number of thermal bridges identified that were specific to particular test caravans. These were as follows:

- At the external wall/floor junction in the master bedroom of caravan A (see Figure 38).
- Below the kitchen/living area window in caravan E (see Figure 39).
- Close to the ridge on the master bedroom end wall of caravan A (see Figure 40).
- At the sloping section of the kitchen/living area end wall in caravan A (see Figure 41).

Figure 27 Thermal bridging at the ground floor joists.

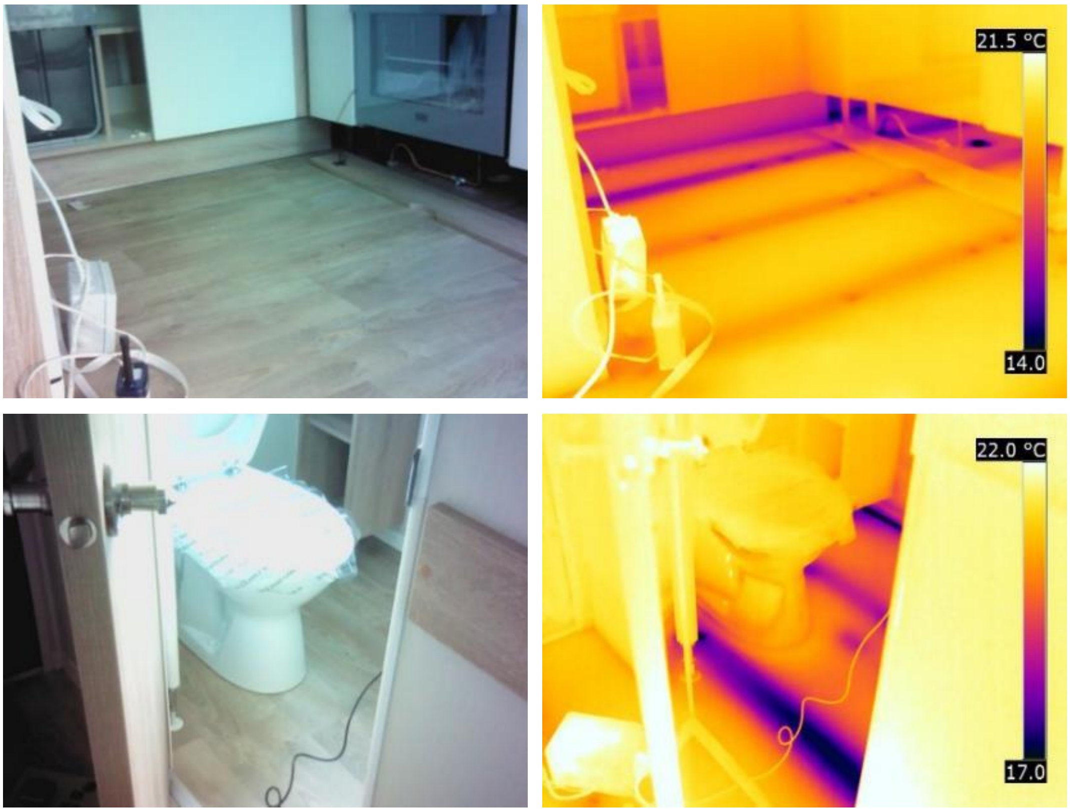


Figure 28 Steel chassis members clearly visible in the kitchen/living area (top) and bathroom (bottom) floor of caravan D.

Figure 29 Joist fixings clearly visible on the floor of a number of the test caravans.

Figure 30 Thermal bridging at the vertical and horizontal studs in the external walls.

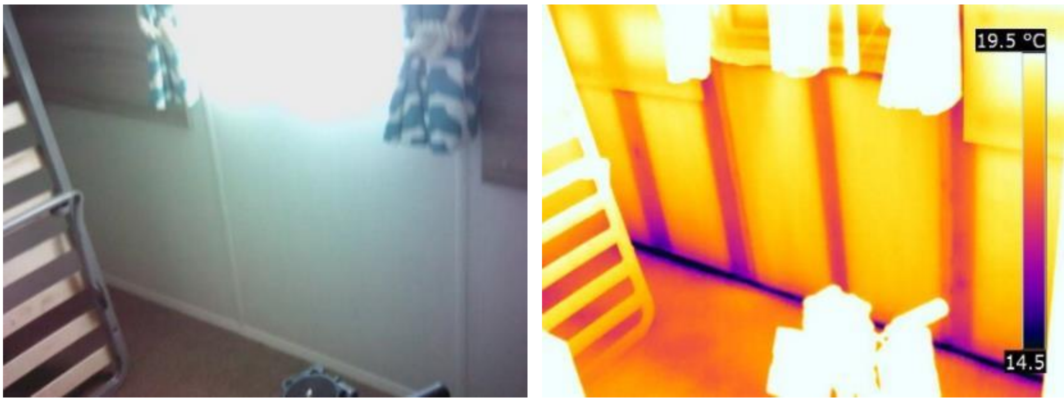


Figure 31 Lack of horizontal members in the external wall of caravan E.

Figure 32 Thermal bridging at the roof joists and noggins.

Figure 33 Thermal bridging around the ceiling mounted extract fan in the kitchen/living area.

Figure 34 Thermal bridging around ceiling and external wall mounted vents.

Figure 35 Thermal bridging around spotlights.

Figure 36 Thermal bridging around wall and light switches, particularly where there are cable runs.

Figure 37 Thermal bridging at the external aerial fixing point.

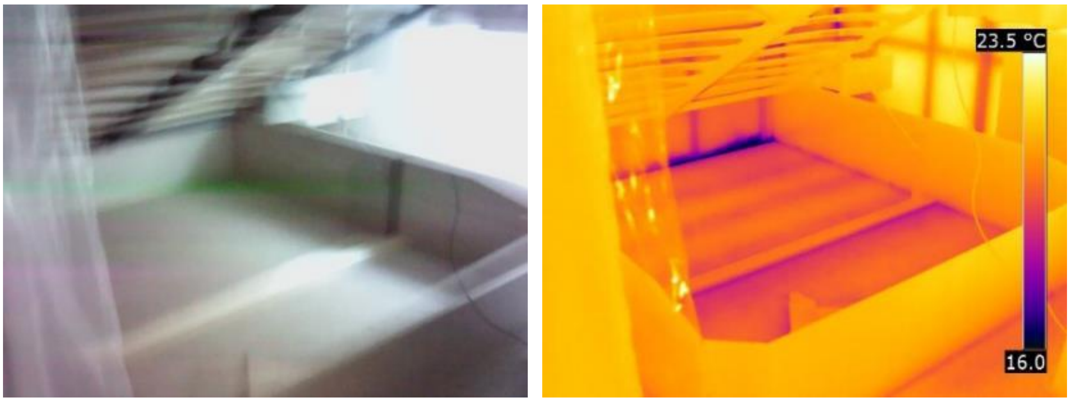


Figure 38 Thermal bridge at the external wall/floor junction in the master bedroom of caravan A.

Figure 39 Thermal bridging below the kitchen/living area window in caravan E.

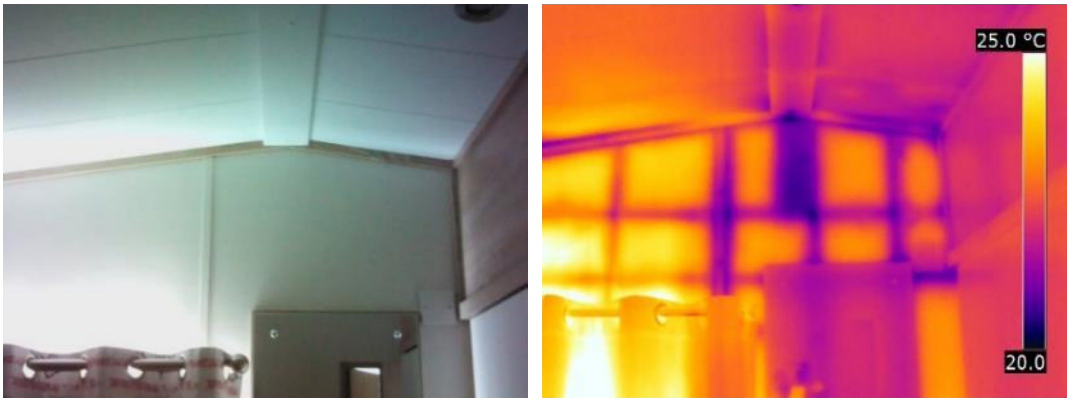


Figure 40 Thermal bridge close to the ridge on the end wall of caravan A.

Figure 41 Thermal bridge at the sloping section of the kitchen/living area end wall in caravan A.

37 Further details regarding the thermal imaging survey can be found within Appendix B.

5.3 CO_2 tracer gas decay measurements

38 The average air change rates obtained for each of the test periods in which CO_2 tracer gas decay measurements were undertaken are summarised within Table 9. The results illustrate that a wide range of background ventilation rates were experienced for the test caravans over the various coheating tests, ranging from as low as 0.24 ach^{-1} for caravan C during coheating Test 2 to as high as 1.60 ach^{-1} for caravan D during coheating Test 1. It is also clear that the background ventilation rate measured for each caravan varied significantly between the different tests, with the highest rates measured during coheating Test 1 and, in the majority of cases, the lowest rates measured during coheating Test 2. This is as to be expected. It is also clear from Table 9 that the amount of ventilation provided by the purpose provided ventilation openings and gas drop-out points is relatively consistent between the different test caravans at around 0.8 ac/h. This figure has been obtained by subtracting the measured background ventilation rate obtained during Test 1 from that obtained during Test 2. The figure of 0.8 ac/h is considerably greater than the purpose provided ventilation figures contained within the NCC Energy Efficiency Calculator for test caravans B, C, D and E.As the external wind conditions varied significantly over the entire testing period, the nightly mean background ventilation rate obtained from the decay measurements has also been compared against the average wind speed recorded over the same time period (see Figure 43, Figure 44 and Figure 45). This analysis indicates that for all of the test caravans, changes in the background ventilation rate appear to be generally consistent with changes in daily average wind speed, with the highest ventilation rates corresponding with the highest wind speeds.

	Measured background ventilation rate (ach^{-1})		
Caravan	**Test 1**	**Test 2**	**Test 3**
B	1.24	0.40	0.44
C	0.96	0.24	0.32
D	1.60	0.79	0.63
E	1.45	0.61	0.61

Table 9 Summary of the CO_2 tracer gas decay measurements.

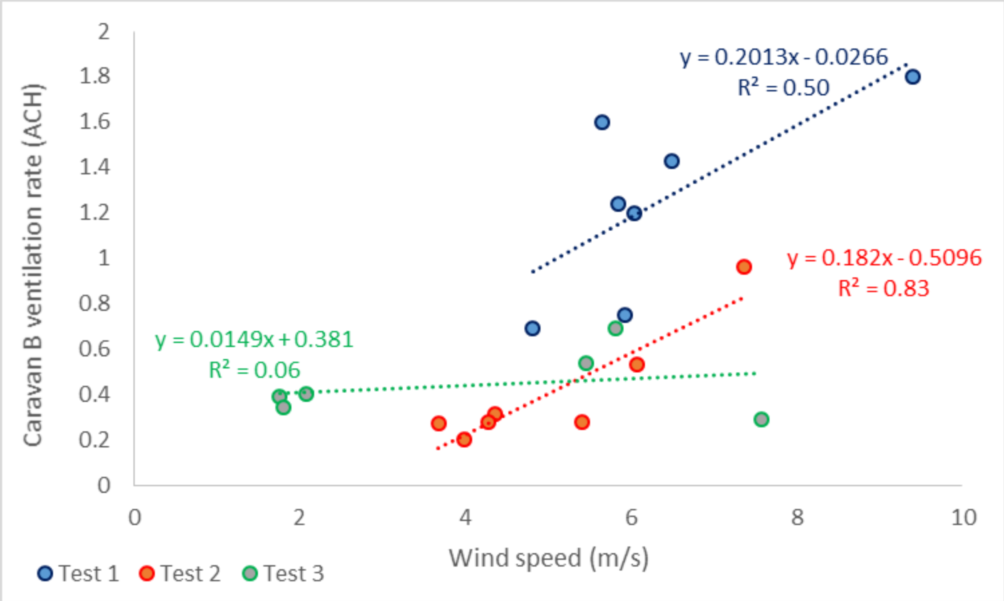


Figure 42 Relationship between background ventilation rate and the average wind speed during the CO_2 tracer gas decay period for caravan B.

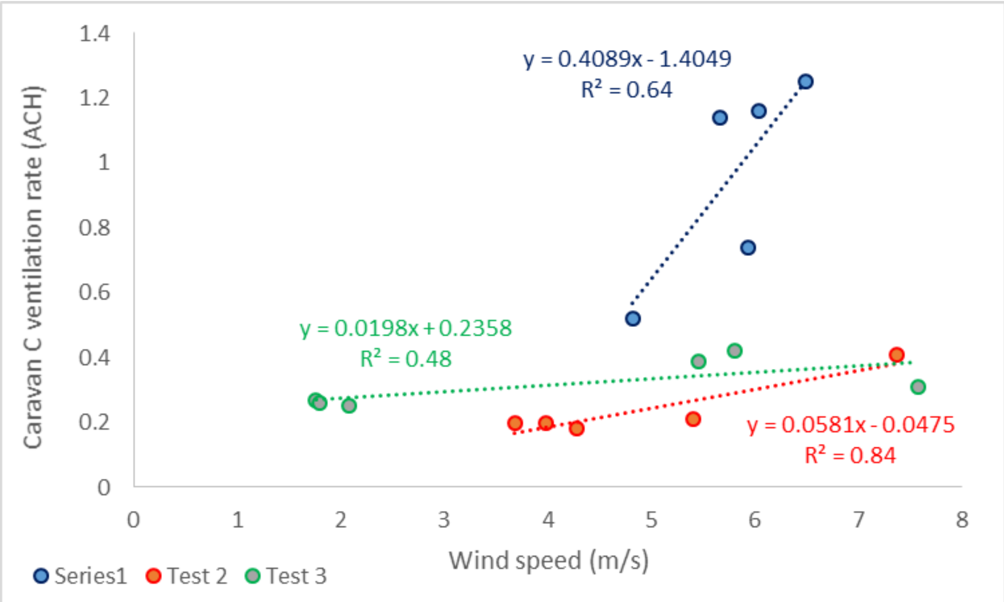


Figure 43 Relationship between background ventilation rate and the average wind speed during the CO_2 tracer gas decay period for caravan C.

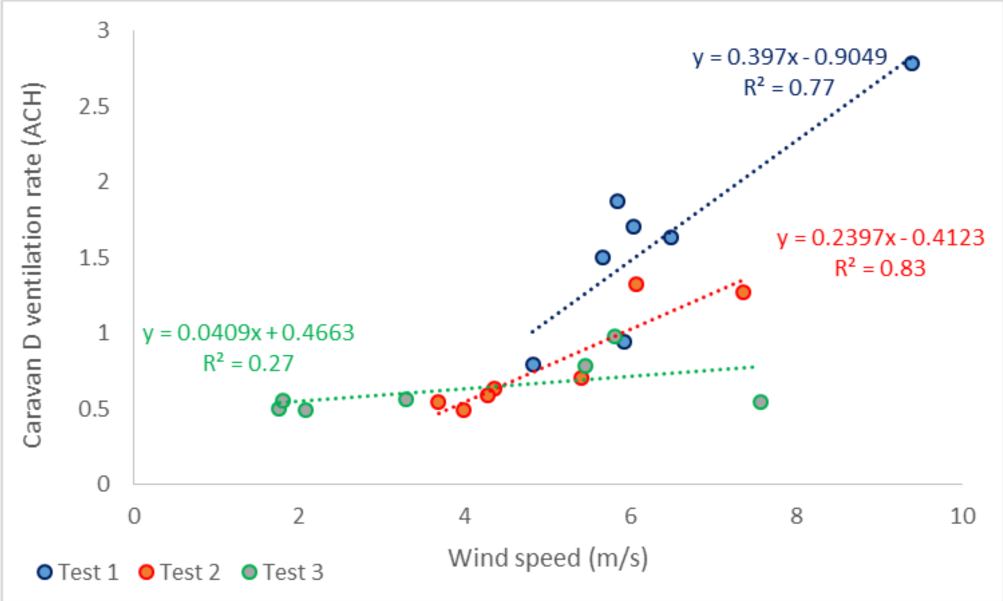


Figure 44 Relationship between background ventilation rate and the average wind speed during the CO_2 tracer gas decay period for caravan D.

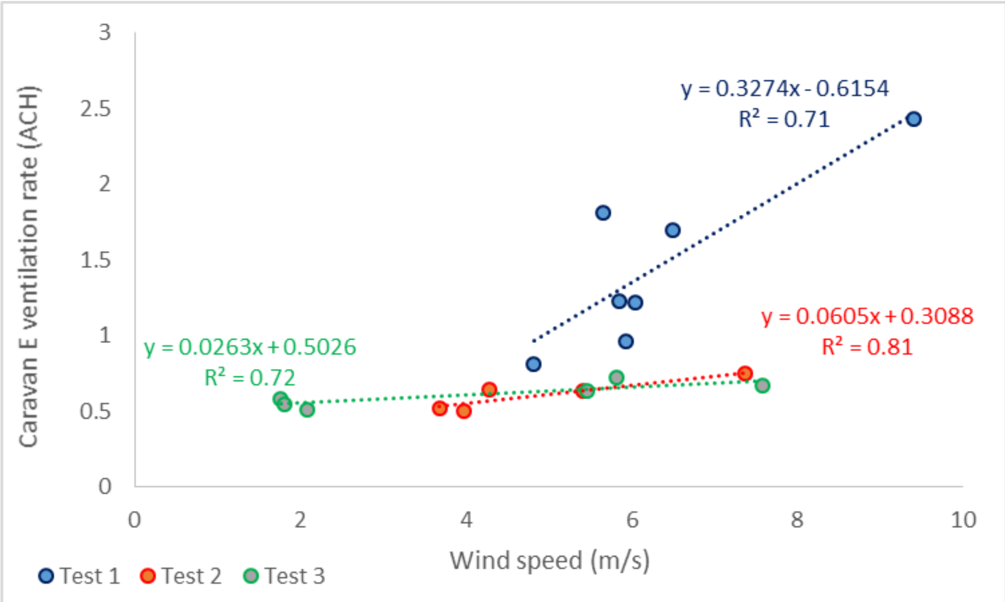


Figure 45 Relationship between background ventilation rate and the average wind speed during the CO_2 tracer gas decay period for caravan E.

39 The CO_2 tracer gas decay measurements contained within Table 9 have also been compared against the approximated average annual background ventilation rate of each test caravan which has been calculated using the n_{50}/20 *'rule of thumb'* (see Table 10). This comparison reveals that for coheating Tests 2 and 3, the ventilation rates approximated using the n_{50}/20 *'rule of thumb'* are greater than those measured from the CO_2 tracer gas decay. This suggests that the devisor of 20 may be too small. However, during coheating Test 1, when all of the purpose provided ventilation openings and the gas drop-out points were unsealed, the opposite is true, indicating that the devisor of 20 may be too large. However, closer analysis of the data reveals that the average wind speed recorded during coheating Test 1 was much greater than that recorded during coheating Test 2 and 3 (6.31 ms^{-1} as opposed to 5.02 and 3.97 ms^{-1}, respectively). This may account for the higher background ventilation rates and consequently lower devisor measured during this period.

	Approximated average annual background ventilation rate (n_{50}/20)		
Caravan	**Test 1**	**Test 2**	**Test 3**
B	1.14	0.52	0.57
C	0.88	0.42	0.45
D	1.03	0.71	0.76
E	1.00	0.64	0.68

Table 10 Summary of the background ventilation rate approximated using measured n_{50}/20 *'rule of thumb'*.

40 The tracer gas figures have also been used in conjunction with the measured air leakage rate to obtain a *'rule of thumb'* devisor for each caravan during each test period. The results are illustrated in Table 11. If the results for coheating Test 1 are discounted due to the high recorded wind speeds measured during the decays, then the average devisor obtained during coheating Test 2 and 3 is around 25. This is 25% greater than the devisor that is currently contained within the latest version of the NCC calculator relating to Q_{50}, which suggests that the devisor incorporated within this calculator is too low. It is also much lower than the devisor of 40 which was proposed by Miles-Shenton, Farmer and Johnston (2015) on some recently tested holiday homes. Further pressurisation testing work and CO_2 tracer gas decay measurements should be undertaken to determine the range of devisors that are likely to be applicable to various geometries of static caravans.

	***'Rule of thumb'* devisor**		
Caravan	**Test 1**	**Test 2**	**Test 3**
B	18.4	25.8	25.7
C	18.3	34.9	28.7
D	12.8	17.9	24.3
E	13.8	21.2	22.3
Average	15.8	24.9	25.2

Table 11 *'Rule of thumb'* devisor based upon tracer gas decay measurements.

5.4 Heat flux density measurements

41 A summary of the of the average *in situ* U-value measurements obtained during the test period is also provided within Table 12. The U-values presented are the average of the U-values measured during each night of each test period. The error associated with the *in situ* U-values presented in this report is estimated to be ±10%. This value was calculated as the quadrature sum of the uncertainties associated with the monitoring equipment and other sources of uncertainty listed in BSI ISO 9869-1:2014.

Location	Calculated nightly average U-value (W/m^{2}K)				
	A	B	C	D	E
External wall between studs	0.61	0.72	0.53	0.49	0.63
External wall at stud	0.92	1.23	0.90	0.52	1.74
External wall anomaly	1.69	1.70	1.71	1.90	1.55
Ground floor between joists	0.49	0.96	0.85	0.51	0.89
Ground floor at joist	1.30	1.52	1.33	1.71	1.42
Ceiling between roof joists	0.30	0.35	0.35	0.28	0.40
Ceiling at roof joist	0.54	0.49	0.76	0.61	0.49
Ceiling anomaly	2.14	1.70	1.40	0.39	0.95
Centre of north-facing glazing	1.60	3.03	1.45	2.52	1.32

Table 12 Summary of the average calculated *in situ* U-value measurements of the entire test period.

42 It is clear from the *in situ* U-values presented within Table 12 that a range of performance exists both within and across the test caravans. In order to illustrate this range of performance, the calculated *in situ* average U-values have been compared against the design intent steady-state U-values incorporated within the NCC Energy Efficiency Calculator for each of the main elements of the test caravans. The results of this comparison are illustrated in Figure 46 to Figure 49. It should be noted that considerable care should be undertaken when making such a comparison, as the design intent steady-state U-values incorporated within the NCC Energy Efficiency Calculator are intended to take into consideration repeating thermal bridges, such as the timber studwork used in the external wall construction. However, they do not take into account non-repeating thermal bridges and there is no methodology for incorporating non-repeating thermal bridges into the fabric heat loss calculated using the NCC Energy Efficiency Calculator, unlike there is in SAP. Consequently, all other things being equal, there is likely to be a discrepancy between what is measured *in situ* and the design intent steady-state U-values obtained from the NCC Energy Efficiency Calculator.

43 As the design intent steady-state U-values obtained from the NCC Energy Efficiency Calculator incorporate repeating thermal bridges, it would be expected that all of the *in situ* measurements undertaken between the studs and joists, where no thermal bridging is present, would be lower than the corresponding NCC design intent values. However, the analysis reveals that this is not the case. In a number of the test caravans, the average calculated *in situ* U-values are comparable to or much greater than the design intent steady-state U-values. This either suggests that the caravans have either not been constructed as the design intent, resulting in a performance gap, or there is an error in the input data used to calculate the design intent steady-state U-value. For instance, in test caravan B, the average *in situ* floor U-value measured between the floor joists is more than twice the design intent steady-state U-value (see Figure 47). Observations revealed that the reason for this discrepancy could be attributed to the fact that the insulation material used for the floor was not installed in accordance with the manufacturer’s instructions.

44 A check through the NCC Energy Efficiency Calculator also revealed that in a number of cases construction elements had been omitted from the calculator. For instance, the air gap between the external wall plastic cladding and the membrane/insulation material, the membrane between the external wall insulation and the external plastic cladding, or in one of the test caravans, the roof covering material. However, these omissions will only have a negligible impact on the calculated U-value, so any discrepancy observed between the measured *in situ* U-value and the design intent steady-state U-value cannot be solely attributed to errors in the input data used within the NCC Energy Efficiency Calculator.

45 In terms of the measurements undertaken at the studs and joists, the analysis reveals that in the majority of cases the measured *in situ* U-values are considerably higher than the design intent steady-state U-values. This is to be expected, as the timber studs and joists represent a thermal bridge through the fabric of the test caravans. However, in the external wall of test caravan D, the measured *in situ* U-values at the stud were lower than the design intent steady-state U-values and only marginally higher than the value obtained between the studs. This suggests that this HFP was not accurately positioned directly across the stud within this caravan. An analysis of the thermal image undertaken once the HFPs were installed within test caravan D reveals that this HFP was positioned slightly off-centre to the stud (see Figure 50).

46 It is also clear from Figure 46 and Figure 48 that the *in situ* U-values measured at the external wall and roof anomalies are significantly higher than the design intent steady-state U-values. This can be attributed to the excessive thermal bridging that was observed at these locations. In the case of the external wall anomaly, the thermal bridging was caused by the insertion of additional timber at this location to enable the mounting of an external aerial. With respect to the ceiling anomaly, removal of the ceiling extract grille revealed either a lack of, or the omission of insulation surrounding the extract grille (see Figure 51).

47 If the *in situ* U-values measured at the anomalies are combined with the *in situ* measured U-values obtained for the studs and joists, then it is highly likely that the average *in situ* U-values for the external walls, ground floor and roof will be greater than the corresponding design intent steady-state U-values, representing a performance gap. Unfortunately, quantifying the scale of this gap is problematic, as it not only requires information on the amount of timber used in the external walls, ground floor and roof (timber fraction), but it also requires all of the non-repeating thermal bridges that exist within the test caravans to be identified and calculated. It also assumes that the heat flux density measurements that have been undertaken as part of this project are representative of the construction element that was measured as a whole. This is unlikely to be the case as a number of the elements of the construction have furniture and fittings attached to them, some of which contain unventilated air voids. These voids and the associated furniture and fittings will provide additional thermal resistance, resulting in lower *in situ* U-values and reduced heat transfer at these locations.

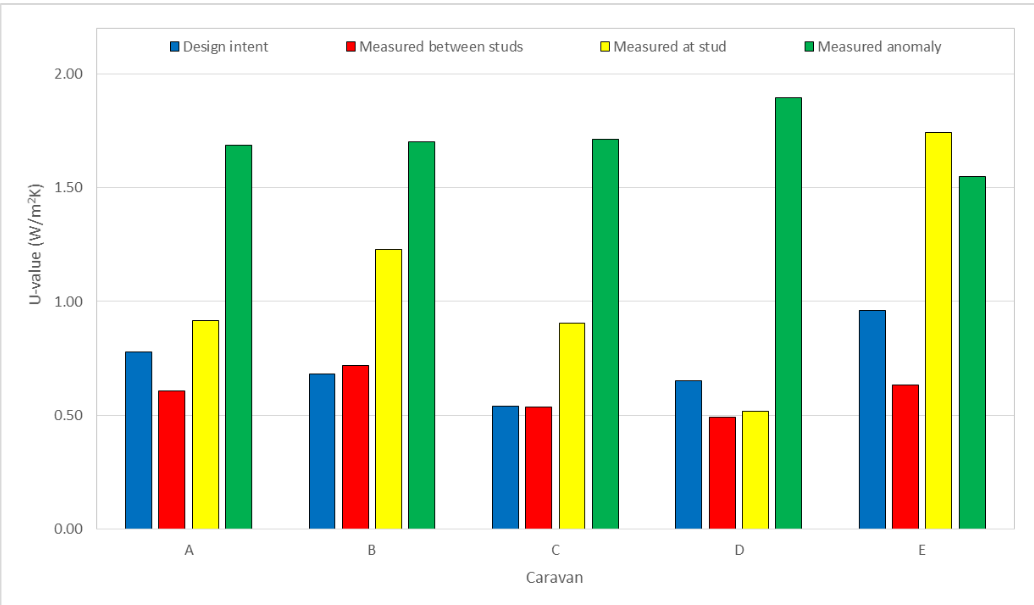


Figure 46 Average *in situ* external wall U-value for each test caravan.

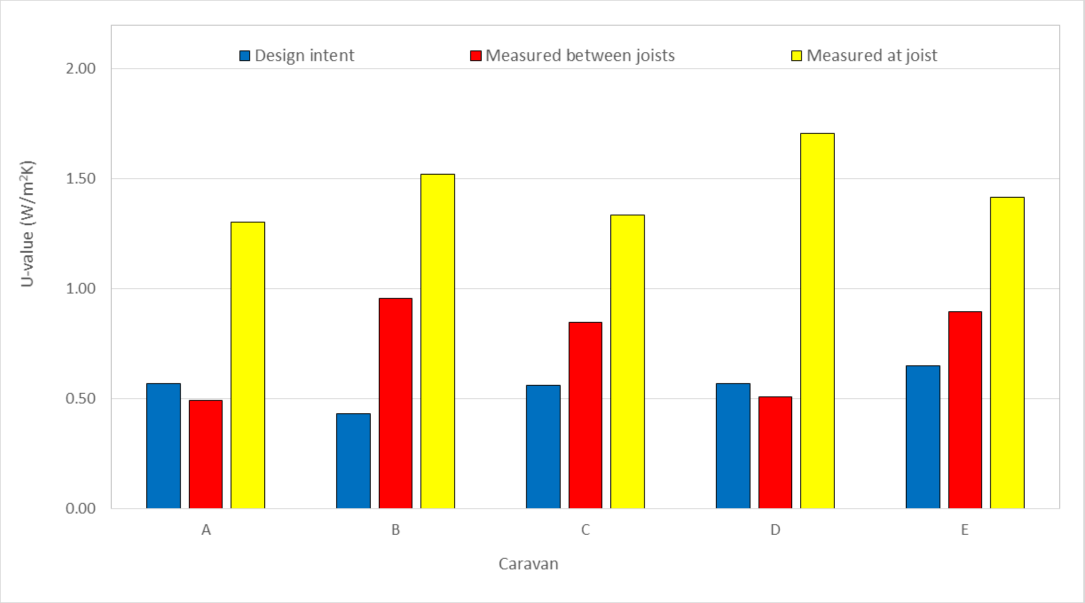


Figure 47 Average *in situ* floor U-value for each test caravan.

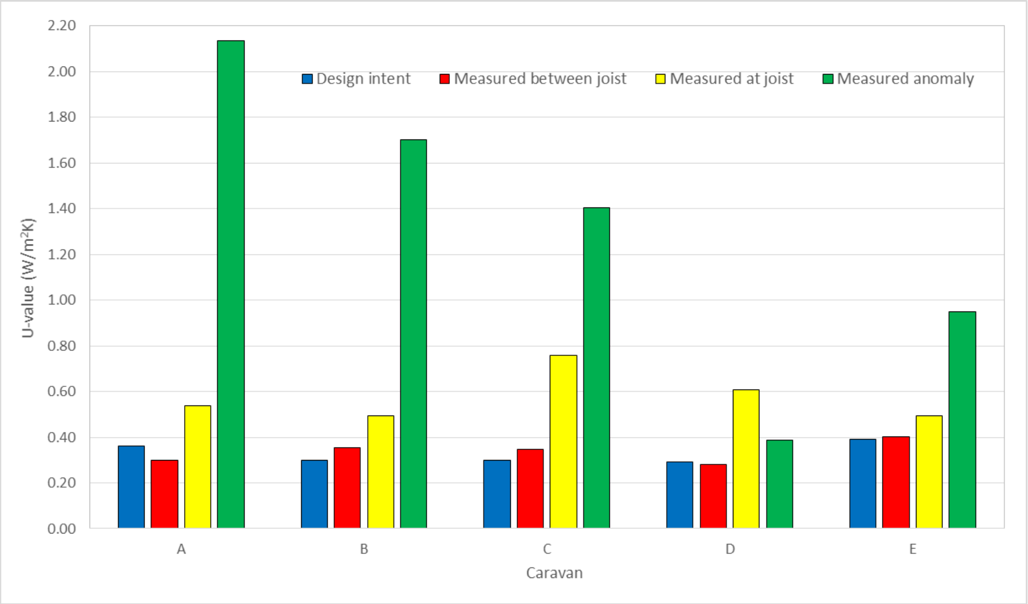


Figure 48 Average *in situ* roof U-value for each test caravan.

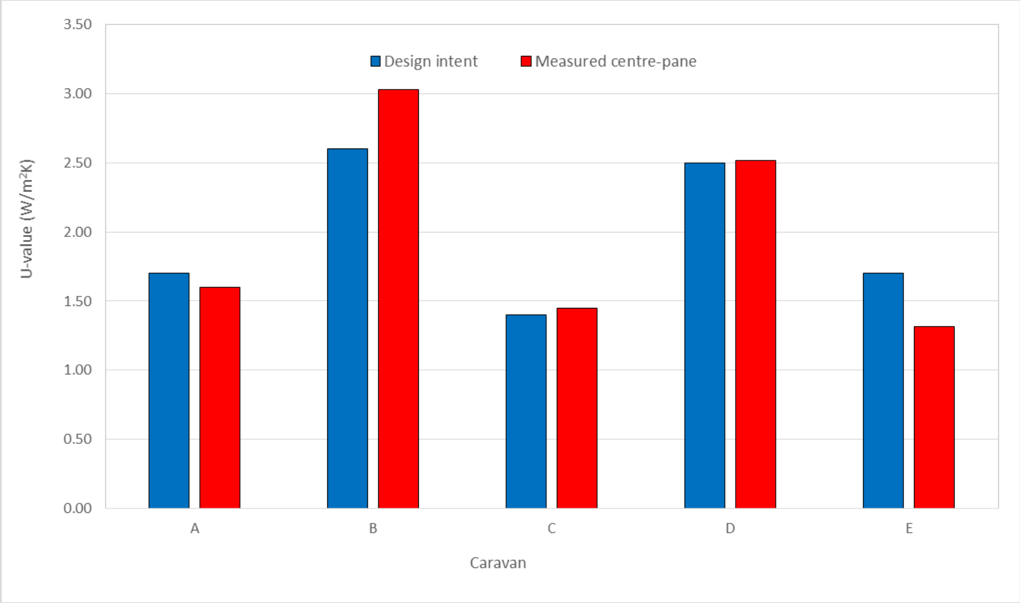


Figure 49 Average *in situ* window U-value for each test caravan.

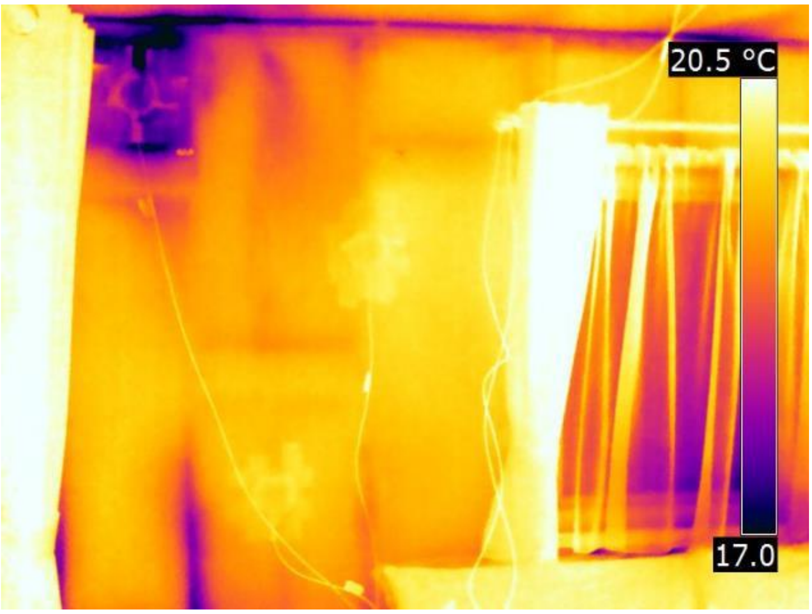


Figure 50 Location of HFP 2 in test caravan D.

Figure 51 Lack of insulation around ceiling extract vent in kitchen area of caravan B.

5.5 Whole caravan heat loss (electric coheating) tests

5.5.1 Electric coheating tests for test periods 1 to 3

48 Figure 52, Figure 53 and Figure 54 provides the electric coheating analysis of test caravans A to E during test periods 1 to 3. The electric coheating test produced an estimate of the wind corrected HLC for each of the test caravans under each test condition (slope of the regression line). The low thermal mass of the caravans is evident by the strong relationship between mean hourly power demand and ΔT (high r^2 values). This relationship provides confidence that reasonable estimate of the HLC can be obtained over a short time period.

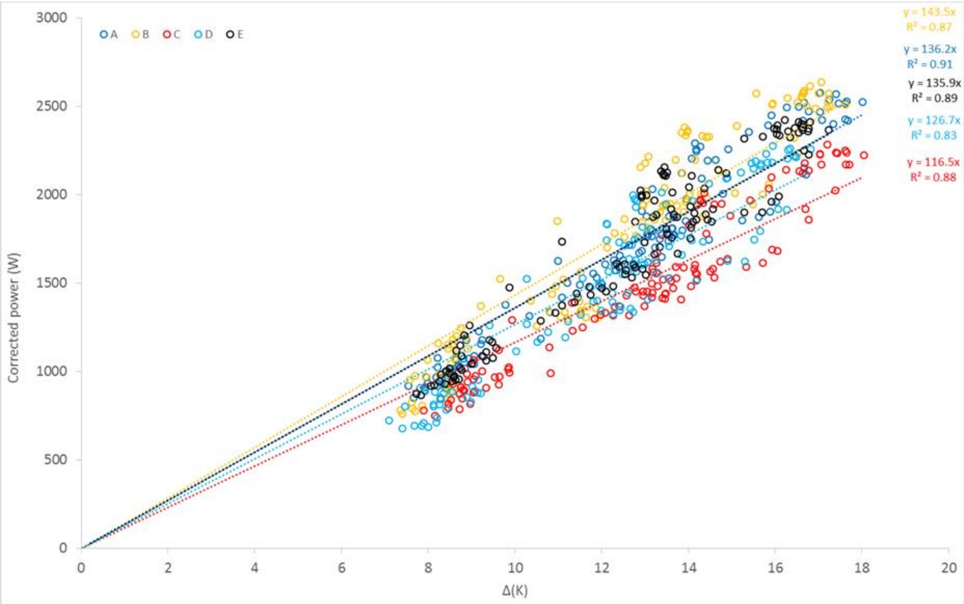


Figure 52 Electric coheating test analysis for all of the test caravans during test period 1.

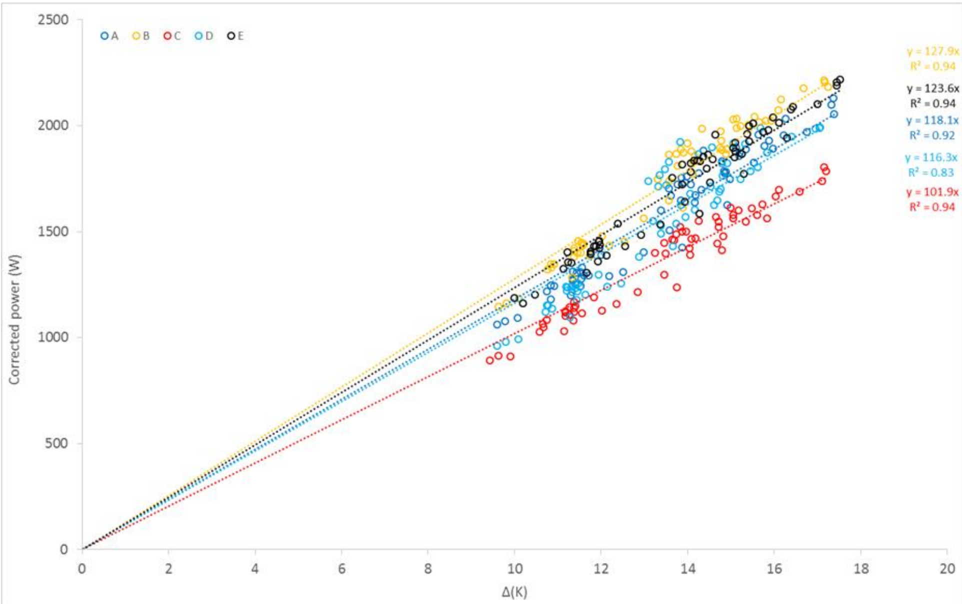


Figure 53 Electric coheating test analysis for all of the test caravans during test period 2.

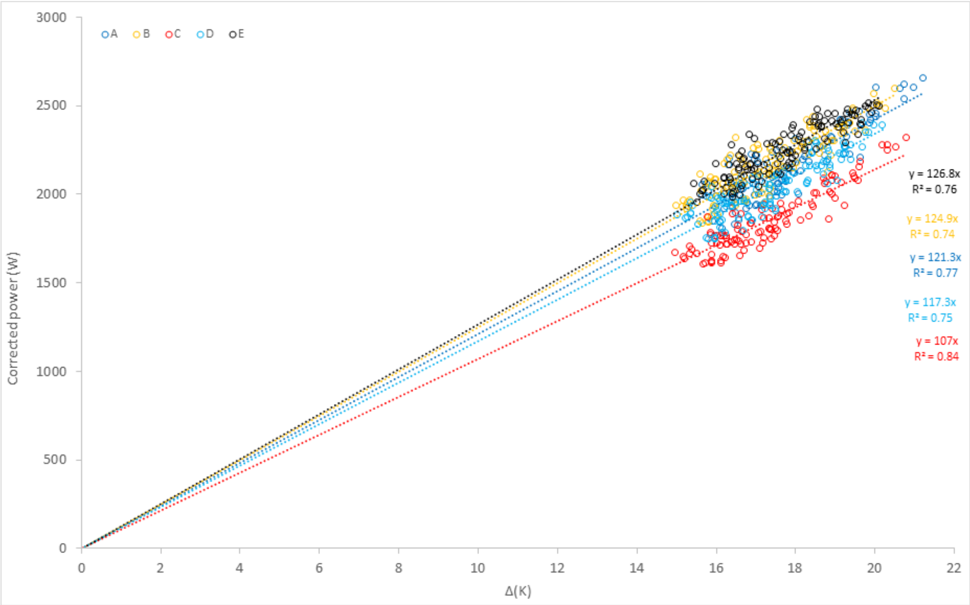


Figure 54 Electric coheating test analysis for all of the test caravans during test period 3.

5.5.2 Summary of the electric coheating tests

49 The results obtained for all of electric coheating test results are illustrated in Figure 55 and summarised in Table 13. It is clear from Figure 55 that a range of performance exists between all of the tested caravans. Caravan C consistently achieves the lowest HLC's for all of the electric coheating tests whilst caravan B consistently achieves the highest HLC's for each of the electric coheating tests. This is despite the fact that caravan A is larger than caravan B. The results also illustrate that the measured HLC only changes very slightly between Test 2 where all of the purpose provided ventilation openings and gas drop-out points were sealed, and Test 3 where all of the purpose provided ventilation openings were sealed and the gas drop-out points were unsealed. This is as to be expected as there were only two small gas drop out points located within all of the test caravans; one beneath the oven in the kitchen and the other beneath the gas-fired boiler. In two of the tests caravans (caravan B and C), the results appear to be counterintuitive, with the HLC reducing rather than increasing as the gas drop-out points are unsealed. However, the magnitude of the difference in HLC between these two tests is so small that the measured reduction in HLC is most likely to be attributable to the sensitivity and precision of the two different tests, rather than representing an actual physical reduction in the HLC.

50 Table 13 and Figure 55 also indicate the scale of the increase in HLC that occurs when all of the purpose provided ventilation openings and gas drop-out points are unsealed (the difference between Test 2 and Test 1). The scale of the increase in HLC varies between each of the caravans, with the smallest increase occurring in caravan C (just over 8 W/K) and the greatest increase in HLC occurring in caravan A (just over 18 W/K). On average, the increase in HLC between Test 2 and Test 1 was around 13 W/K.

Caravan	Test 1 (W/K)	Test 2 (W/K)	Test 3 (W/K)
A	136.2 (±2.8)	118.1 (±2.4)	121.3 (±1.1)
B	143.4 (±3.7)	127.9 (±2.1)	124.9 (±1.0)
C	116.5 (±2.8)	108.1 (±1.7)	107.0 (±0.8)
D	126.7 (±3.7)	115.4 (±3.6)	117.3 (±0.8)
E	135.9 (±2.9)	123.5 (±2.0)	126.8 (±0.8)

Table 13 Summary of the electric coheating tests.

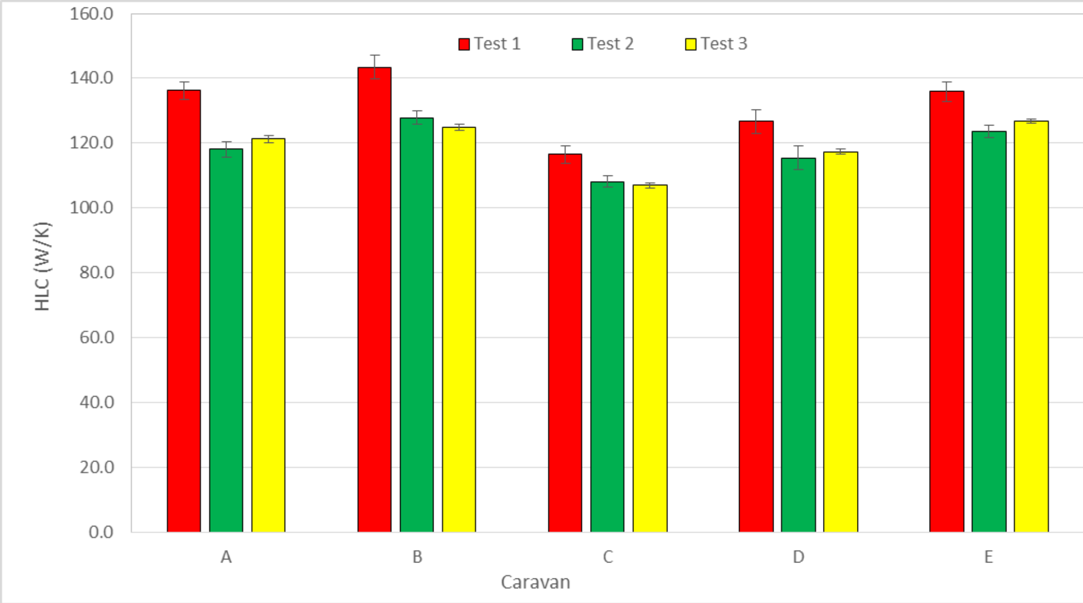


Figure 55 Results of the electric coheating tests.

51 The results of the 2nd set of electric coheating tests (Test 2), where all of the purpose provided ventilation and gas drop-out points were sealed, have been compared against the design intent HLC (see Figure 56) and the predicted HLC for each test caravan (see Figure 57). The design intent HLC has been obtained directly from the NCC calculator with the background ventilation rate based upon the air permeability figure that has been inserted into the NCC calculator. The predicted HLC is based upon the design intent fabric heat losses contained within the NCC calculator and the measured air permeability for each caravan which was obtained when all of the purpose provided ventilation openings and the gas drop-out points were sealed. The background ventilation rate has been approximated using the $Q_{50}/20$ *'rule of thumb'*.

52 As can be seen from Figure 56, in the majority of cases, the measured HLC obtained from Test 2 is greater than the design intent HLC, indicating a building fabric performance gap. The only instance where this is not the case is in caravan A, where the measured HLC is comparable to the design intent HLC. However, such a comparison can be misleading, as the design intent HLC figure incorporates background ventilation heat losses which have been calculated based upon the air permeability figures incorporated with the NCC calculator. In all of the tested caravans, a difference was observed between the air permeability figures measured and those inserted into the NCC calculator and, in some cases, this difference was considerable.

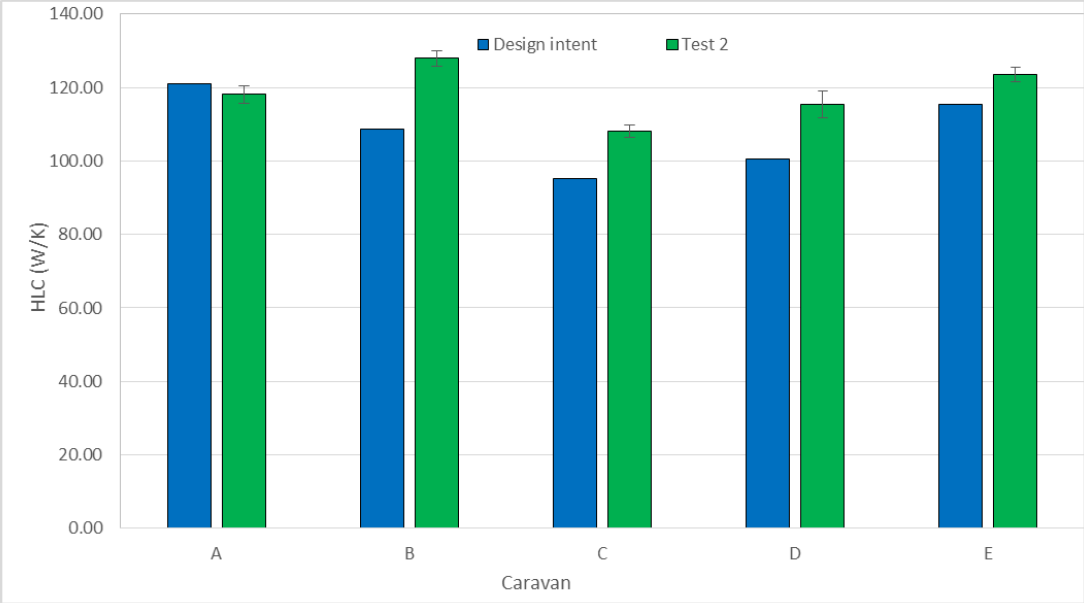


Figure 56 Comparison of the electric coheating test results with the design intent HLCs.

53 A more appropriate comparison would be to compare the results from Test 2 with the predicted HLC, as is illustrated in Figure 57. This comparison shows that in all of the test caravans, the measured HLC obtained from the electric coheating test is greater than the predicted HLC, indicating that a building fabric performance gap exists within all of the test caravans. Closer analysis of the data reveals that the scale of the gap varies considerably between the various test caravans. For caravans A, D and E the size of the gap is small (3.3 W/K, 6.2 W/K and 5.5 W/K, respectively). However, for caravans B and C, the size of the gap in performance is considerable. For caravan B the measured HLC is 31.0 W/K greater than predicted and for caravan C the measured HLC is 26.6 W/K greater than predicted. This represents an increase in HLC of just over 30% for both of these caravans.

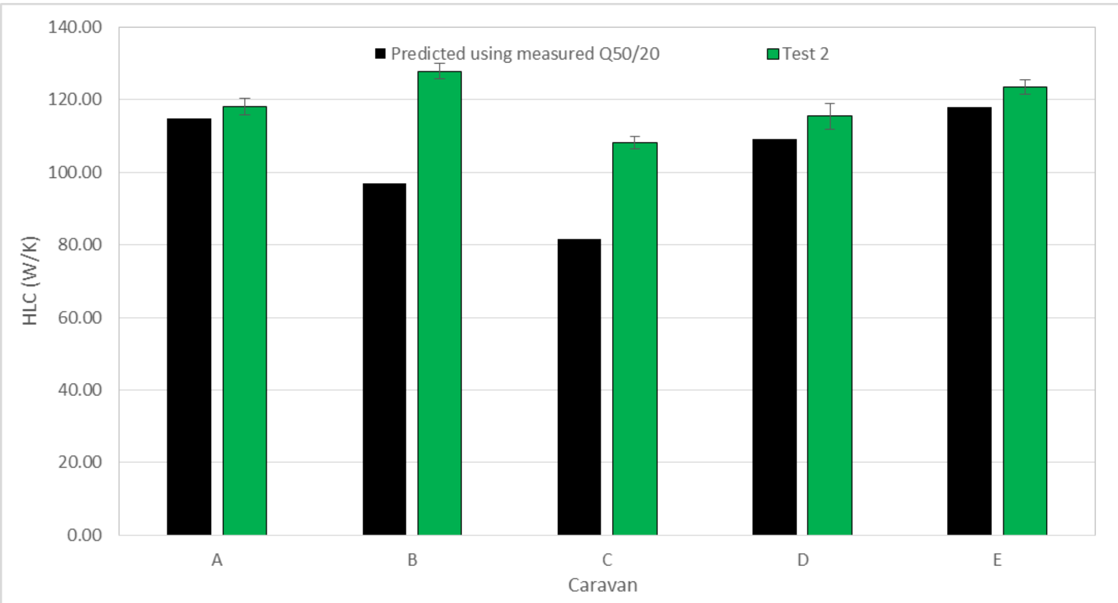


Figure 57 Comparison of the electric coheating test results with the predicted HLCs.

54 To account for the potential issues associated with using $Q_{50}/20$ as opposed to $n_{50}/20$, the predicted HLC contained within Figure 57 has been modified such that the background ventilation rate has been determined using n_{50} divided by the average devisor obtained during the CO_2 tracer gas decay measurements; in this case 25. The result of this analysis is illustrated in Figure 58. As

can be seen from Figure 58, the measured HLC is much greater than the predicted HLC for test caravans B and C (28.2 and 24.5 W/K, respectively). For caravans A, D and E the difference between the measured and predicted HLC is marginal (0.4, 3.0 and 2.1 W/K respectively). However, it should be noted that test caravan A is larger than all of the other test caravans and was not subject to any CO_2 tracer gas decay measurements. Therefore, it may be that the devisor of 25 is not appropriate for this test caravan. Despite this, the results obtained for test caravans A, D and E appear to be counterintuitive, particularly when the results of the heat flux density measurements are considered. As the calculated *in situ* U-values were in the main much greater than the design intent steady-state U-values, the measured HLC's for these caravans would have expected to have been much greater than the predicted HLC's, rather than being comparable, if these U-values are deemed to be representative of the construction as a whole. If this is the case, this would add weight to the suggestion that the *'rule of thumb'* devisor of 25 is likely to be too low. However, as previously discussed, this may not necessarily be the case, as the *in situ* U-values of the main elements of the building fabric are likely to be lower than those calculated from the heat flux density measurements.

55 Figure 59 also illustrates what would happen to the predicted HLC of the test caravans if a much greater n/50 devisor is used, such as 40 which was proposed by Miles-Shenton, Farmer and Johnston (2015). If such a devisor was deemed to be appropriate for these caravans, then the measured HLC would greater than the predicted HLC in all of the test caravans, resulting in an even larger fabric performance gap.

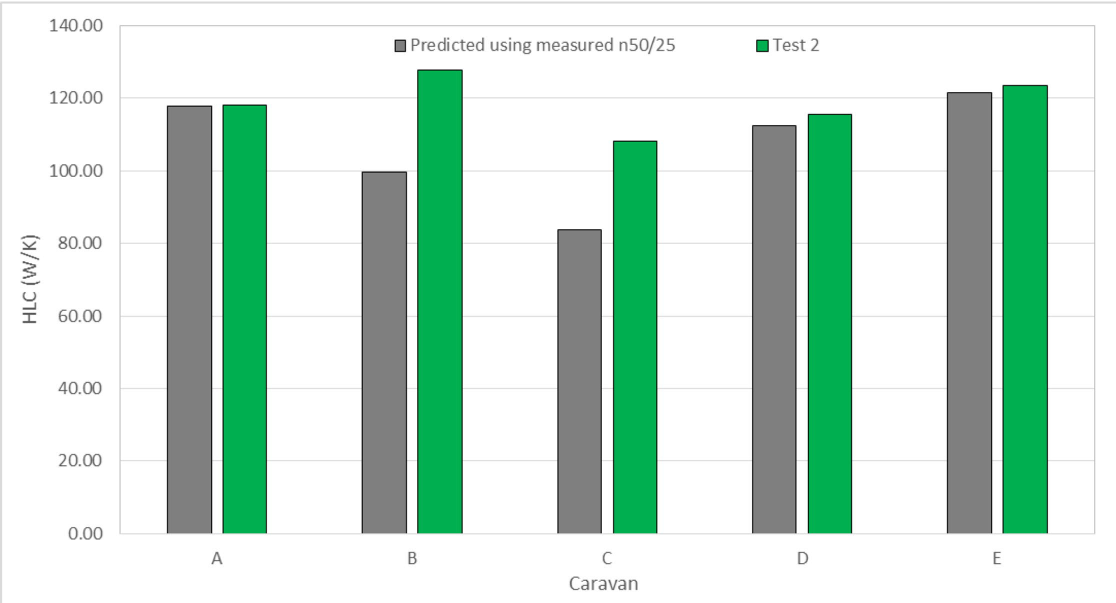


Figure 58 Comparison of the electric coheating test results with the predicted HLCs using n_{50}/25.

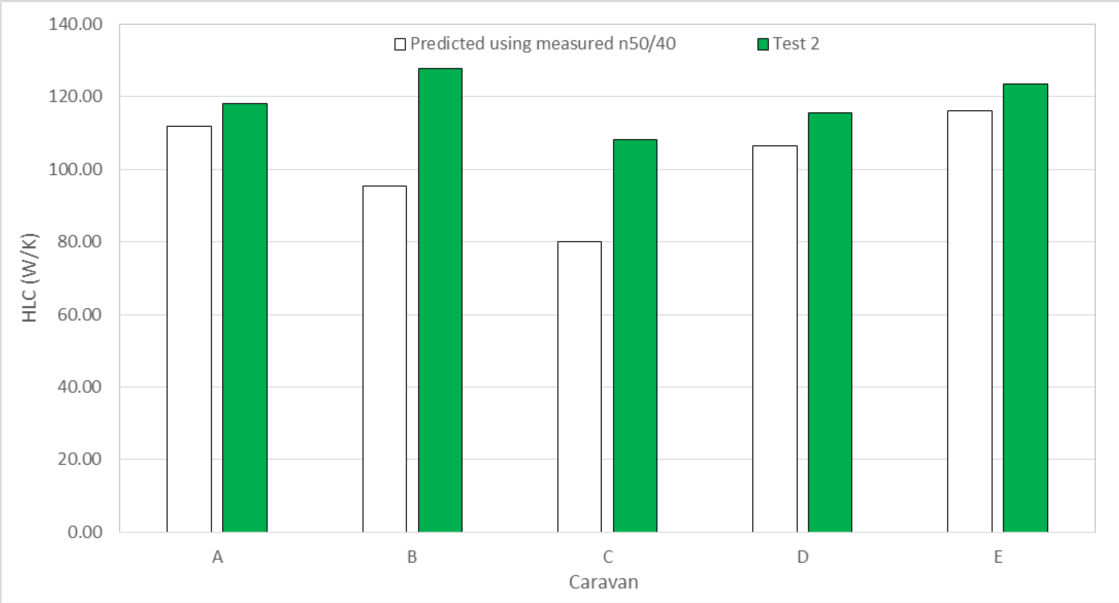


Figure 59 Comparison of the electric coheating test results with the predicted HLCs using n50/40.

6.0 Other observations

56 A comparison has been undertaken between the design intent U-values inserted by each manufacturer into the NCC calculator and the maximum U-values specified by Bourne Leisure Limited for the 2016 hire fleet models. This was undertaken to establish if any of the elements of the fabric of the test caravans fail to meet the Bourne Leisure Limited 2016 fleet hire specification. The results of this analysis are illustrated in Figure 60.

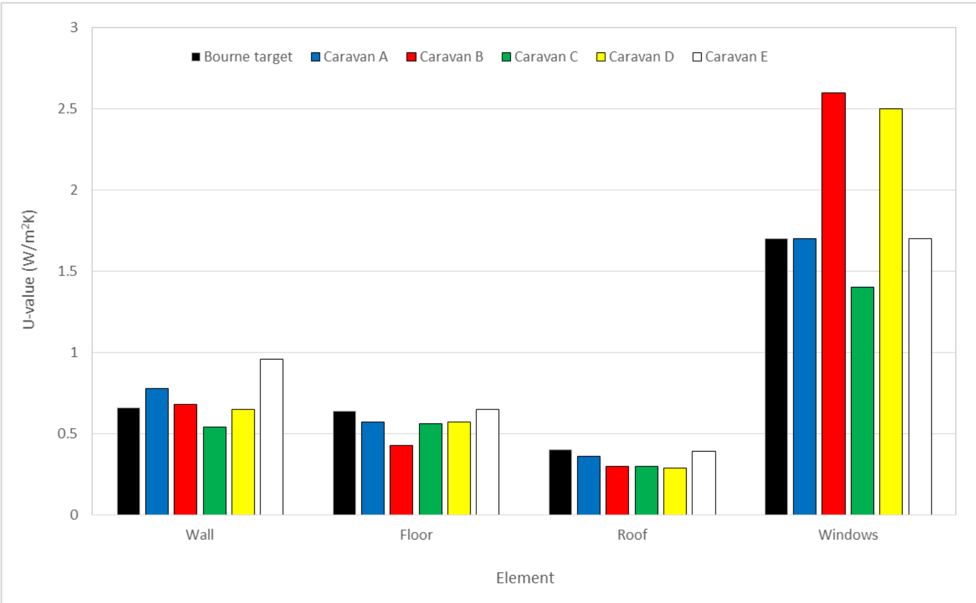


Figure 60 Comparison between the design intent U-values and the Bourne specification.

57 As can be seen from Figure 60, four of the five caravans failed to meet one or more elements of the U-value specification, resulting in only the caravan meeting all of the U-value specifications (caravan C). The caravans that failed to meet the greatest number of elements of the specification were caravans B & E, which failed to meet 50% of the U-value specification. In terms of the individual fabric elements, although all of caravans met the roof U-value specification, caravans A,

B and E failed to meet the external wall U-value specification, caravan E failed to meet the ground floor U-value specification and caravans B and D failed to meet the windows U-value specification.

58 The data contained within the NCC calculator has also been used to determine the proportion of the design intent heat losses that are attributable to the various elements of the building fabric and to background ventilation, for each test caravan. This breakdown of these various heat losses is illustrated in Figure 61.

59 It is clear from Figure 61 that the proportion of heat losses attributable to the various elements of the building fabric vary between the caravans. Consequently, the most appropriate way of reducing the heat losses in one caravan may not necessarily be the most appropriate way to reduce the heat losses in another caravan. Despite this, it is clear that the aggregate fabric heat losses are far greater than the background ventilation heat losses, even in those caravans where the default air permeability of 15 $m^3/(h.m^2)$ @ 50Pa has been used (caravans B and C). This suggests that large reductions in the heat losses attributable to the test caravans cannot be achieved by tackling airtightness alone. Therefore, if large reductions in the heat losses of the test caravans are to be achieved, then measures will have be targeted at the airtightness and the fabric performance of the caravans.

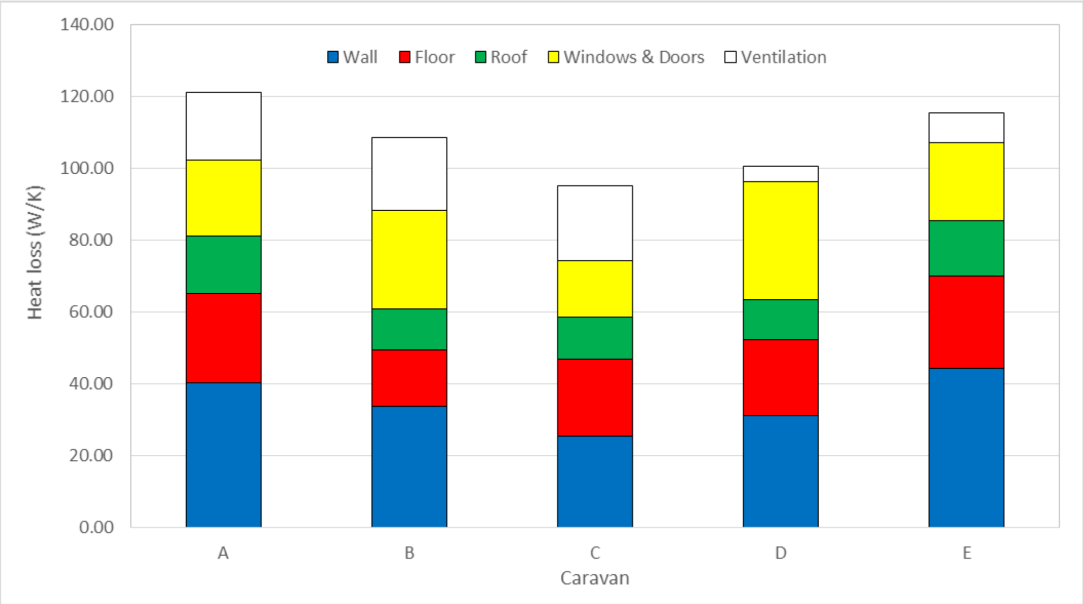


Figure 61 Design intent heat losses attributable to each of the test caravans.

7.0 Proposed Bourne Leisure Limited 2017 fleet hire specification

60 The purpose of undertaking all of the *in situ* fabric performance tests was to enable Bourne Leisure Limited to determine the optimum levels of insulation (and U-values) that should be specified for their 2017 fleet hire caravans (external walls, floor and roof) in terms of cost versus performance. However, following preliminary discussions with Bourne Leisure Limited regarding the preliminary findings of the *in situ* fabric performance tests, it became apparent that due to the uncertainties associated with the attempting to split the aggregate heat loss coefficient of each of the tested caravans into a fabric and ventilation heat loss component, an alternative approach to the specification may be more appropriate.

61 It was suggested that instead of adopting a highly prescriptive approach to the 2017 fleet hire specification, with maximum U-values being specified for each of the elements of the caravan fabric, a much more flexible approach could be adopted. This approach would involve adopting a similar approach to that contained within the Building Regulations Approved Document Part L1 (NBS, 2013), where a series of targets are specified based upon the performance of a notional dwelling. For the Bourne specification, a series of targets would be defined based upon the performance of a notional 35 ft x 12 ft caravan. These targets would comprise a maximum fabric heat loss coefficient target and a maximum air permeability target. The advantage associated with such an approach is that it does give each of the caravan manufacturers a degree of design

flexibility, such that different approaches and U-values can be used for each of the main elements of the building fabric, as long as the overall fabric heat loss target and air permeability target are met.

62 The notional caravan that has been used to determine the target specification has been assumed to have the following characteristics:

- 11 x 3.6 m in plan.
- 1.98 m high side walls internally.
- 2.2 m high front and rear end wall internally.
- Symmetrical pitched roof with insulation placed in the roof slope.
- External door area of 1.64 m^2.
- External window area of 11 m^2.

63 This results in a notional caravan with an internal volume of approximately 83m^3 and an internal surface area of 138m^2.

64 Based upon the maximum specified U-values incorporated within the Bourne Leisure Limited 2016 fleet hire specification, the total fabric heat loss coefficient attributable to the notional caravan equates to 93.1 W/K (see Table 14). If it is assumed that the notional caravan has an air permeability of 15 $m^3/(h.m^2)$ @ 50Pa, based upon the $Q_{50}/20$ *'rule of thumb'* incorporated within the NCC Energy Efficiency Calculator, the background ventilation heat loss equates to 20.48 W/K. This results in a total heat loss coefficient of 113.58 W/K for the notional caravan.

65 For comparative purposes, the notional caravan has also been used in conjunction with the lowest design intent fabric U-values specified within Figure 60, to determine the lowest theoretical heat loss coefficients that are possible based upon each manufacturers response to the 2016 Bourne fleet hire specification. The resultant fabric heat loss coefficients are illustrated in Table 15. In addition, if one assumes a relatively conservative air permeability of 10 $m^3/(h.m^2)$ @ 50Pa, the background ventilation heat loss equates to 13.66 W/K, resulting in a total fabric heat loss coefficient of 89.90 W/K. This represents just over a 20% reduction in heat loss coefficient compared to the 2016 fleet hire specification notional caravan.

Element	Area (m^2)	U-value (W/m^2K)	Heat Loss Coefficient (W/K)
External walls	45.97	0.66	30.34
Floor	39.60	0.64	25.34
Roof	39.82	0.40	15.93
Windows	11.00	1.7	18.70
Door	1.64	1.7	2.79
		Total	93.10

Table 14 Heat loss coefficients attributable to the notional caravan based upon the 2016 Bourne Leisure Limited specification.

Element	Area (m^2)	U-value (W/m^2K)	Heat Loss Coefficient (W/K)
External walls	45.97	0.54	24.82
Floor	39.60	0.46	22.18
Roof	39.82	0.29	11.55
Windows	11.00	1.40	15.40
Door	1.64	1.40	2.30
		Total	76.24

Table 15 Heat loss coefficients attributable to the notional caravan based upon the lowest U-values specified within the NCC Energy Efficiency Calculator for all of the test caravans.

66 Based upon the above results for the notional caravan, it is proposed that the Bourne 2017 fleet hire specification is as follows:

- Maximum fabric heat loss coefficient of 90 W/K.
- Maximum air permeability of 10 $m^3/(h.m^2)$ @ 50Pa. This test is to be undertaken in accordance with the method outlined in the Airtightness Testing and Measurement Association (ATTMA) Technical Standard L1 testing protocol for building envelopes (ATTMA, 2010).

67 This specification results in a total heat loss coefficient of approximately 104 W/K for the notional caravan, representing just under a 10% reduction in the total heat loss coefficient of the notional caravan compared to the Bourne 2016 fleet hire specification (assumes an air permeability of 15 $m^3/(h.m^2)$ @ 50Pa).

8.0 Summary

68 This report has outlined the results of a number of fabric performance tests that were undertaken on five static hire fleet caravans located adjacent to one another at the Hillcrest touring pitch area of the Reighton Sands site, Reighton, North Yorkshire. The tests were undertaken in order to determine the optimum levels of insulation (and U-values) that should be specified for the main external elements of the fleet hire caravans (external walls, floor and roof) in terms of cost versus performance.

69 The main findings obtained from the *in situ* measurements, the associated observations and the analysis of the measured data are as follows:

- In terms of design intent, only one of the test caravans (caravan C) satisfied all of the components of the Bourne 2016 fleet hire U-value specification. In addition, two of the test caravans (caravans B & E) failed to meet 50% of the requirements of the Bourne 2016 fleet hire U-value specification.
- An analysis of the design intent heat losses obtained from the NCC Energy Efficiency calculator reveals that the proportion of the heat losses attributable to the various elements of the building fabric not only varies between the test caravans, but the proportion of the heat losses attributable to background ventilation tend to be small in comparison to those attributable to conductive fabric heat loss. This suggests that if large reductions in the heat losses of the test caravans are to be achieved, then measures will have be targeted at both the airtightness and the fabric performance of the caravans. In addition, those measures introduced to reduce heat losses in one test caravan may not necessarily be appropriate for another test caravan.
- The measured air permeability figures varied considerably between the test caravans, ranging from just over 5 $m^3/(h.m^2)$ @ 50 Pa for caravan C to just over 9 $m^3/(h.m^2)$ @ 50 Pa for caravan D. On average, the air permeability of the test caravans was just over 7 $m^3/(h.m^2)$ @ 50 Pa. All of these results were obtained with all of the purpose provided ventilation openings and gas drop out points sealed. Although all of the test caravans achieved air permeability figures that were significantly less than the default figure of 15 $m^3/(h.m^2)$ @ 50Pa contained within the NCC Energy Efficiency Calculator, in two of the test caravans (D and E) the measured air permeability figures were significantly greater than that the design intent value incorporated within the NCC Energy Efficiency calculator. This represents an air permeability performance gap in these two test caravans.
- Leakage identification, using thermal imaging, revealed a number of common air leakage points and paths within each of the test caravans. These were identified at locations where the services penetrated through the floor, wall or roof, such as at waste pipes, water pipes, central heating system pipes, gas entry point, etc. As the majority of these penetrations are located beneath the kitchen cupboards, or beneath/behind sanitary fittings, in the main they are either hidden or obscured from view. In addition, leakage was also identified at the interfaces between different elements, such as the external wall/ground floor junction, the external wall corners, the external wall/roof junction and around window frames.
- The thermal imaging surveys revealed a number of significant areas of thermal bridging that were common across the majority of the test caravans. These areas could be categorised into repeating and non-repeating thermal bridges. The repeating thermal bridges comprised the floor joists, horizontal and vertical studwork in the external walls, and the roof joists. The non-repeating thermal bridges comprised areas of missing insulation around extract grilles and light

fittings, areas of missing insulation or insulation discontinuity in the external walls and insulation discontinuities around electrical cables.

- The CO_2 tracer gas decay measurements revealed that a wide range of background ventilation rates were experienced over the various electric coheating tests, ranging from as low as 0.24 ach^{-1} for caravan C during coheating Test 2 to as high as 1.60 ach^{-1} for caravan D during electric coheating Test 1. The measurements also revealed that for all of the test caravans, changes in the background ventilation rate appear to be generally consistent with changes in daily average wind speed, with the highest ventilation rates corresponding with the highest wind speeds. A comparison of the CO_2 decay measurements against the approximated average annual background ventilation rate suggests that the current devisor incorporated within the NCC Energy Efficiency Calculator of 20 is likely to be too low. In addition, this devisor incorporated within the calculator also relates to air permeability (Q_{50}), as is the case for SAP, rather than air leakage rate (n_{50}) from which the *'rule of thumb'* devisor was originally devised. In the case of the test caravans, this is important, as the difference between the n_{50} and Q_{50} value can be significant due to the test caravans form factor (they have a high surface area to volume ratio). Further analysis reveals that the average devisor for the test caravans is more likely to be around 25, some 25% greater than the devisor that is currently contained within the NCC Energy Efficiency Calculator. However, this figure is much lower than the devisor of 40 proposed by Miles-Shenton, Farmer and Johnston (2015) on some recently tested holiday homes.
- A series of *in situ* heat flux density measurements were also undertaken on the caravans. These measurements revealed that not only was a range of performance measured both within and across the test caravans, but in a number of instances, the calculated *in situ* U-values were much greater than the design intent steady-state U-values, even in locations where no thermal anomalies or thermal bridging were present. In those locations where studs, joists and thermal anomalies had been identified, the calculated *in situ* U-values were in the main significantly higher than the design intent steady-state U-values for the fabric elements as a whole. Further analysis of the data revealed that although some errors were observed in the steady-state U-values incorporated within the NCC Energy Efficiency Calculator, caused by the omission of various construction elements, these errors were only likely to have a negligible impact on the resultant design intent steady-state U-values. Consequently, the discrepancy between the calculated *in situ* and the design intent steady-state U-values is most likely attributed to a gap in the performance of the various elements of the building fabric. Unfortunately, as part of this project, it has not been possible to quantify the scale of this performance gap. To be able to do so, would not only require information on the amount of timber used in the external walls, ground floor and roof (timber fraction), it would also require all of the non-repeating thermal bridges that exist within the test caravans to be identified and calculated. It also requires the assumption to be made that all of the heat flux density measurements that have been undertaken as part of this project are representative of the construction element that was measured as a whole. This is unlikely to be the case, as a significant proportion of the building fabric of the test caravans have furniture and fittings attached to them, which will provide additional thermal resistance. This will result in lower *in situ* U-values and reduced heat transfer at these locations.
- The electric coheating test results revealed that a range of performance exists between all of the tested caravans, with caravan C consistently achieved the lowest HLC's and caravan B consistently achieved the highest HLC's for each of the electric coheating tests. A comparison between the three electric coheating tests that were undertaken revealed that whilst a very small difference in HLC was measured when the gas drop-out points were unsealed, a much larger difference in HLC was measured when all of the purpose provided ventilation openings and gas drop-out points were unsealed, as expected. The scale of this difference varied between each of the test caravans and ranged from just over 8 W/K for caravan C to just over 18 W/K for caravan A. On average, the increase in HLC was around 13 W/K. An attempt was also made to compare the results obtained from electric coheating Test 2 against the design intent HLC and the predicted HLC for each caravan. However, undertaking such a comparison was problematic, as the background ventilation heat loss incorporated within the design intent includes a mixture of both assumed and measured air permeability values. Therefore, a more appropriate comparison was undertaken by comparing the results of coheating Test 2 with the predicted HLC, which takes into account the actual measured air permeability values (Q_{50}) that were obtained for each test caravan. This comparison revealed that in all of the test caravans, the measured HLC obtained from the electric coheating test was greater than the predicted HLC, indicating the presence of a building fabric performance gap. Closer analysis of the data

revealed that the scale of the gap varied considerably between the various test caravans, with only a marginal difference being observed for caravans A, D and E. However, in caravans B and C, the size of the gap in performance was considerable and represented an increase in HLC of just over 30% for both of these caravans. To account for the potential issues associated with using $Q_{50}/20$ as opposed to $n_{50}/20$ when calculating the background ventilation rate and the associated heat losses, the predicted HLC figures were amended to take into account the average *'rule of thumb'* devisor obtained from the CO_2 tracer gas decay measurements of 25. When this devisor is used in conjunction with the measured air leakage rate (n_{50}), a negligible difference in HLC was observed for caravans A, D and E. With respect to caravans B and E, although the difference between the measured and the predicted HLC also reduced, the difference in HLC was still considerable (28.2 W/K and 24.5 W/K, respectively). Taking into account the heat flux density measurements, the electric coheating test results obtained for test caravans A, D and E appear to be counterintuitive, as these measurements highlighted the occurrence of a potentially significant building fabric thermal performance gap. Assuming that the *in situ* U-values that were calculated from the heat flux density measurements can be deemed to be representative of the construction as a whole, this would add additional weight to the earlier suggestion that the *'rule of thumb'* devisor of 25 is likely to be too low for the test caravans. However, as previously discussed, this may not necessarily be the case, as the *in situ* U-values of the main elements of the building fabric are most likely to be lower than those calculated from the heat flux density measurements, due the influence of furniture, fittings and additional air gaps.

70 Based upon the above results, and the difficulties associated with attempting to split the measured aggregate heat loss obtained from the electric coheating tests into their respective fabric and ventilation heat loss component, it has been proposed that a more flexible approach should be adopted for the Bourne 2017 fleet hire specification. Instead of continuing to adopt the highly prescriptive approach, where maximum U-values are specified for each of the elements of the caravan fabric, it is proposed that a maximum fabric heat loss coefficient target and a maximum air permeability target are defined based upon the performance of a notional 35 ft x 12 ft caravan. Utilising this approach it is proposed that the Bourne Leisure Limited 2017 fleet hire specification is defined as follows:

- Maximum fabric heat loss coefficient of 90 W/K.
- Maximum air permeability of 10 $m^3/(h.m^2)$ @ 50Pa. This test is to be undertaken in accordance with the method outlined in the Airtightness Testing and Measurement Association (ATTMA) Technical Standard L1 testing protocol for building envelopes (ATTMA, 2010).

71 The major advantage associated with the proposed approach is that it allows each of the caravan manufacturers to have a degree of design flexibility, such that different approaches and U-values can be used for each of the main elements of the building fabric, as long as the overall fabric heat loss target and air permeability target are met.

9.0 Recommendations for future work

72 During the course of this project it has become clear that in order to improve our understanding of the building fabric thermal performance of the caravans, further research work needs to be undertaken in a number of areas. These areas have been identified as follows:

- The work presented within this report highlights that the use of the Q_{50} and the 20 devisor in the $Q_{50}/20$ *'rule of thumb'* is not appropriate for the test caravans, in port due to their high surface area to volume ratio. To address this issue, the air pressure test results should be presented as an air leakage rate at 50Pa (n_{50}) rather than an air permeability figure at 50Pa (Q_{50}) and n_{50} should be used to develop a new background ventilation rate *'rule of thumb'*. To develop this new *'rule of thumb'*, a series of CO_2 tracer gas decay measurements should be undertaken in parallel with air pressurisation tests to investigate the most appropriate devisor/s to use for caravans with different geometries.
- In terms of airtightness, the measured air permeability values used by some of the manufacturers within the NCC Energy Efficiency Calculator were significantly lower than the air permeability values measured as part of this project. This is despite the fact that the measured air permeability figures inserted within the Calculator are likely to represent the worst case scenario for a particular construction. Consequently, more air pressurisation tests should be undertaken to establish the variability in airtightness that can be achieved across different construction types and sizes of caravans.

- In all of the test caravans, a number of common air leakage points and pathways were identified. These points and pathways result in additional and unwanted adventitious and uncontrolled ventilation within the caravans. Work should be undertaken to examine various techniques and strategies that can be adopted so that these adventitious air leakage points and pathways can be minimised.
- The thermal imaging survey and heat flux density measurements illustrated that all of the test caravans suffered from a number of significant and common areas of thermal bridging. If attempts are made to improve the thermal performance of the various elements of the construction, without addressing this thermal bridging, then the proportion of the overall heat loss that will be attributable to thermal bridging will increase. Work should be undertaken to begin to quantify the proportion of heat losses that are attributable to thermal bridging (both repeating and non-repeating thermal bridges) and to quantify the timber fraction used in the external walls, the floor and the roof. In addition to quantifying the amount of thermal bridging, additional work also needs to be undertaken to investigate possible solutions that could be adopted to minimise thermal bridging within caravans.
- The calculated *in situ* U-values and the electric coheating results suggest that there is a fabric thermal performance gap. Further heat flux density measurements and electric coheating tests need to be undertaken on a range of caravans in order to quantify this gap.
- The results obtained from this work suggest that the fixtures and fittings that installed in direct contact with the external elements of the caravans contribute towards improving the thermal performance of these caravans and reducing the size of the building fabric thermal performance gap. Additional work should be undertaken to investigate the effect that these fixtures and fittings have on both the theoretical and actual thermal performance of the caravans.

10.0 References

ATTMA (2010) ATTMA Technical Standard L1. Measuring the Air Permeability of Building Envelopes (Dwellings). October 2010 Issue. Northampton, UK, Air Tightness Testing and Measurement Association.

BRE (2014) SAP 2012: The Government's Standard Assessment Procedure for Energy Rating of Dwellings. 2012 Edition. Garston, Watford, Building Research Establishment.

Johnston, D. Miles-Shenton, D. Farmer, D. and Wingfield, J. (2013) Whole House Heat Loss Test Method (Coheating). June 2013. Leeds, UK, Centre for the Built Environment, Leeds Metropolitan University.

Miles-Shenton, D. Farmer, D. and Johnston, D. (2015) Investigation into the In Situ Thermal Performance of 2 Static Caravans - Assessing the Change in Heat Loss Behaviour due to Thermally Superior Replacement Windows. April, 2015. Leeds, UK, Leeds Sustainability Institute, Leeds Beckett University.

Modera, M.P. Dickerhoff, D. Jansky, R. and Smith, B. (2009) Cited in ASHRAE Fundamentals. Atlanta, American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), p. 16.8.

NBS (2013) The Building Regulations 2010 Approved Document L1A: Conservation of fuel and power in new dwellings. 2013 Edition. London, NBS.

NCC (2016) NCC Energy Rating Calculator. [Internet]. Aldershot, National Caravan Council (NCC). Available from: < http://www.thencc.org.uk/energy-rating-calculator.aspx> [Accessed on: 7th April 2015].

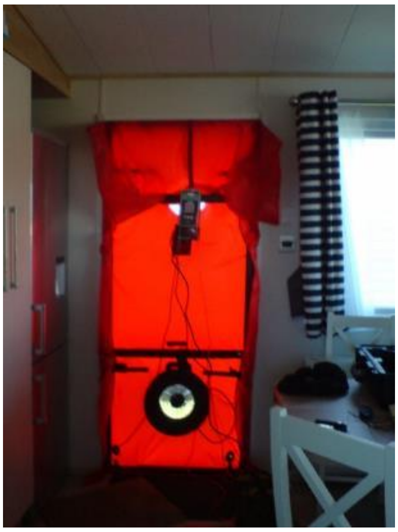
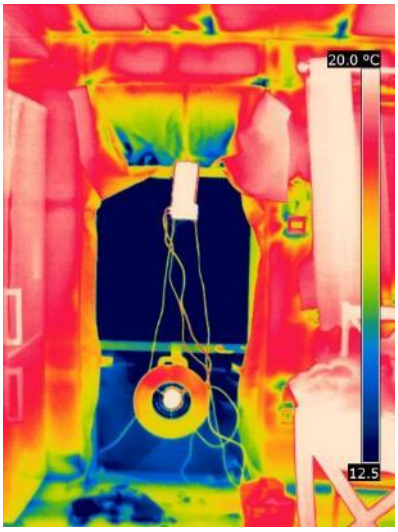
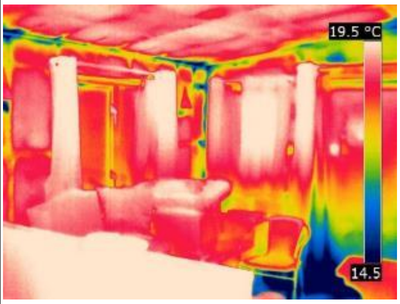
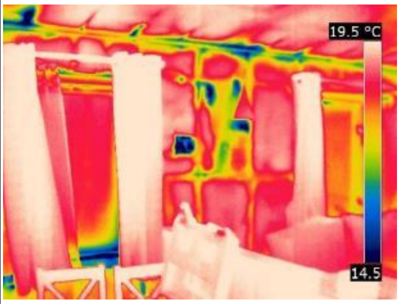
Roulet, C.A. and Foradini, F. (2002) Simple and Cheap Air Change Rate Measurement Using CO_2 Concentration Decays. *International Journal of Ventilation*, Volume 1, No. 1, pp. 39-44.

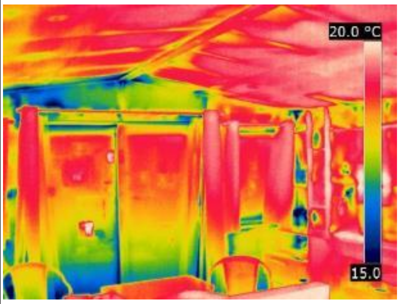
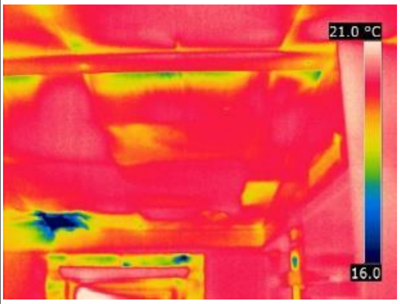
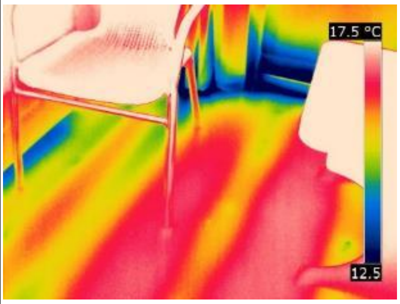
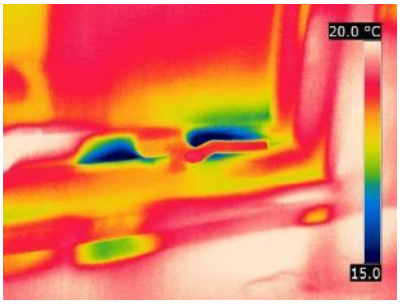
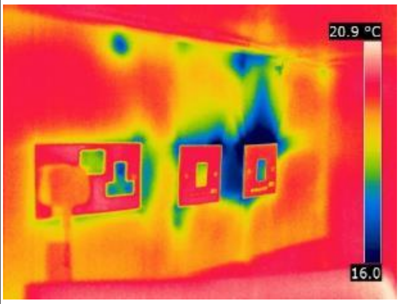
Sherman, M. (1987) Estimation of Infiltration for Leakage and Climate Indicators. *Energy and Buildings,* 10 pp. 81-86.

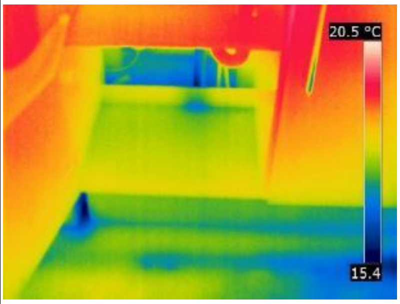
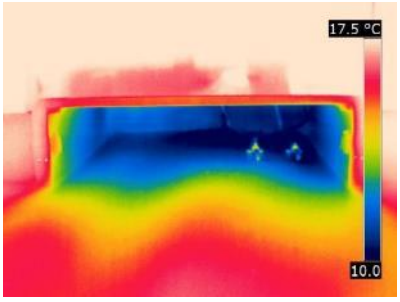
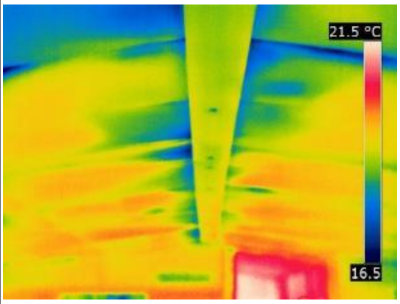
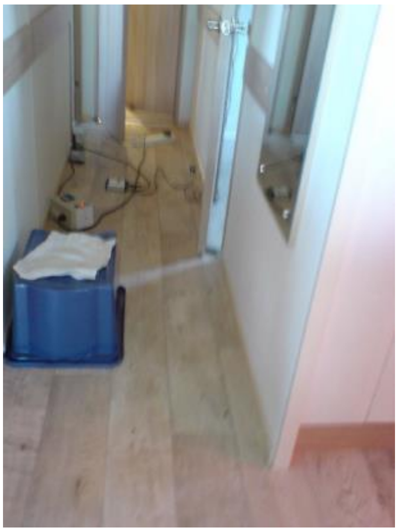
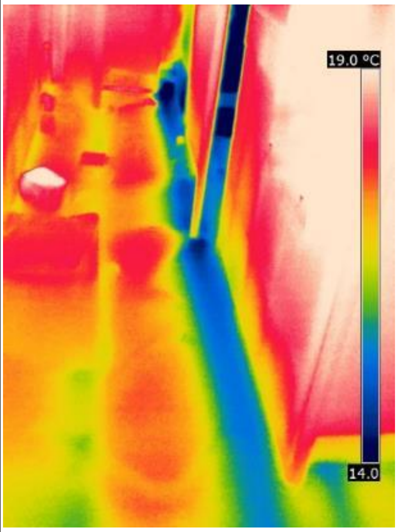
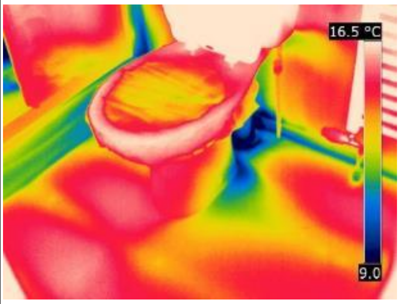
Appendix A

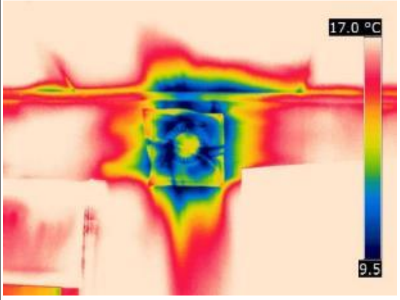
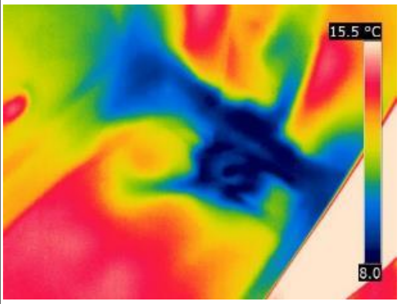
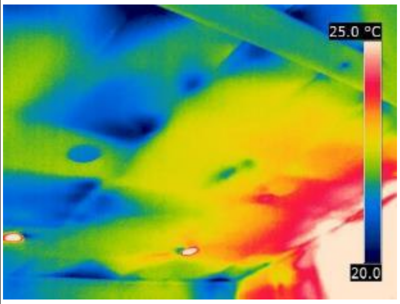
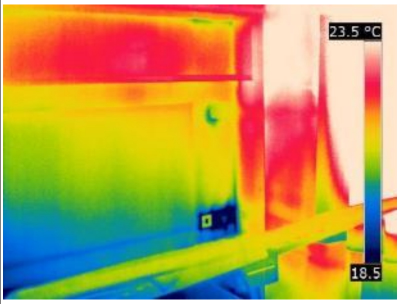
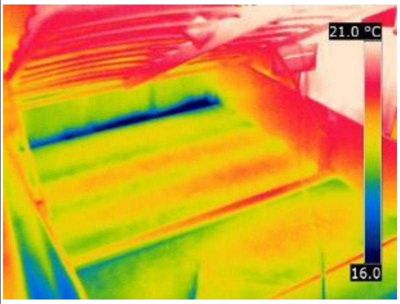
Pressurisation tests conducted on 18th and 19th February 2016.

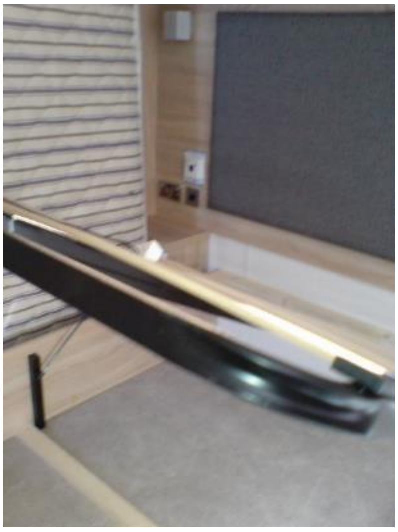
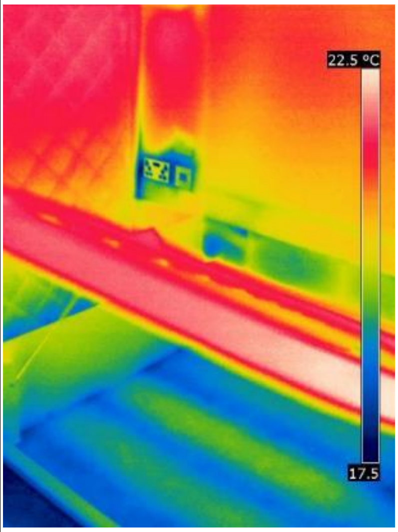
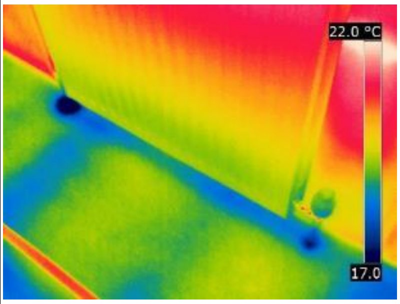
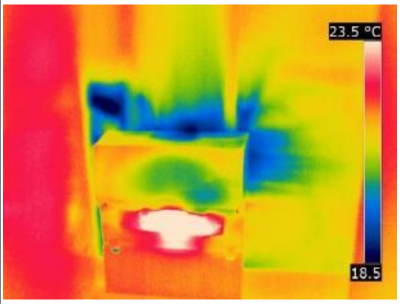
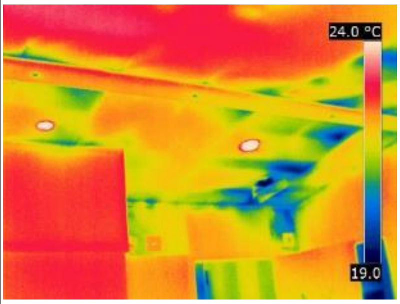
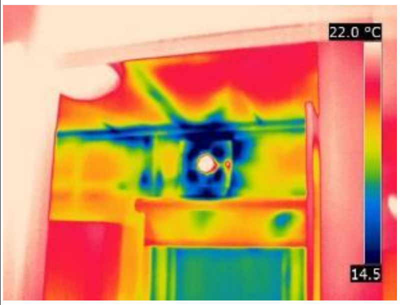
Leakage detection was performed under depressurisation, with the caravans at approximately 35 Pa below the external barometric pressure, using a Flir B620 thermal imaging camera. The internal/external temperature differential (ΔT) ranged from 11.4 °C to 6.0 °C between tests, making direct comparisons between the images listed below for different tests unreliable; however, for each individual caravan the cooler temperatures of the infiltrating air observed can be construed as either a more direct or more severe leakage path than those where warmer air is seen emerging. All the thermal images have been adapted to a temperature span of a minimum of 5 °C. Where larger temperature spans have been adopted it usually reflects the most serious air leakage paths.

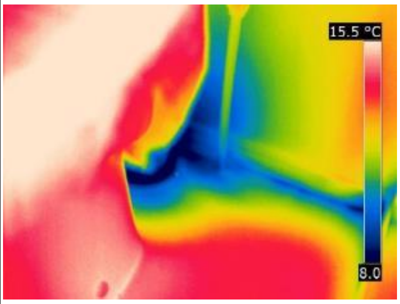
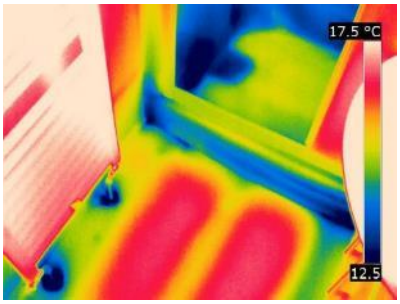
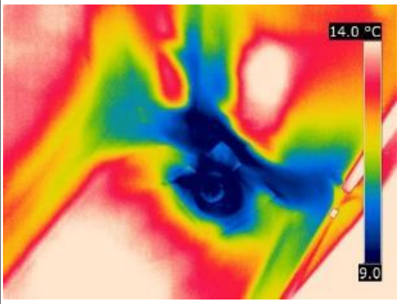
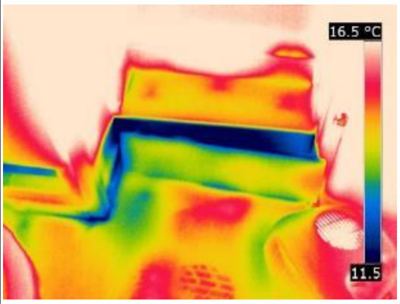
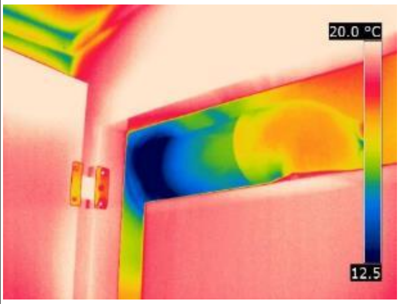
Caravan A – 18th February 2016 External temperature 6.7 °C, Internal mean temperature 18.1 °C, ΔT ≈ 11.4 °C		
		Room – Lounge/Kitchen Span – 7.5 °C
		Room – Lounge/Kitchen Span – 5 °C
		Room – Lounge/Kitchen Span – 5 °C

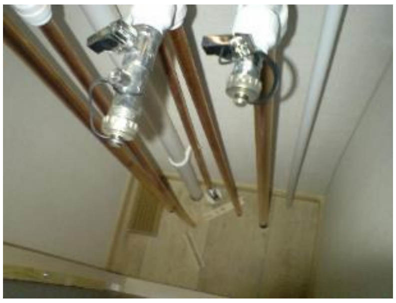
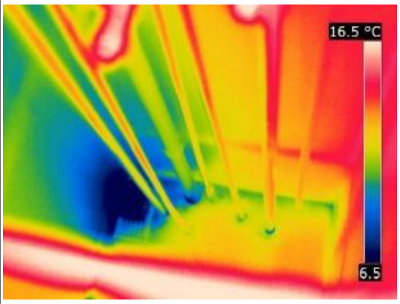
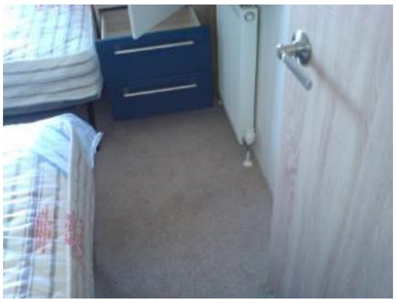
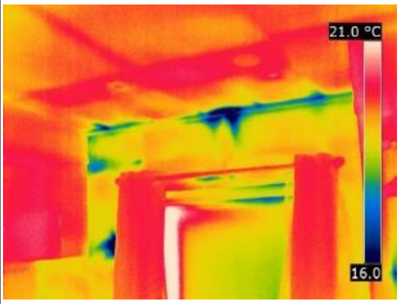
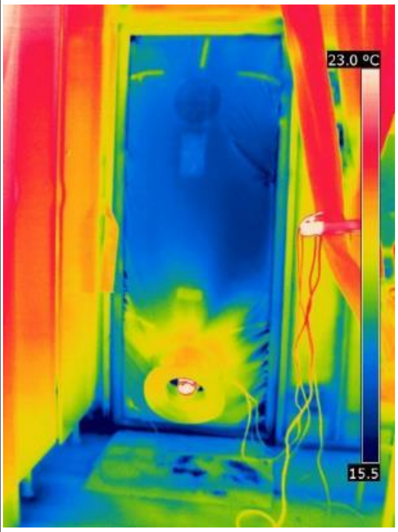
		Room – Lounge/Kitchen Span – 5 °C
		Room – Lounge/Kitchen Span – 5 °C
		Room – Lounge/Kitchen Span – 5 °C
		Room – Lounge/Kitchen Span – 5 °C
		Room – Lounge/Kitchen Span – 5 °C

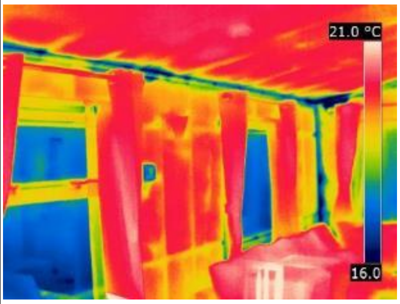
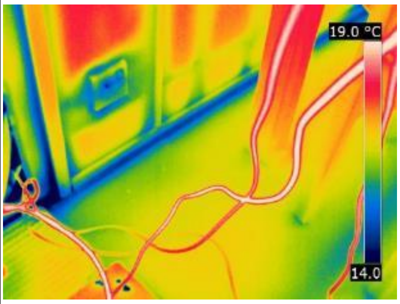
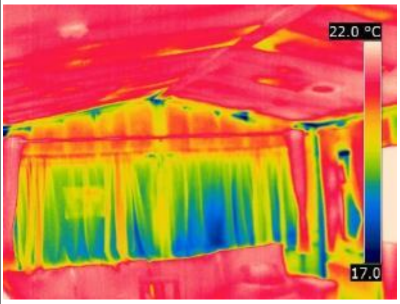
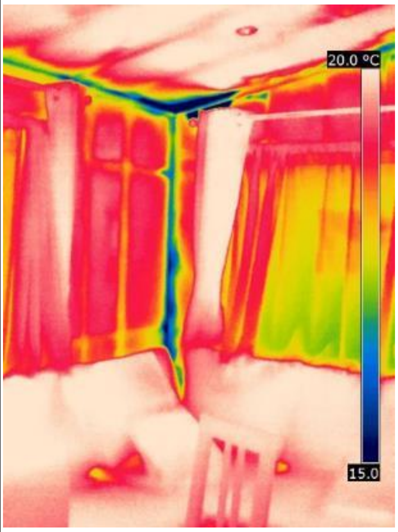
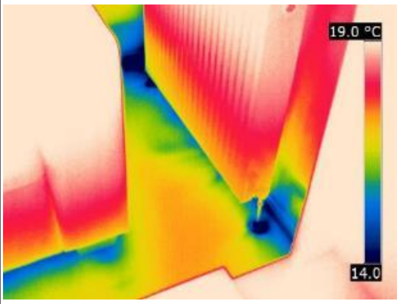
		Room – Lounge/Kitchen Span – 5 °C
		Room – Lounge/Kitchen Span - 7.5 °C
		Room – Lounge/Kitchen Span – 5 °C
		Room – Corridor Span – 5 °C
		Room – Bathroom Span – 7.5 °C

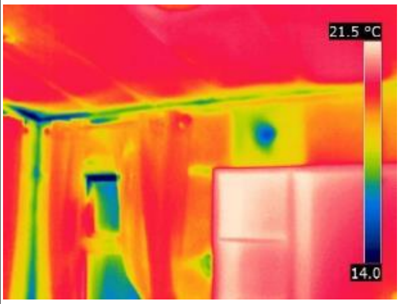
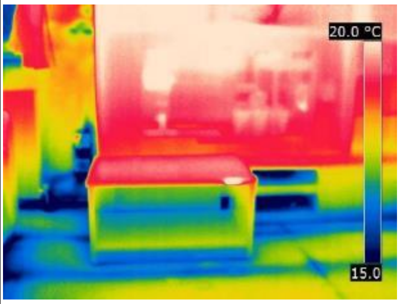
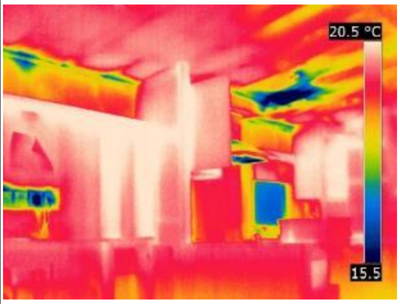
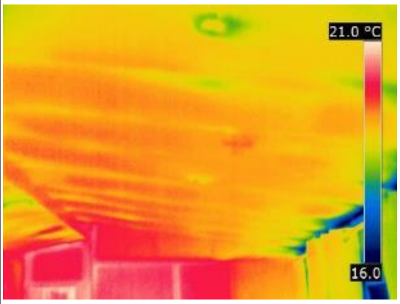
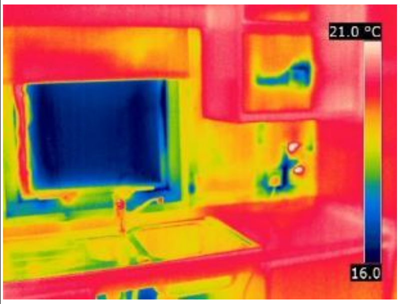
		Room – Bathroom Span - 7.5 °C
		Room – Bathroom Span - 7.5 °C
		Room – End Bedroom Span – 5 °C
		Room – End Bedroom Span – 5 °C
		Room – End Bedroom Span – 5 °C

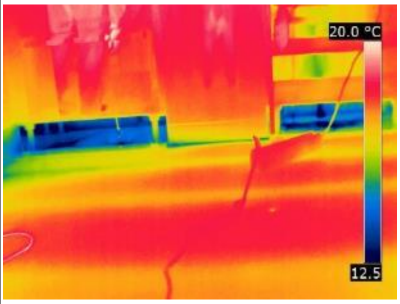
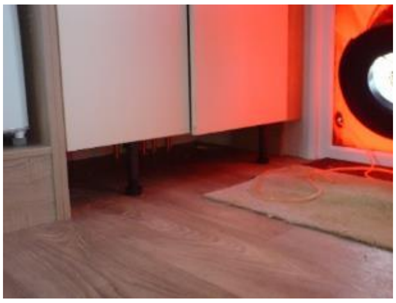
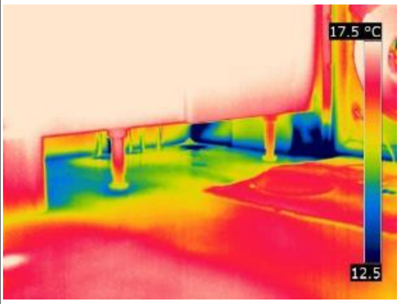
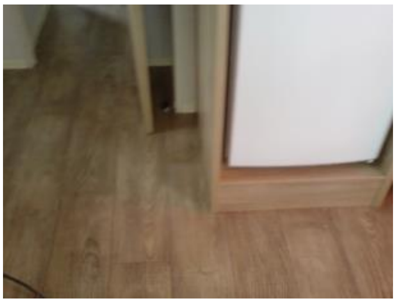
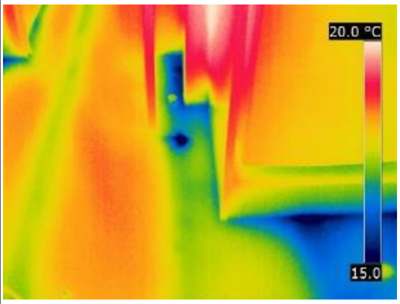
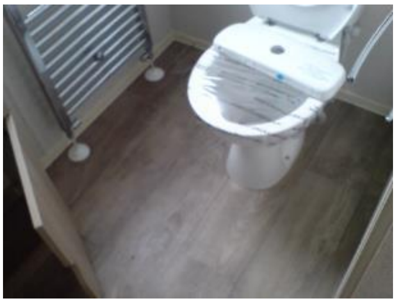
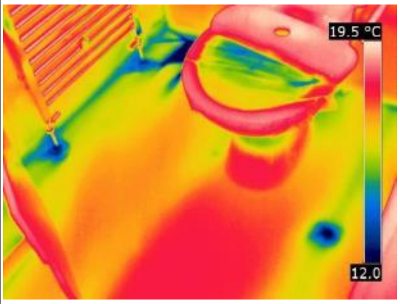
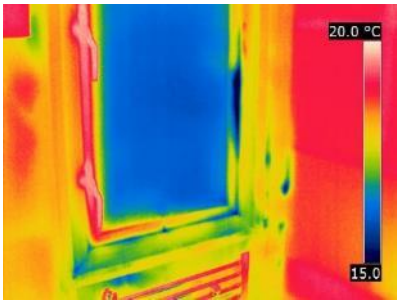
		Room – End Bedroom Span – 5 °C
		Room – End Bedroom Span – 5 °C
		Room – End Bedroom Span – 5 °C
		Room – End Bedroom Span – 5 °C
		Room – En-Suite Span - 7.5 °C

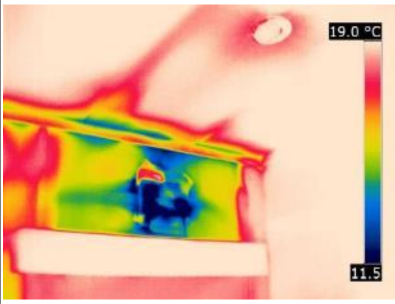
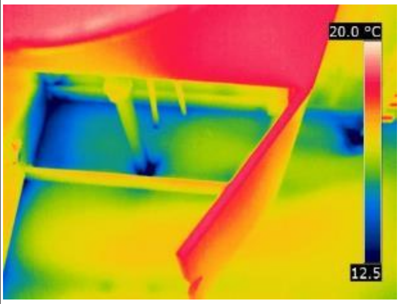
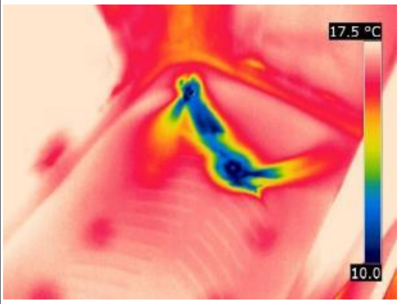
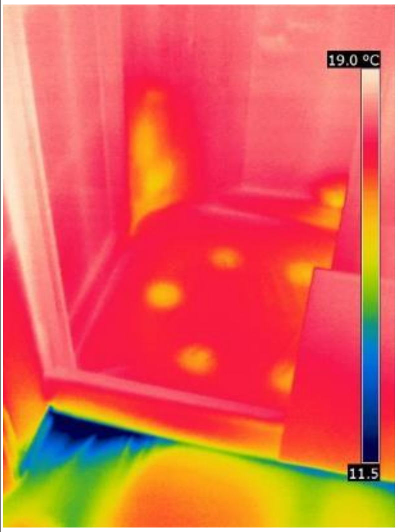
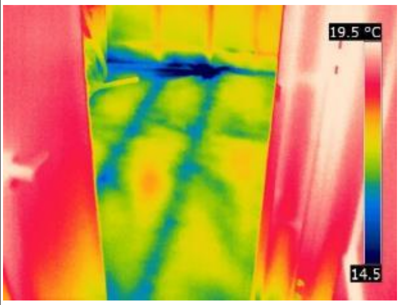
		Room – En-Suite Span - 7.5 °C
		Room – En-Suite Span – 5 °C
		Room – En-Suite Span – 5 °C
		Room – En-Suite Span – 5 °C
		Room – Boiler Span - 7.5 °C

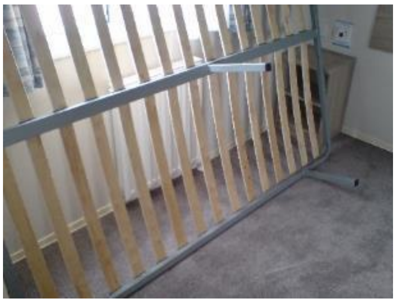
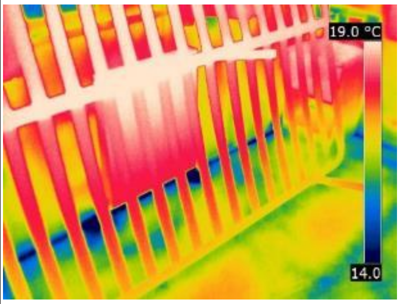
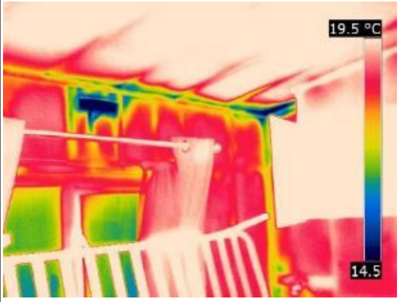
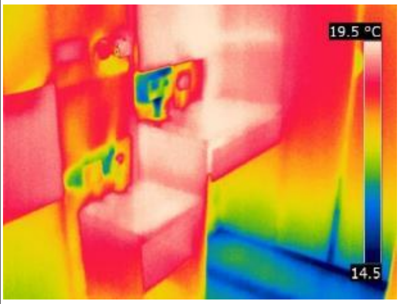
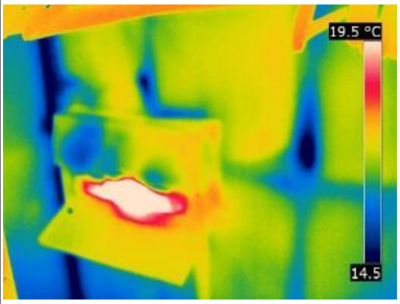
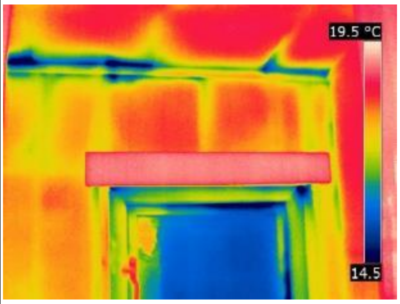
		Room – Boiler Span – 10 °C
		Room – Side Bedroom Span – 10 °C
		Room – Side Bedroom Span – 5 °C
Caravan B – 19th February 2016 External temperature 4.0 °C, Internal mean temperature 19.2 °C, ΔT ≈ 15.2 °C		
		Room – Lounge/Kitchen Span – 7.5 °C

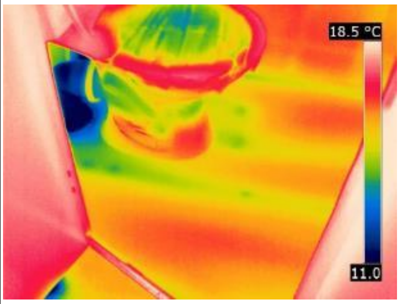
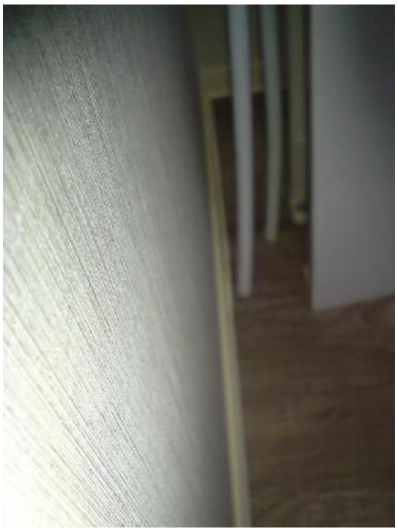
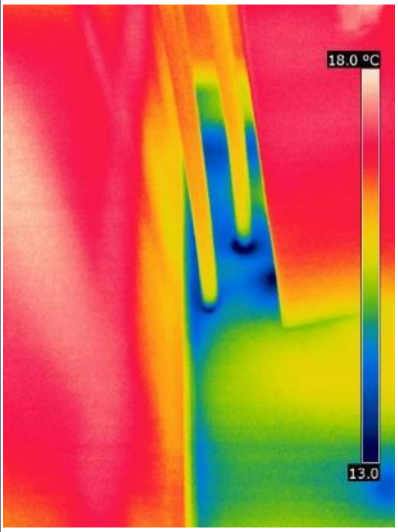
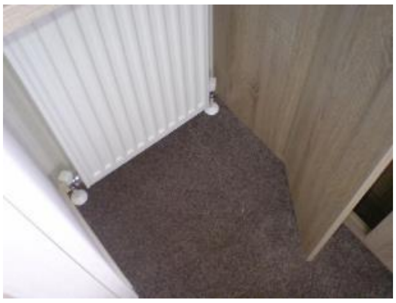
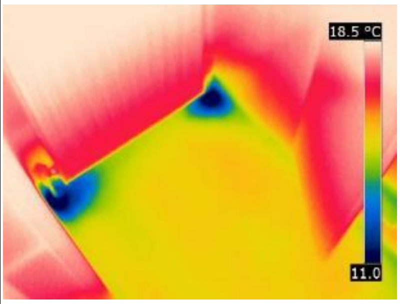
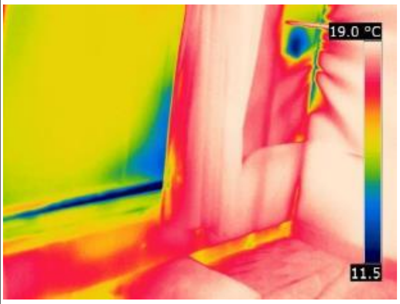
		Room – Lounge/Kitchen Span – 5 °C
		Room – Lounge/Kitchen Span – 5 °C
		Room – Lounge/Kitchen Span – 5 °C
		Room – Lounge/Kitchen Span – 5 °C
		Room – Lounge/Kitchen Span – 5 °C

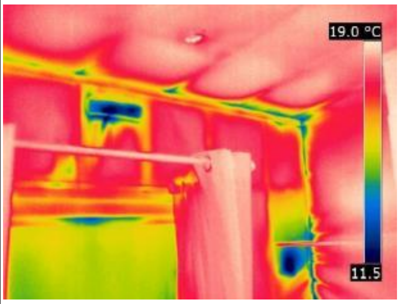
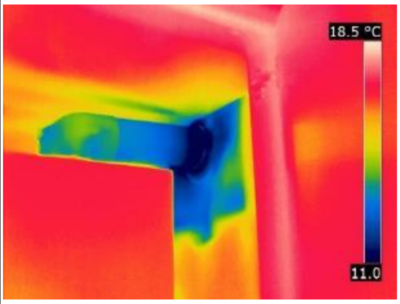
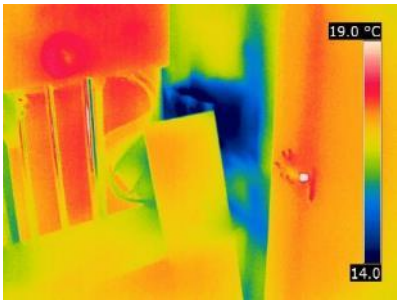
		Room – Lounge/Kitchen Span – 7.5 °C
		Room – Lounge/Kitchen Span – 5 °C
		Room – Lounge/Kitchen Span – 5 °C
		Room – Lounge/Kitchen Span – 5 °C
		Room – Lounge/Kitchen Span – 5 °C

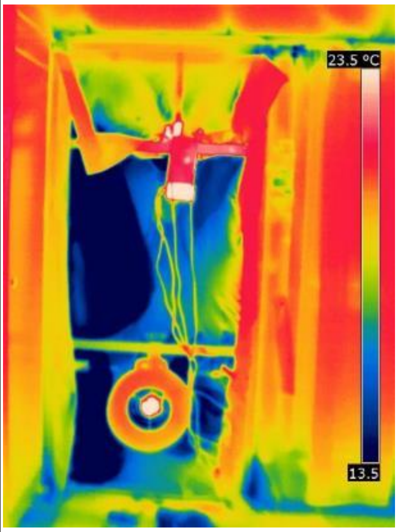
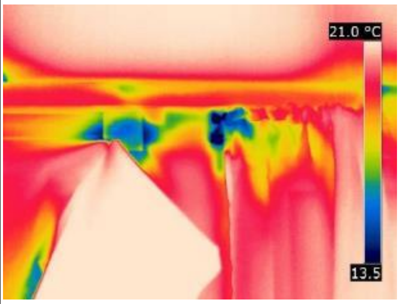
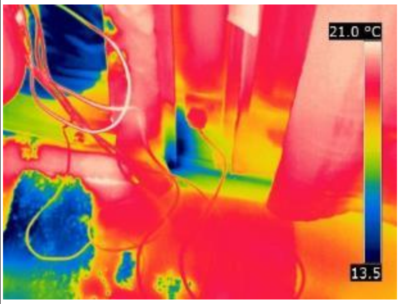
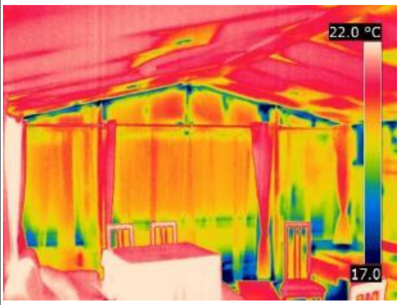
		Room – Lounge/Kitchen Span – 7.5 °C
		Room – Lounge/Kitchen Span – 5 °C
		Room – Lounge/Kitchen Span – 5 °C
		Room – Bathroom Span – 7.5 °C
		Room – Bathroom Span – 5 °C

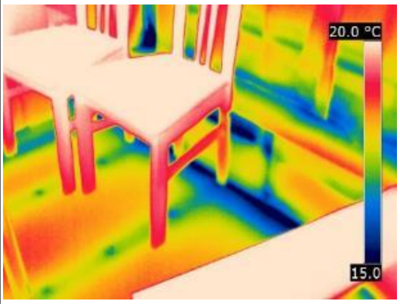
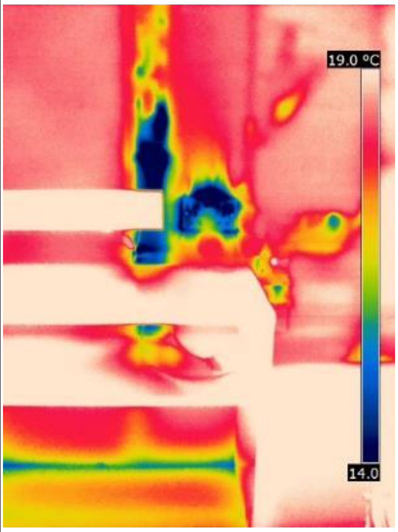
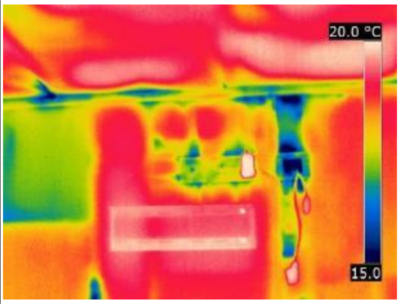
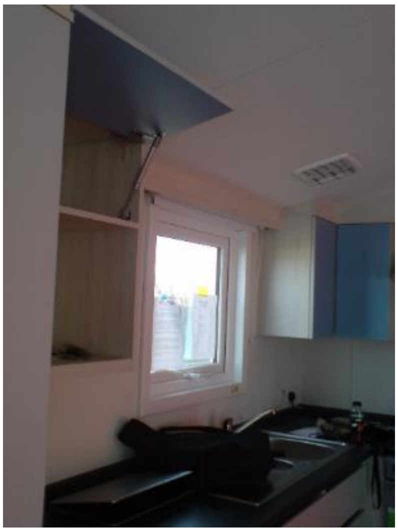
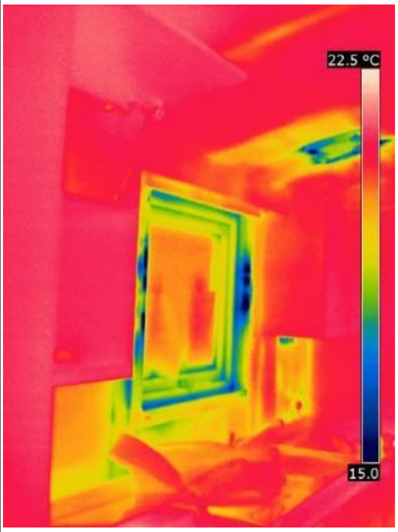
		Room – Bathroom Span – 7.5 °C
		Room – Bathroom Span – 7.5 °C Daylight visible through a gap at the waste pipe penetration – a photo of this detail from beneath is shown at the end of this section.
		Room – Bathroom Span – 7.5 °C
		Room – Bathroom Span – 7.5 °C
		Room – End Bedroom Span – 5 °C Under depressurisation, at higher pressures, the carpet in this room was seen ballooning upwards; air can be seen moving beneath the carpet in the thermal images.

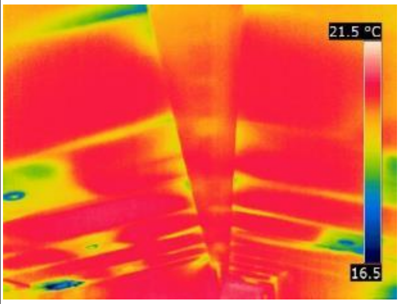
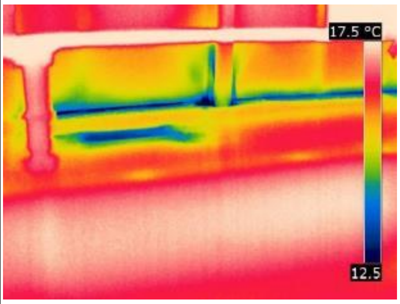
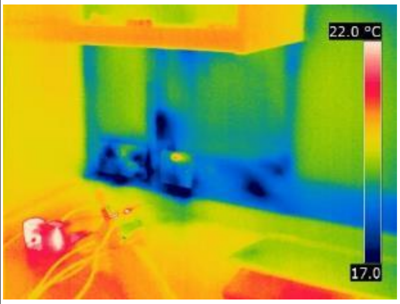
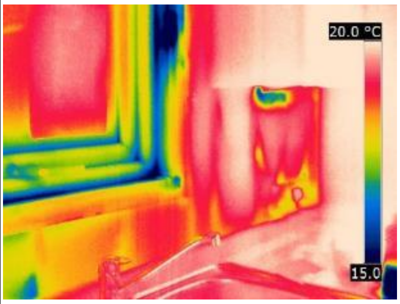
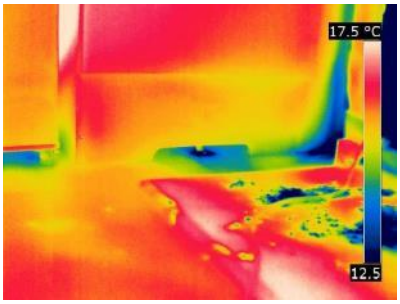
		Room – End Bedroom Span – 5 °C
		Room – End Bedroom Span – 5 °C
		Room – End Bedroom Span – 5 °C
		Room – End Bedroom Span – 5 °C
		Room – En-Suite Span – 5 °C

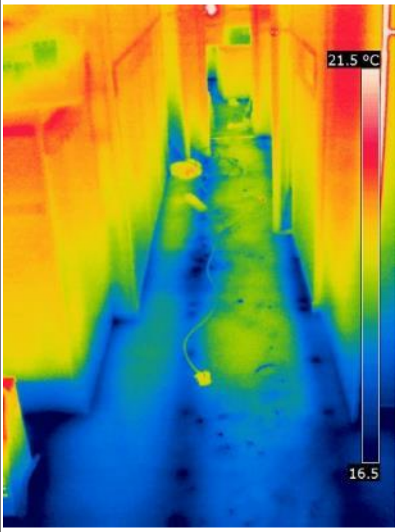
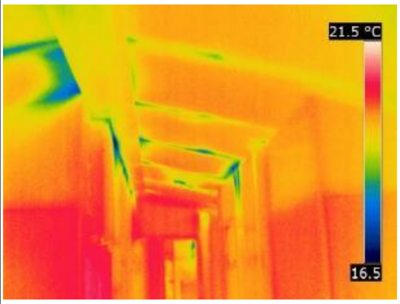
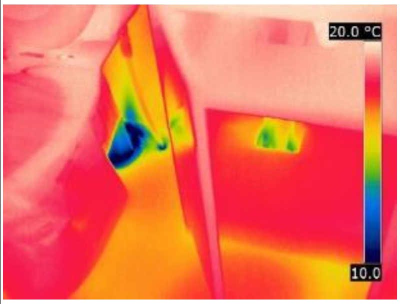
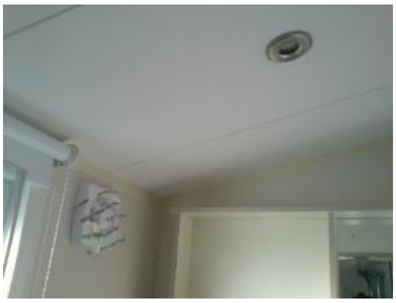
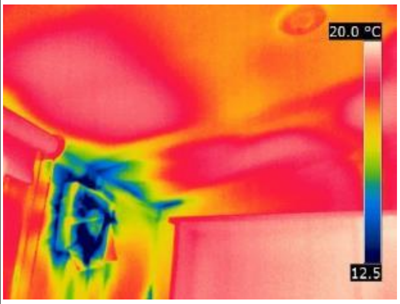
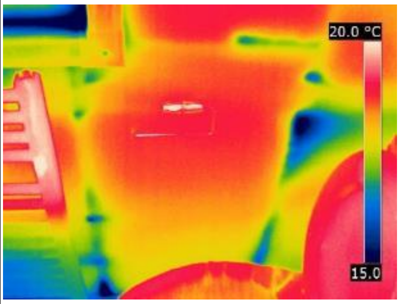
		Room – En-Suite Span – 5 °C
		Room – En-Suite Span – 7.5 °C
		Room – En-Suite Span – 5 °C
		Room – Side Bedroom Span – 7.5 °C
		Room – Side Bedroom Span – 7.5 °C

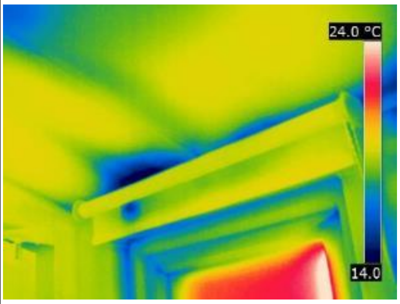
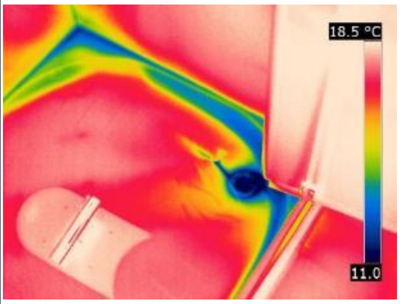
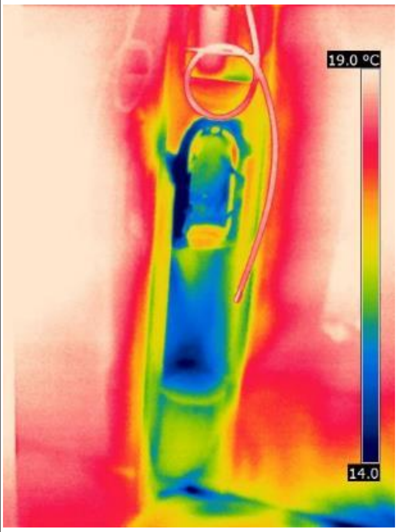
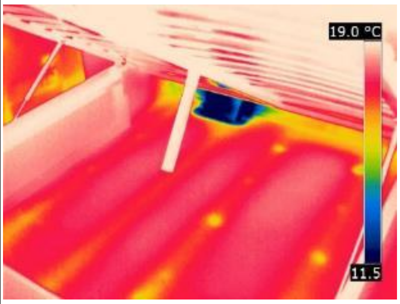
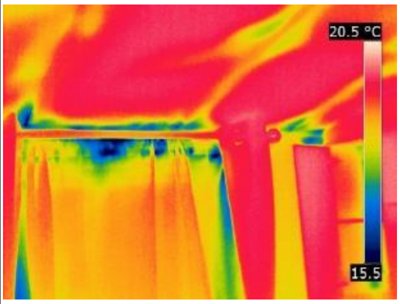
		Room – Side Bedroom Span – 7.5 °C
		Room – Boiler Span – 7.5 °C
		Room – Boiler Span – 7.5 °C
		
Caravan C – 18th February 2016 External temperature 6.7 °C, Internal mean temperature 18.1 °C, ΔT ≈ 11.4 °C		

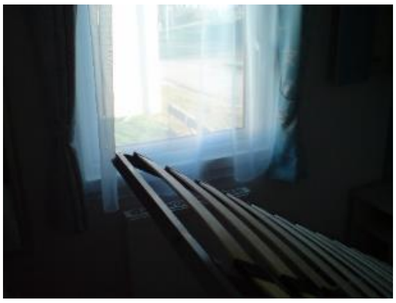
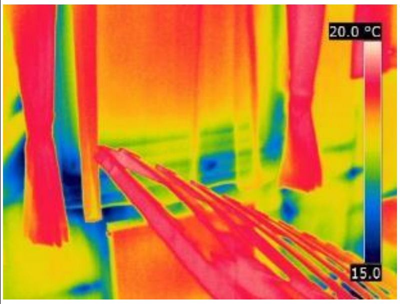
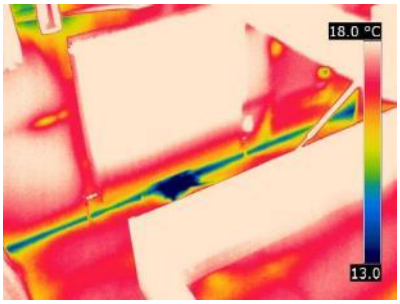
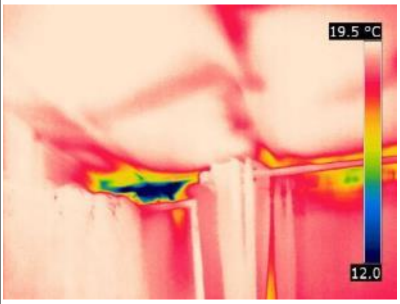
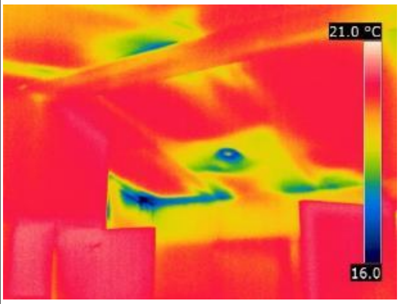
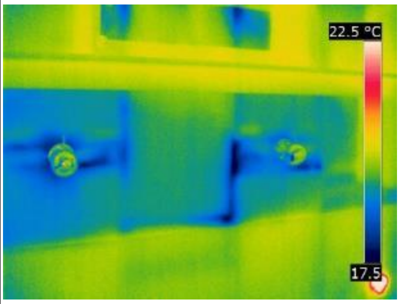
		Room – Lounge/Kitchen Span – 10 °C
		Room – Lounge/Kitchen Span – 7.5 °C
		Room – Lounge/Kitchen Span – 7.5 °C
		Room – Lounge/Kitchen Span – 7.5 °C
		Room – Lounge/Kitchen Span – 5 °C

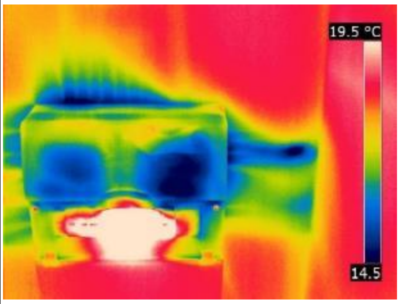
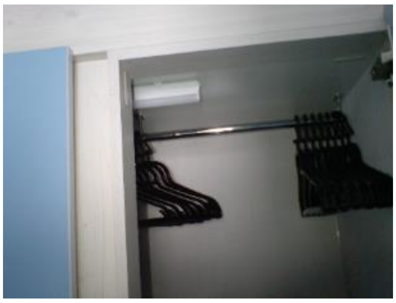
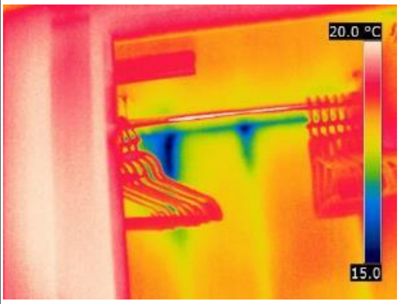
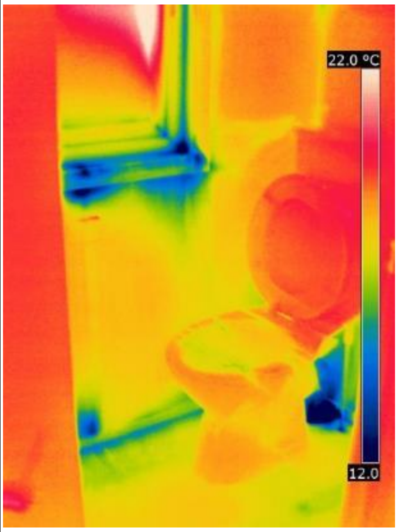
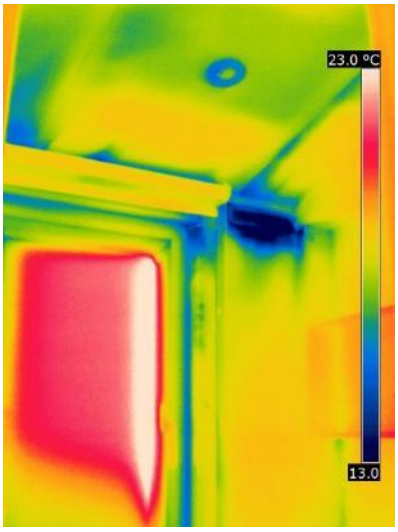
		Room – Lounge/Kitchen Span – 5 °C
		Room – Lounge/Kitchen Span – 5 °C
		Room – Lounge/Kitchen Span – 5 °C
		Room – Lounge/Kitchen Span – 7.5 °C

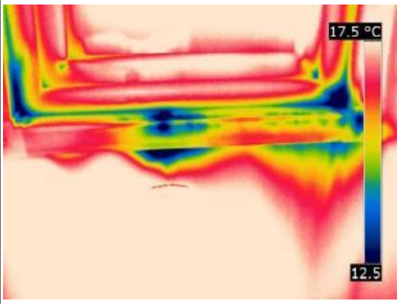
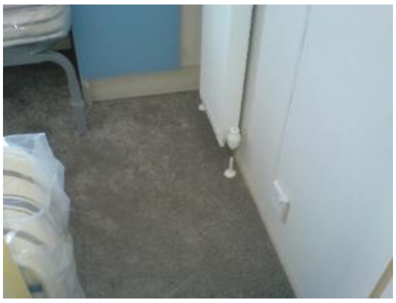
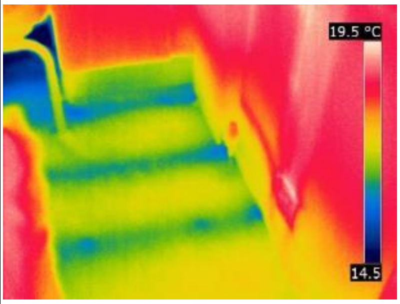
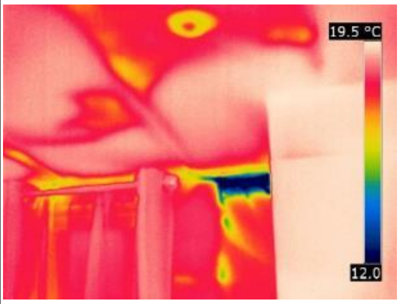
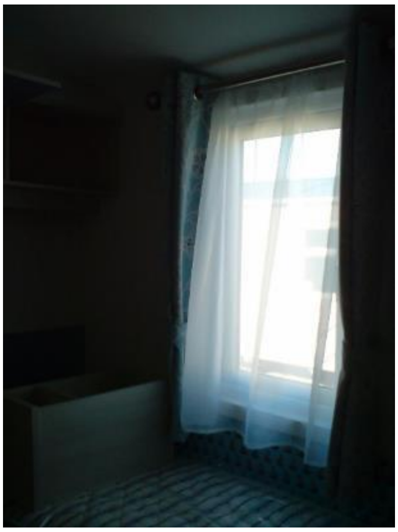
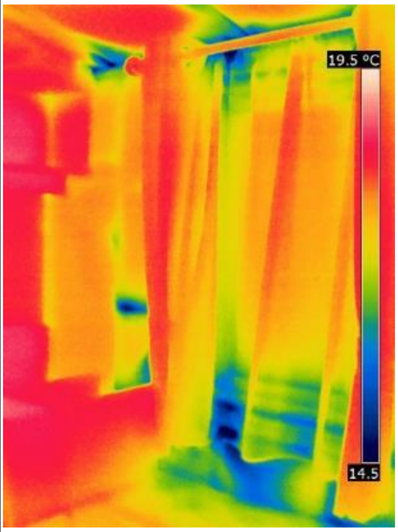
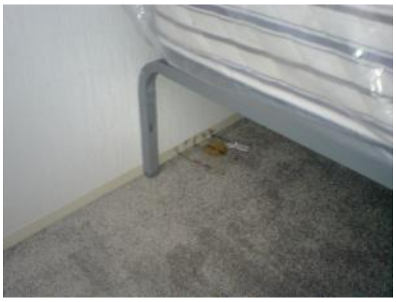
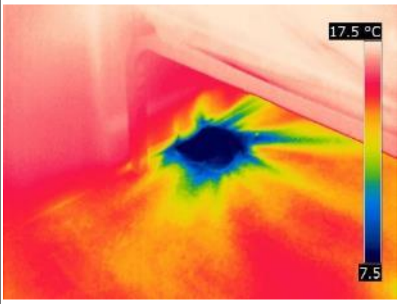
		Room – Lounge/Kitchen Span – 5 °C
		Room – Lounge/Kitchen Span – 5 °C
		Room – Lounge/Kitchen Span - 5°C
		Room – Lounge/Kitchen Span – 5 °C
		Room – Lounge/Kitchen Span – 5 °C

		Room – Corridor Span – 5 °C
		Room – Corridor Span – 5 °C
		Room – Bathroom Span – 10 °C
		Room – Bathroom Span – 7.5 °C
		Room – Bathroom Span – 5 °C

		Room – Bathroom Span – 10 °C
		Room – Bathroom Span – 7.5 °C
		Room – Bathroom Span – 5 °C
		Room – End Bedroom Span – 7.5 °C
		Room – End Bedroom Span – 5 °C

		Room – End Bedroom Span – 5 °C
		Room – End Bedroom Span – 5 °C
		Room – End Bedroom Span – 7.5 °C
		Room – End Bedroom Span – 5 °C
		Room – End Bedroom Span – 5 °C

		Room – End Bedroom Span – 5 °C
		Room – End Bedroom Span – 5 °C
		Room – En-Suite Span – 10 °C
		Room – En-Suite Span – 10 °C

		Room – En-Suite Span – 5 °C
		Room – Side Bedroom Span – 5 °C
		Room – Side Bedroom Span – 7.5 °C
		Room – Side Bedroom Span – 5 °C
		Room – Side Bedroom Span – 10 °C Temporary sealing film used to seal the floor vent did not form an effective seal on the carpet.

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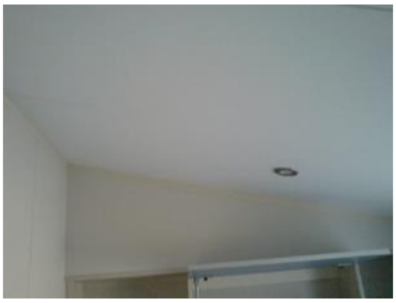
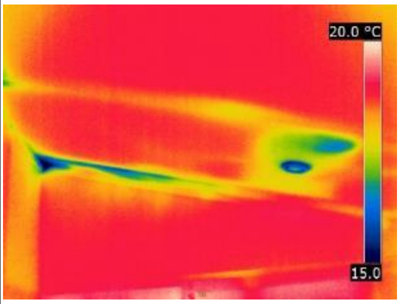
<tr><td></td><td>
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Span – 5 °C</td></tr>
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<tr><td colspan="3">Caravan D – 19th February 2016
External temperature 4.0 °C, Internal mean temperature 18.9 °C, ΔT ≈ 14.9 °C</td></tr>
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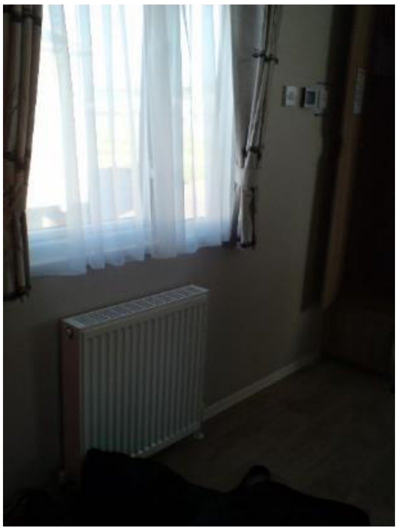
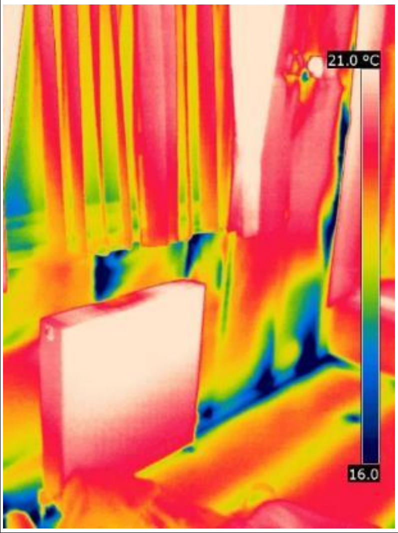
</td><td>Room – Lounge/Kitchen
Span – 7.5 °C</td></tr>
<tr><td></td><td>
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Span – 5 °C</td></tr>
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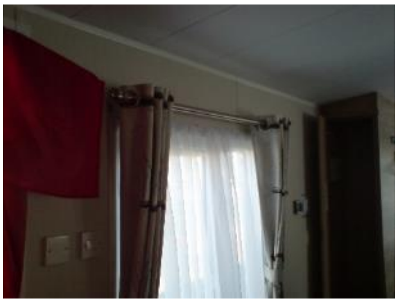
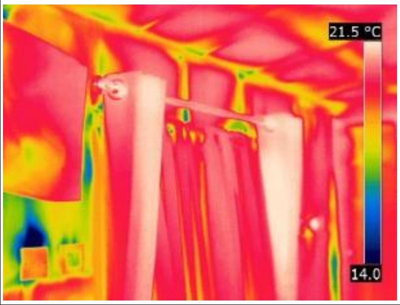
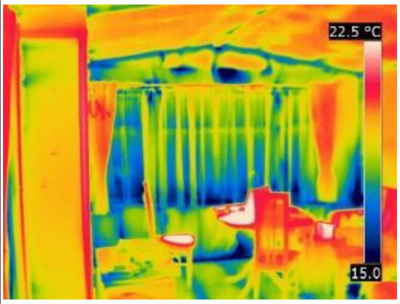
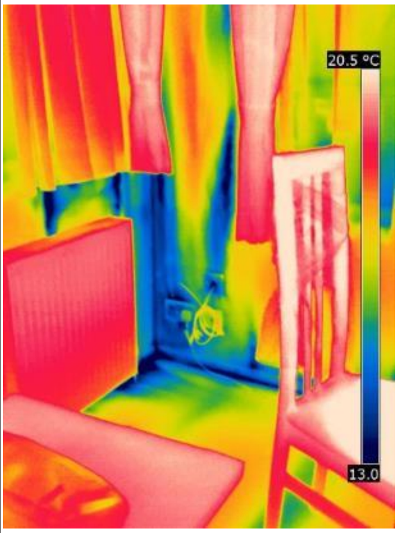
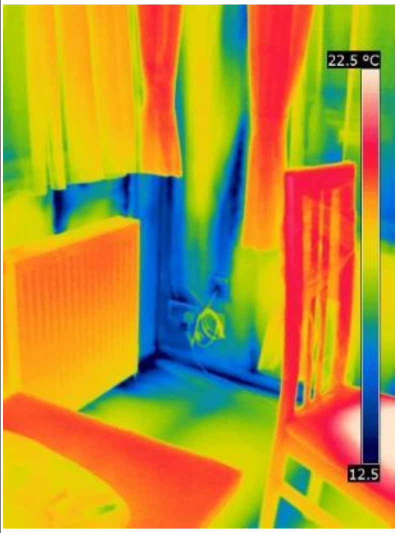
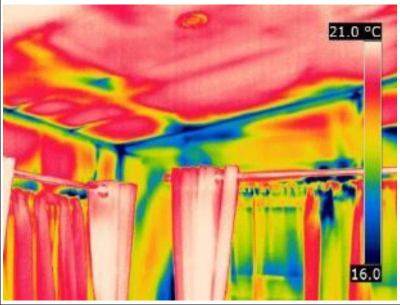
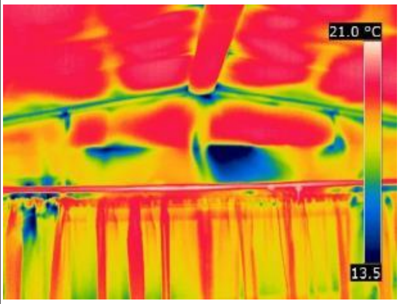
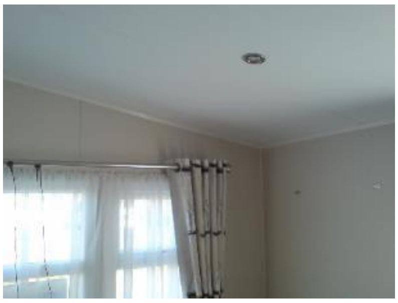
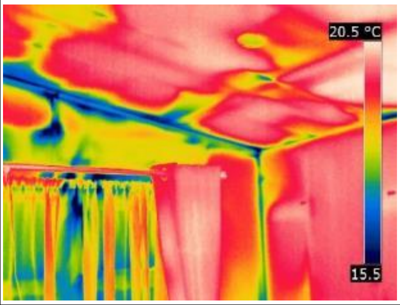
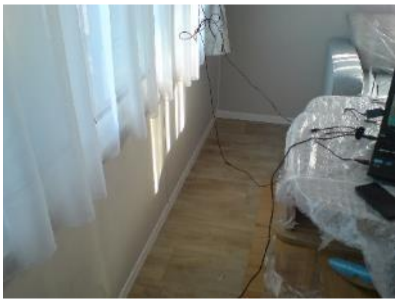
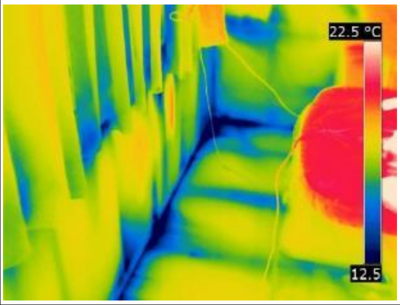
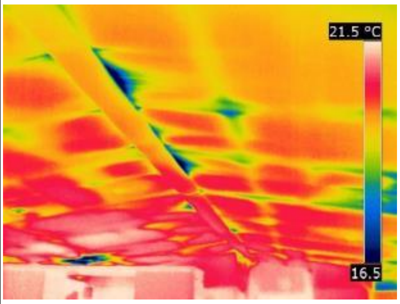
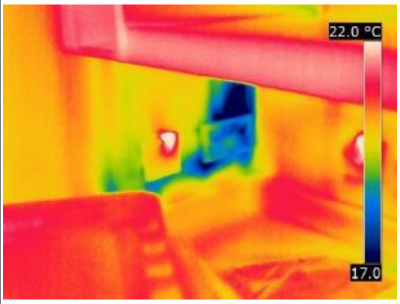
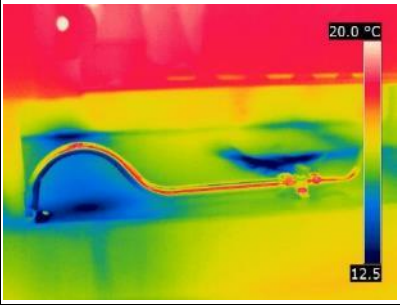
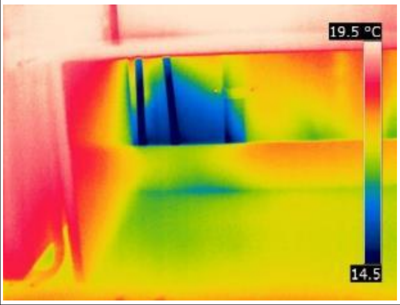
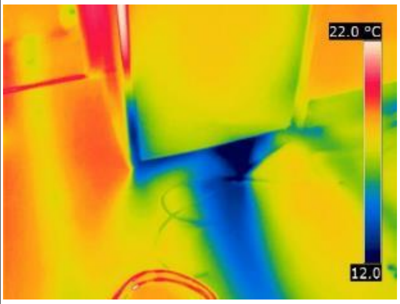
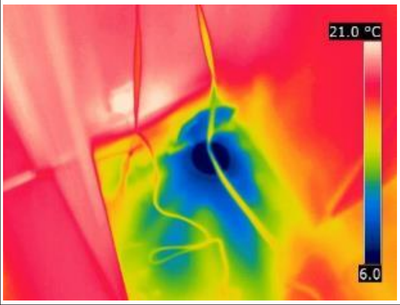
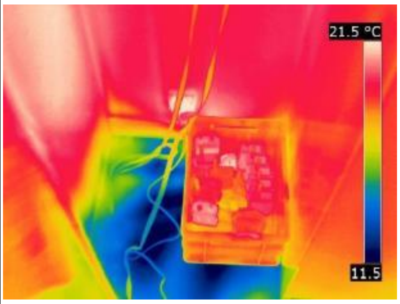
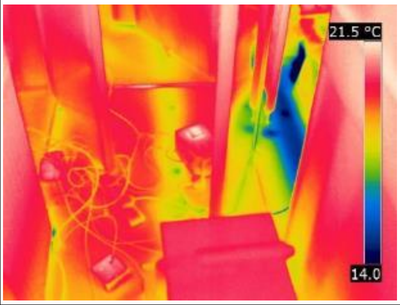
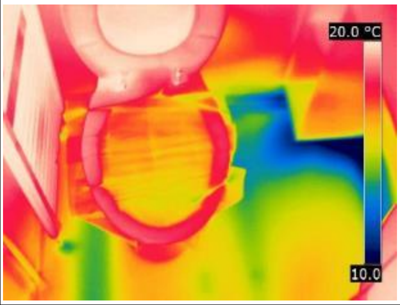
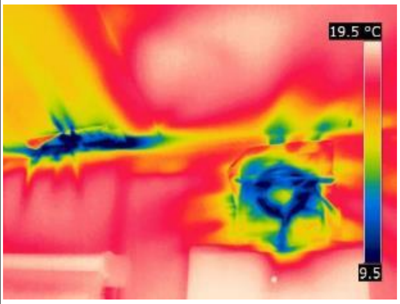
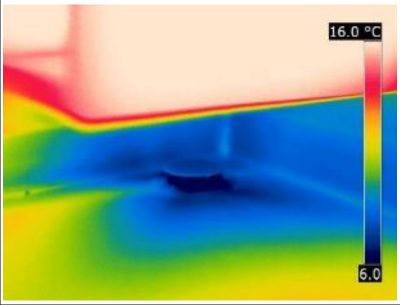
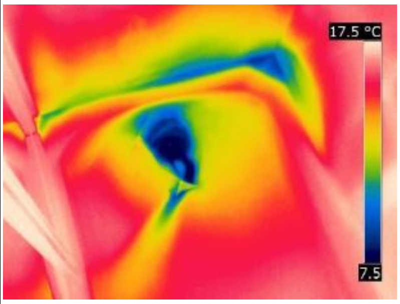
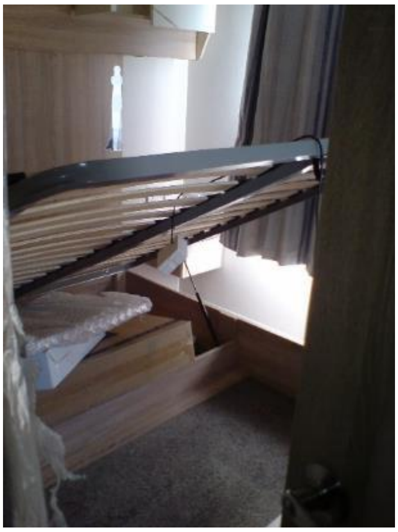
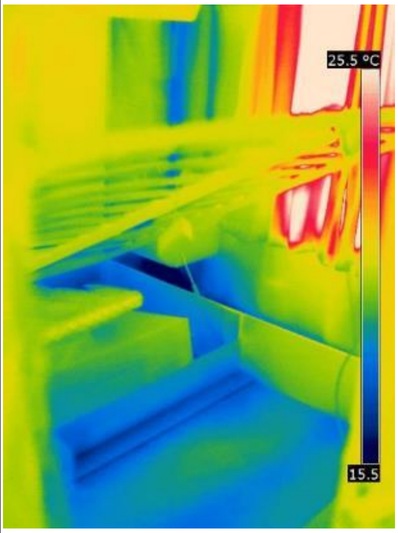
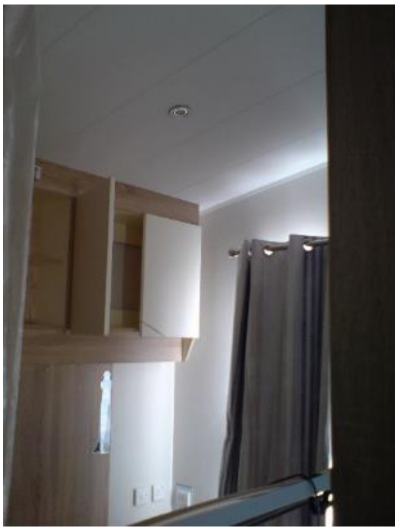
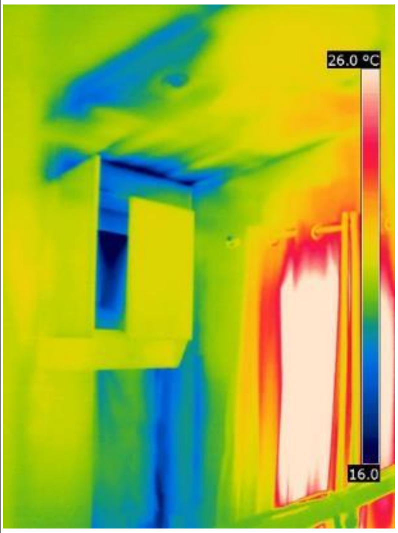
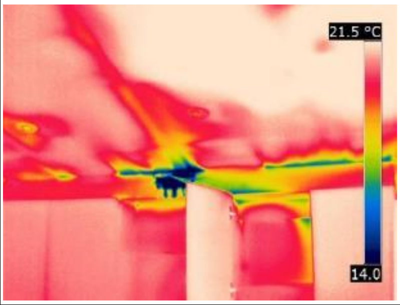
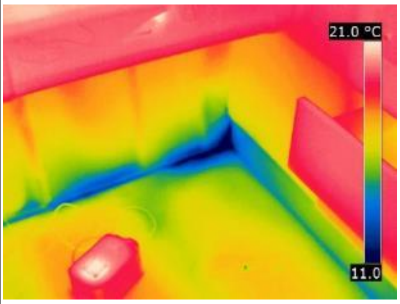
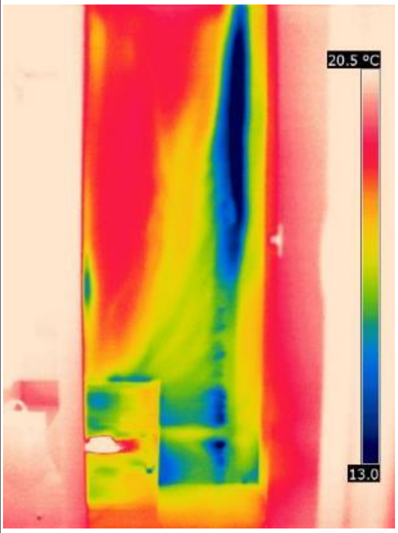
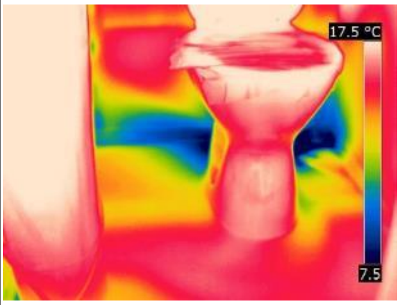
		Room – Lounge/Kitchen Span – 7.5 °C
		Room – Lounge/Kitchen Span – 7.5 °C
		Room – Lounge/Kitchen Span – 7.5 °C
		Room – Lounge/Kitchen Span – 10 °C

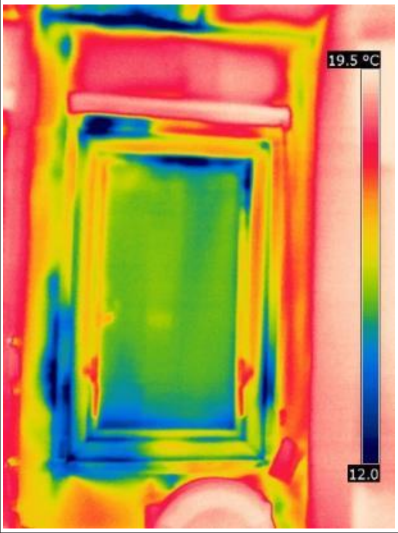
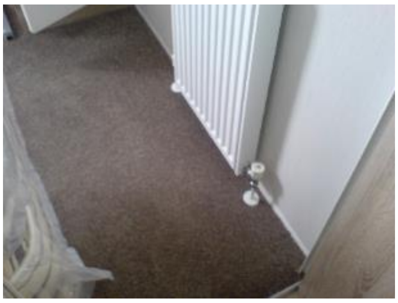
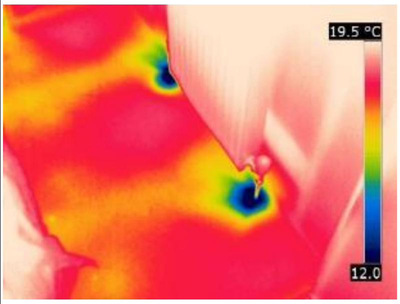
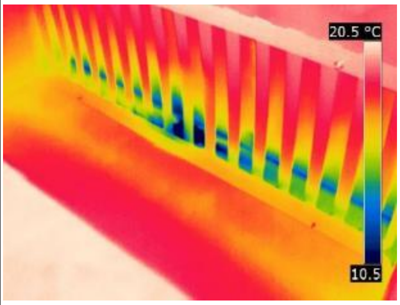
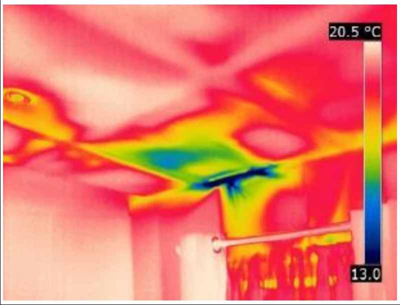
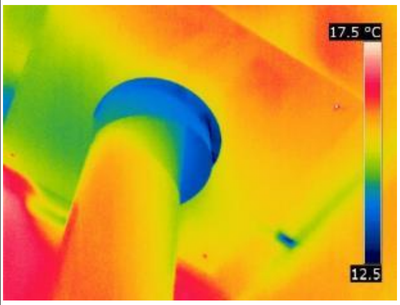
		Room – Lounge/Kitchen Span – 5 °C
		Room – Lounge/Kitchen Span – 7.5 °C
		Room – Lounge/Kitchen Span – 5 °C
		Room – Lounge/Kitchen Span – 10 °C
		Room – Lounge/Kitchen Span – 5 °C

		Room – Lounge/Kitchen Span – 7.5 °C
		Room – Lounge/Kitchen Span – 5 °C
		Room – Lounge/Kitchen Span – 7.5 °C
		Room – Lounge/Kitchen Span – 5 °C
		Room – Lounge/Kitchen Span – 10 °C Excessive air leakage observed from under the fridge.

		Room – Lounge/Kitchen Span – 15 °C Fridge removed to reveal the temporary sealing below the fridge had become displaced.
		Room – Lounge/Kitchen Span – 10 °C Temporary sealing over the grille was replaced and a box placed over the sealed grille to keep the seal in place and the test was re-run.
		Room – Corridor Span – 7.5 °C
		Room – Bathroom Span – 10 °C
		Room – Bathroom Span – 10 °C

		Room – Bathroom Span – 10 °C
		Room – Bathroom Span – 10 °C
		Room – End Bedroom Span – 10 °C Higher span in the thermal images in this room is due to direct sunlight creating warmer internal surface temperatures rather than cooler air emerging.
		Room – End Bedroom Span – 10 °C

		Room – End Bedroom Span – 7.5 °C
		Room – End Bedroom Span – 10 °C
		Room – End Bedroom Span – 7.5 °C
		Room – En-Suite Span – 10 °C

		Room – En-Suite Span – 7.5 °C
		Room – Side Bedroom Span – 7.5 °C
		Room – Side Bedroom Span – 10 °C
		Room – Side Bedroom Span – 7.5 °C
		Room – Boiler Span – 5 °C Daylight visible around the penetration for the boiler flue.

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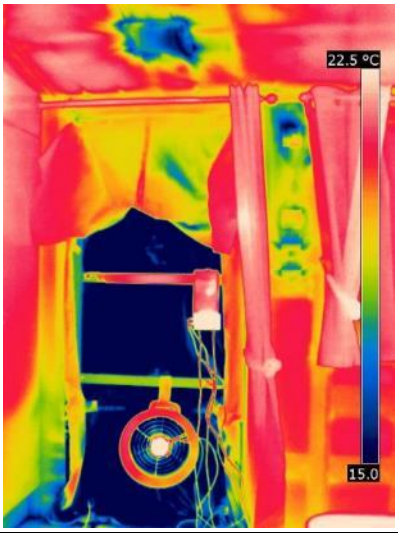
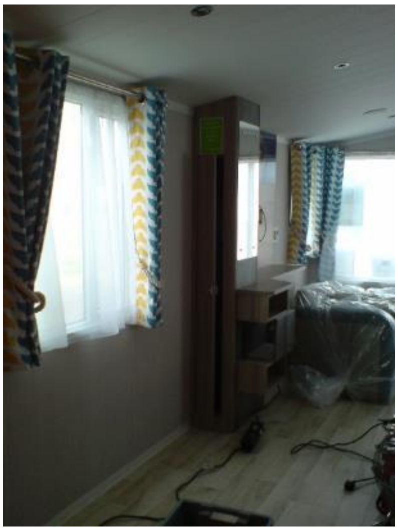
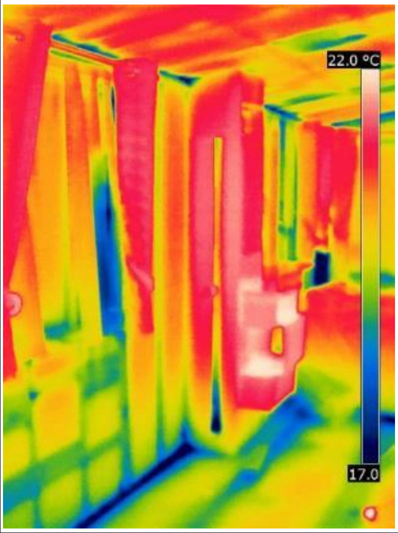
External temperature 4.0 °C, Internal mean temperature 20.0 °C, ΔT ≈ 16.0 °C</td></tr>
<tr><td></td><td>
</td><td>Room – Lounge/Kitchen
Span – 7.5 °C</td></tr>
<tr><td></td><td>
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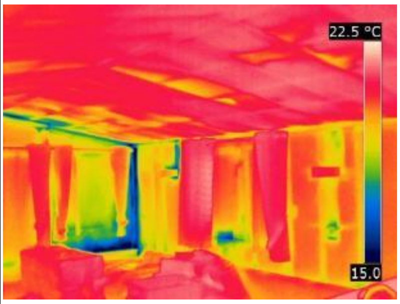
Span – 5 °C</td></tr>
<tr><td></td><td>
</td><td>Room – Lounge/Kitchen
Span – 7.5 °C</td></tr>
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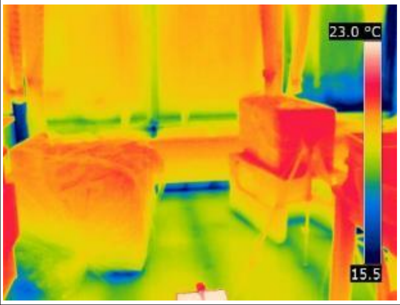
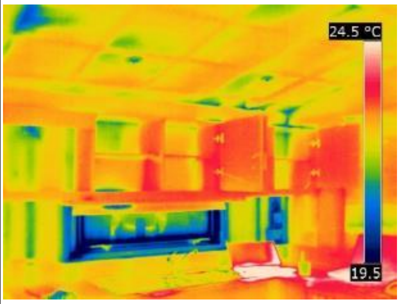


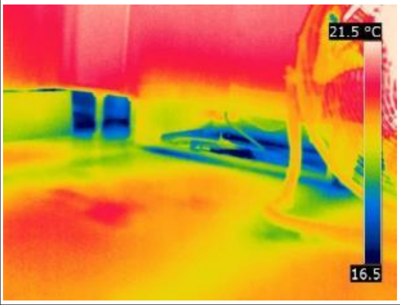
Room – Lounge/Kitchen

Span – 7.5 °C



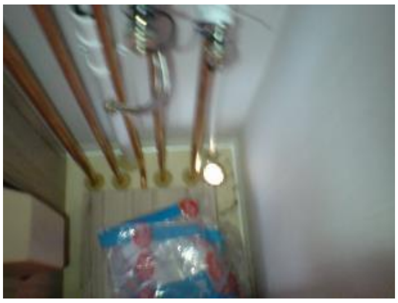
Room – Lounge/Kitchen

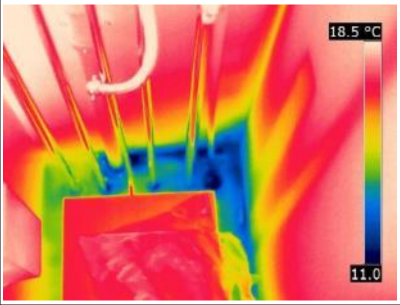
Span – 5 °C



Room – Lounge/Kitchen

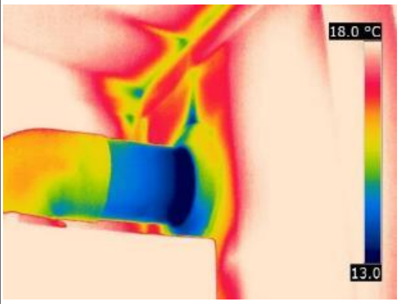
Span – 5 °C





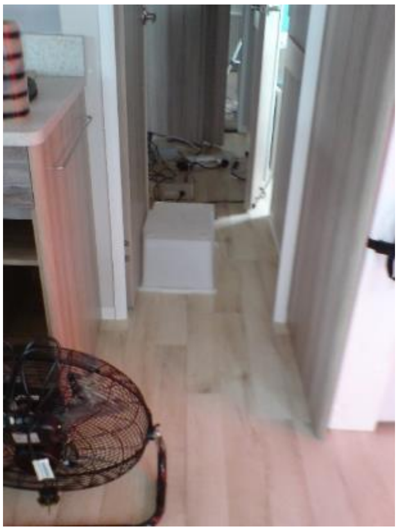
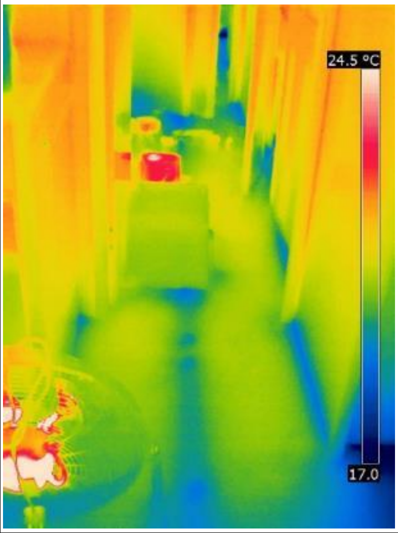
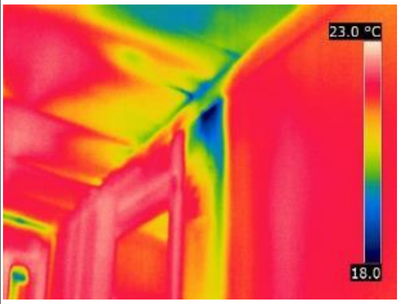
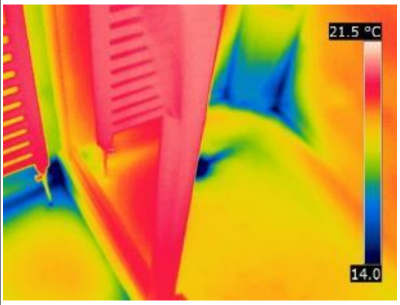
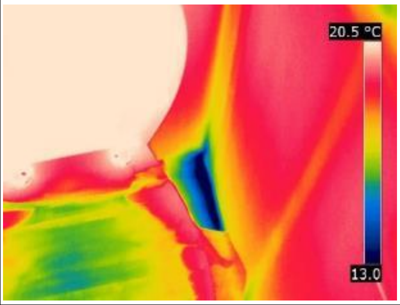
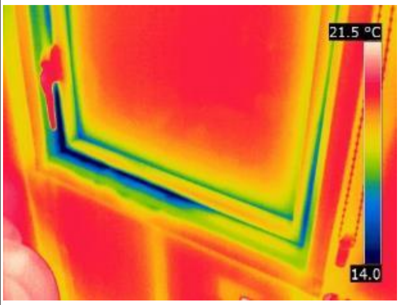
Room – Boiler

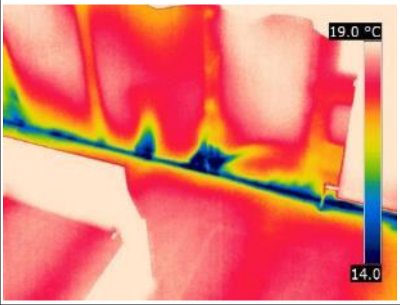
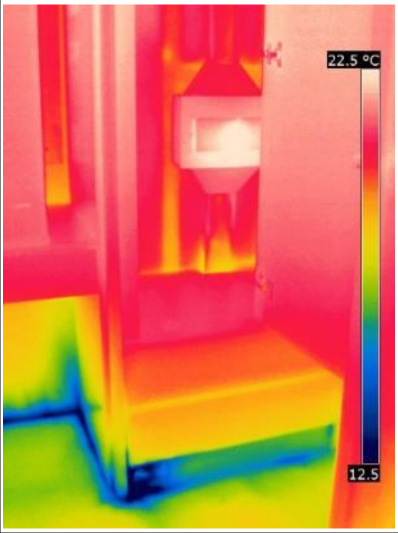
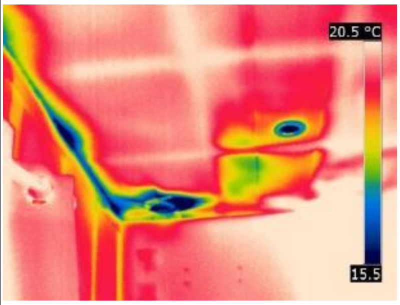
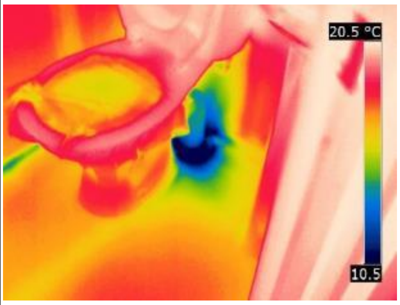
Span – 7.5 °C

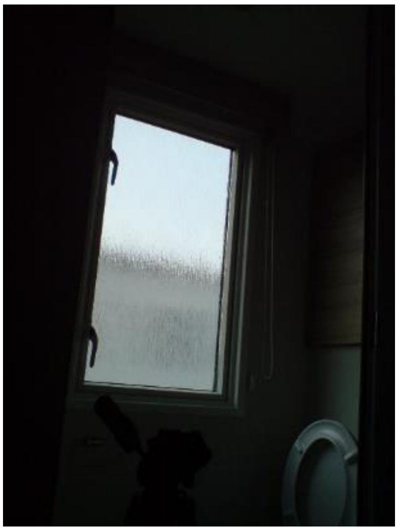
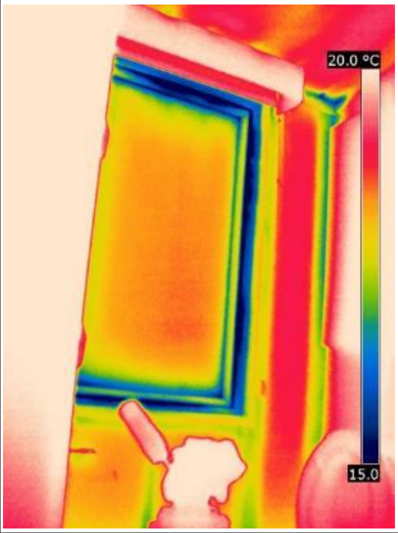
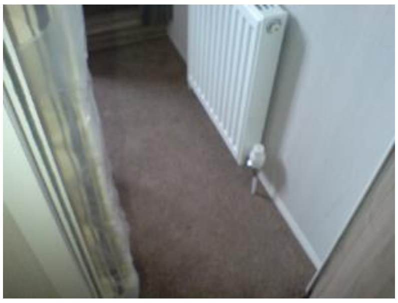
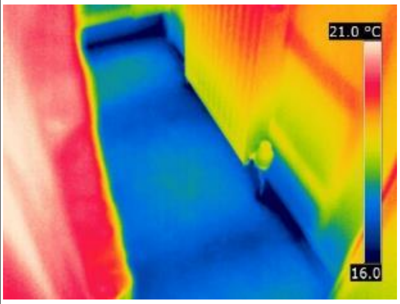
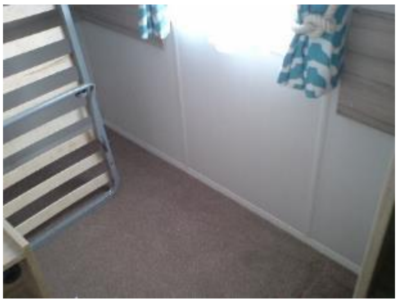
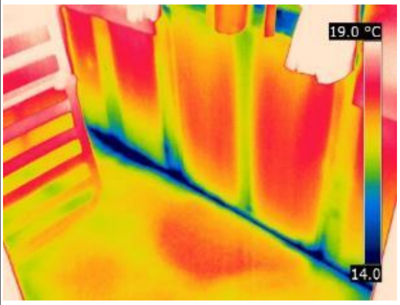
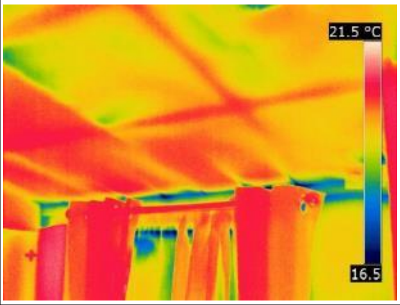


Room – Boiler

Span – 5 °C

		Room – Corridor Span – 7.5 °C
		Room – Corridor Span – 5 °C
		Room – Bathroom Span – 7.5 °C
		Room – Bathroom Span – 7.5 °C
		Room – Bathroom Span – 7.5 °C

		Room – End Bedroom Span – 5 °C
		Room – End Bedroom Span – 10 °C
		Room – End Bedroom Span – 5 °C
		Room – En-Suite Span – 10 °C

		Room – En-Suite Span – 5 °C
		Room – Side Bedroom Span – 5 °C
		Room – Side Bedroom Span – 5 °C
		Room – Side Bedroom Span – 5 °C

Appendix B

Thermal imaging survey conducted on the afternoon of 12th February 2016.

The thermal images listed below were captured under natural conditions, with no induced pressure differential, using a Flir B660 infrared thermal imaging camera. Unfortunately, some direct sunlight impinged on the caravans during the survey period. Consequently, areas when this had unduly affected the surface temperatures have been omitted from this report. An emissivity (ε) setting of 0.95 has been used throughout; this provides adequate interpolation of temperatures for most non-reflective surfaces, but the apparent surface temperatures of lower emissivity surfaces (e.g. glass and porcelain) may be misleading. The internal/external temperature differential (ΔT) ranged from 14.6 °C to 13.3 °C between tests, however there was some uneven heat distribution within rooms (such as cooler stagnant air beneath furniture); thus direct comparisons between the images below between caravans and within any caravan can only be done on a qualitative basis. All the thermal images have been adapted to a temperature span of a minimum of 5 °C. Where larger temperature spans have been adopted, it usually reflects more critical anomalies, including serious thermal bridges and direct air infiltration.

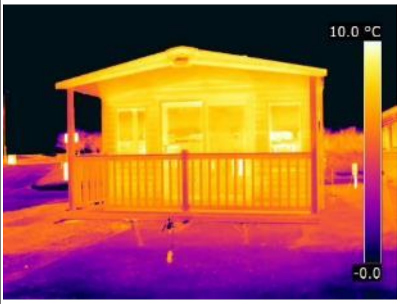
Thermal bridging and condensation risk:

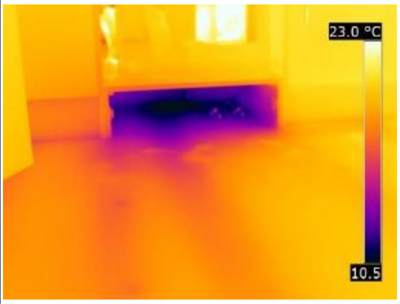
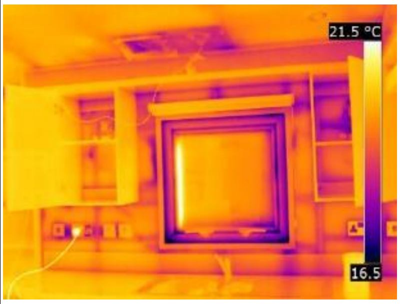
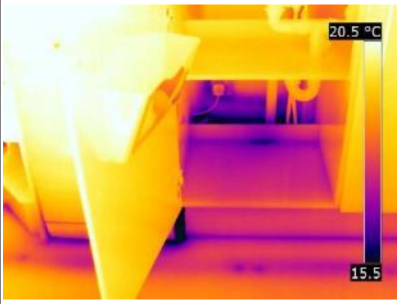
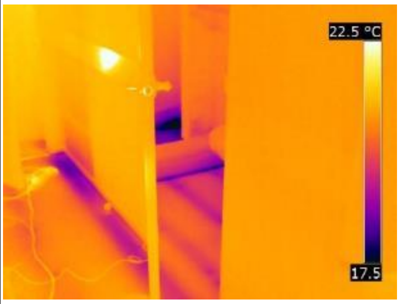
In steady state modelling, an unacceptable risk of surface condensation at a thermal bridge or anomaly occurs when the “Temperature Factor” drops below a value of 0.75.

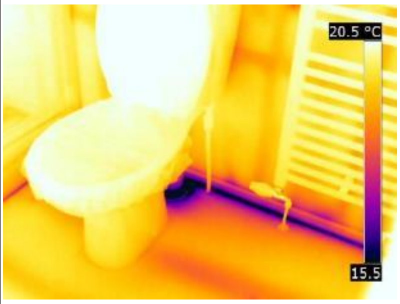
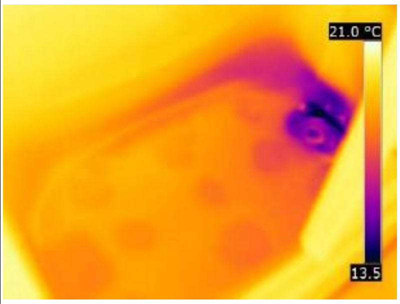
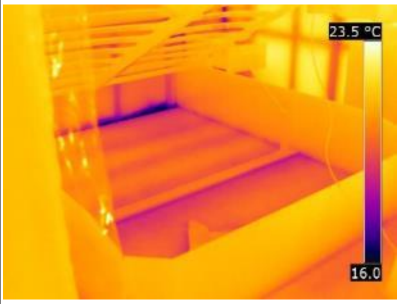
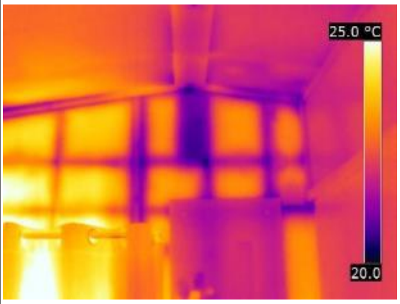
Temperature Factor → $\boldsymbol{f}_{Rsi} = \dfrac{(\mathbf{T}_{Surface} - \mathbf{T}_{ExtAmb})}{(\mathbf{T}_{IntAmb} - \mathbf{T}_{ExtAmb})}$ If $\boldsymbol{f}_{Rsi} < 0.75$, high risk of surface condensation

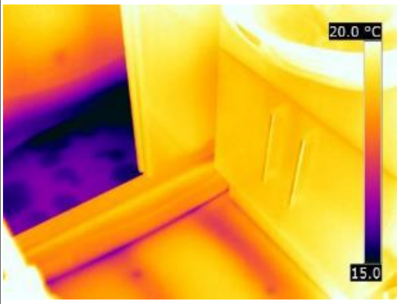
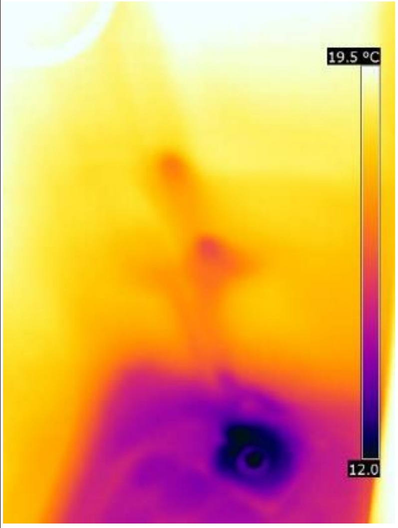
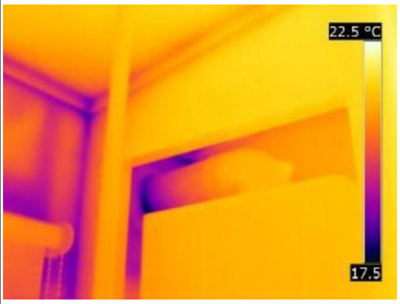
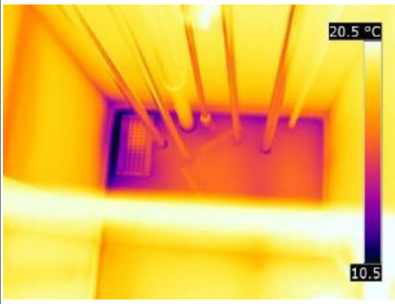
The electric coheating test creates quasi-steady state conditions which can roughly be equated to steady state conditions internally for the preceding few days. The thermal survey was undertaken when the external air temperature had remained within a 1 to 1.5 °C range over the immediately previous 3~5 hours. For each caravan surveyed, an internal surface temperature where $\boldsymbol{f}_{Rsi}$ <0.75 is listed. Internal surfaces below this temperature may indicate where there is a high risk of surface condensation, but whether condensation will actually occur is also dependent upon a number of other criteria (humidity, ventilation, etc.). However, particularly on the caravan floors, the lower temperatures observed in the images may be primarily due to cold air infiltration rather than thermal bridging.

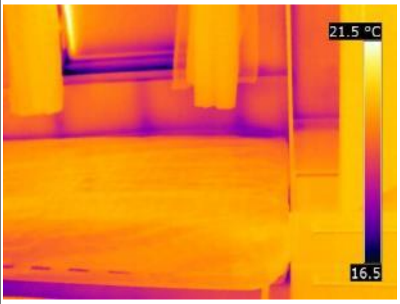
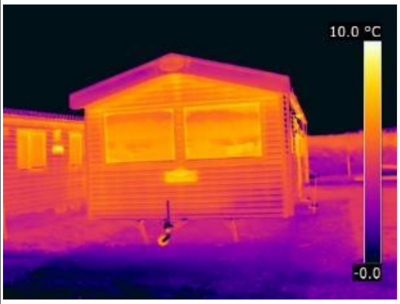
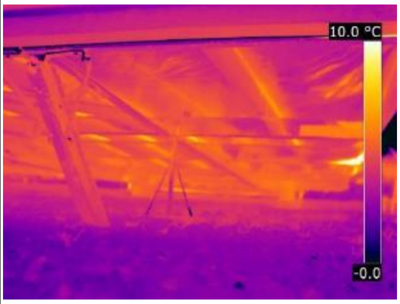
Caravan A External temperature 6.5 °C, Internal mean temperature 20.4 °C, ΔT ≈ 13.9 °C, $\boldsymbol{f}_{Rsi}$ < 0.75 @ 16.9 °C		
		External Span – 10 °C

		External Span – 10 °C
		Room – Lounge/Kitchen Span – 5 °C
		Room – Lounge/Kitchen Span – 5 °C
		Room – Lounge/Kitchen Span – 5 °C
		Room – Lounge/Kitchen Span – 5 °C

		Room – Lounge/Kitchen Span – 12.5 °C
		Room – Lounge/Kitchen Span – 5 °C
		Room – Lounge/Kitchen Span - 5 °C
		Room – Bathroom Span – 5 °C
		Room – Bathroom Span – 5 °C

		Room – Bathroom Span - 5 °C
		Room – Bathroom Span - 7.5 °C
		Room – End Bedroom Span – 7.5 °C
		Room – End Bedroom Span – 5 °C
		Room – End Bedroom Span – 5 °C

		Room – En-Suite Span - 5 °C
		Room – En-Suite Span - 7.5 °C
		Room – Boiler Span - 5 °C
		Room – Boiler Span – 10 °C
		Room – Side Bedroom Span – 5 °C

<table>
<tr><td></td><td></td><td>Room – Side Bedroom
Span – 5 °C</td></tr>
<tr><td></td><td></td><td>Room – Side Bedroom
Span – 5 °C</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td colspan="3">Caravan B
External temperature 6.5 °C, Internal mean temperature 19.8 °C, ΔT ≈ 13.3 °C, f_{Rsi} < 0.75 @ 16.4 °C</td></tr>
<tr><td></td><td></td><td>External
Span – 10 °C</td></tr>
<tr><td></td><td></td><td>External
Span – 10 °C</td></tr>
<tr><td></td><td></td><td>External
Span – 10 °C</td></tr>
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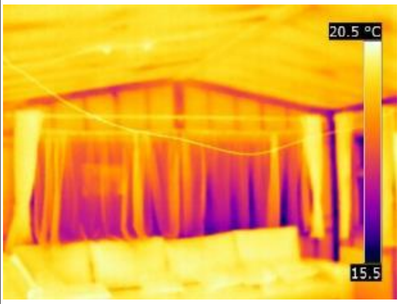
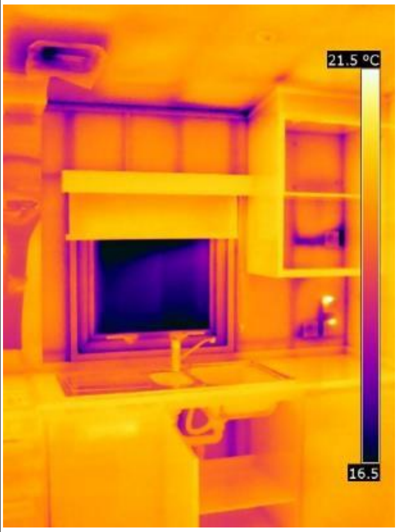
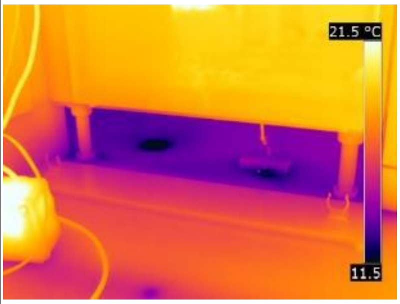
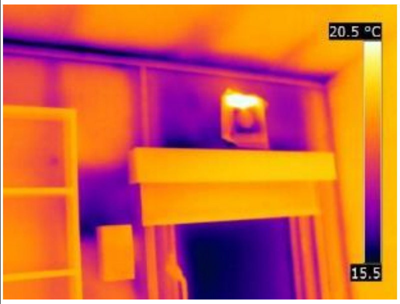
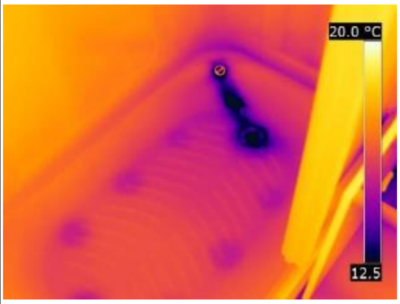
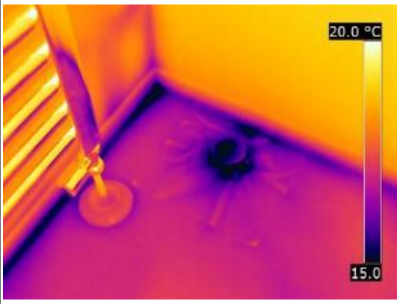
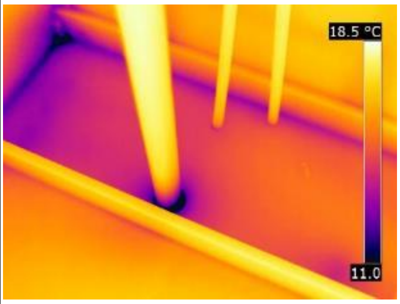
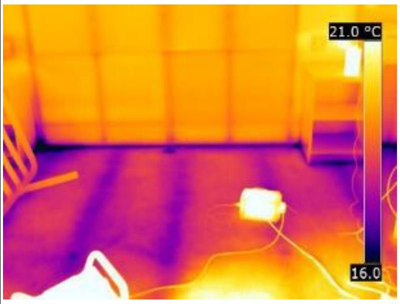
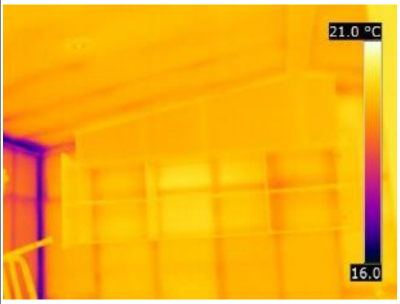
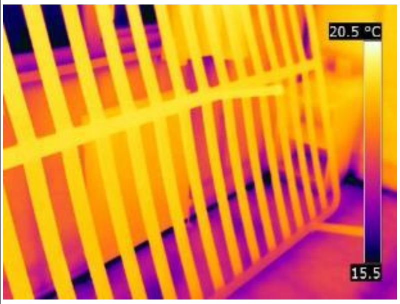
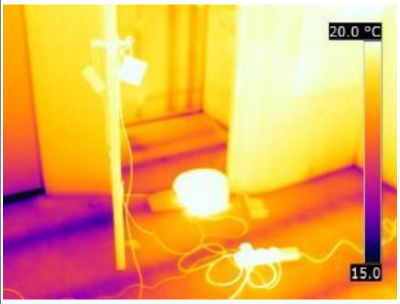
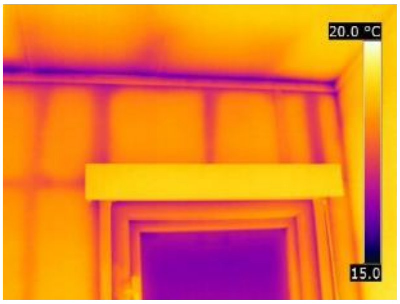
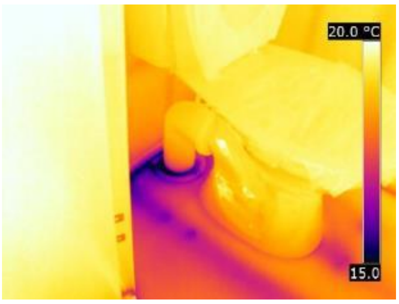
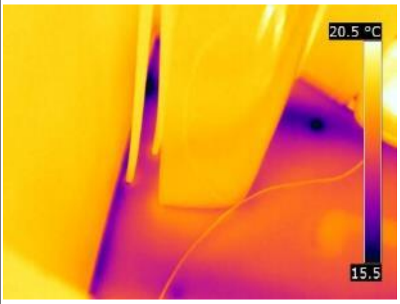
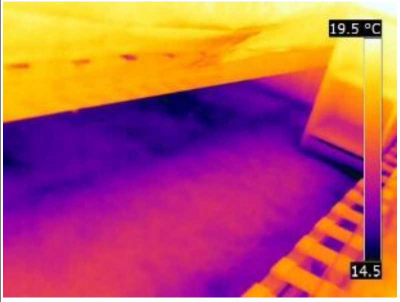
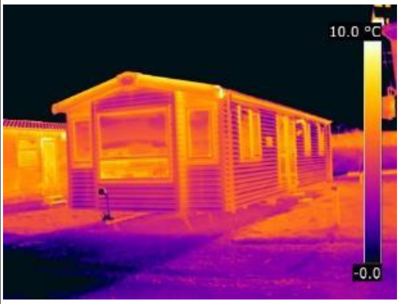
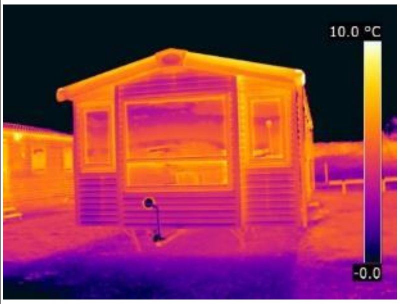
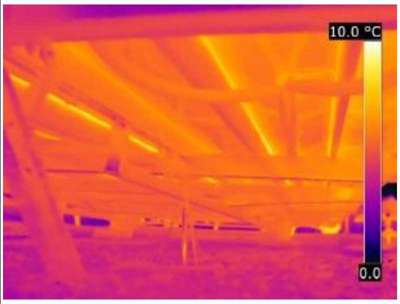
		Room – Lounge/Kitchen Span – 5 °C
		Room – Lounge/Kitchen Span – 7.5 °C
		Room – Lounge/Kitchen Span – 5 °C
		Room – Lounge/Kitchen Span – 5 °C
		Room – Lounge/Kitchen Span – 5 °C

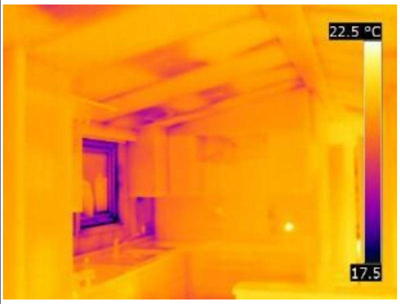
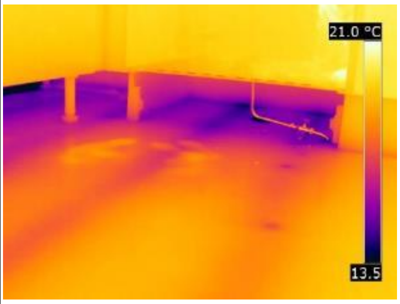
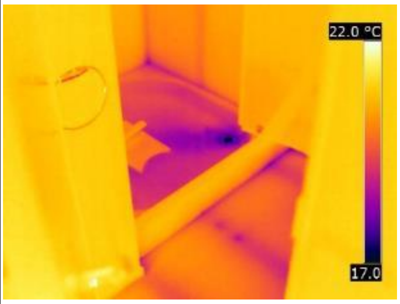
		Room – Lounge/Kitchen Span – 10 °C
		Room – Lounge/Kitchen Span – 5 °C
		Room – Corridor Span – 5 °C
		Room – Bathroom Span – 5 °C
		Room – Bathroom Span – 5 °C

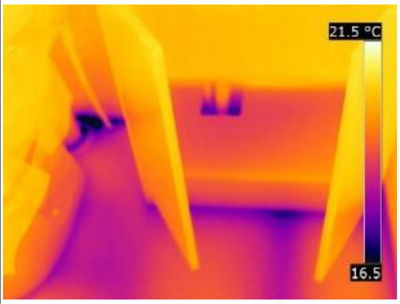
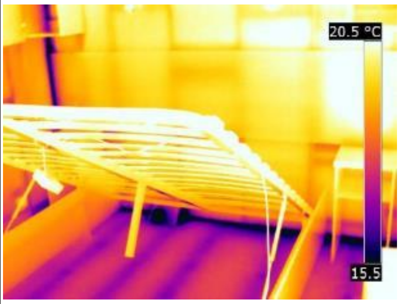
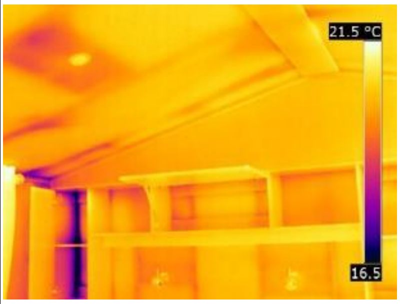
		Room – Bathroom Span – 7.5 °C
		Room – Bathroom Span – 5 °C
		Room – Bathroom Span – 7.5 °C
		Room – End Bedroom Span – 5 °C
		Room – End Bedroom Span – 5 °C

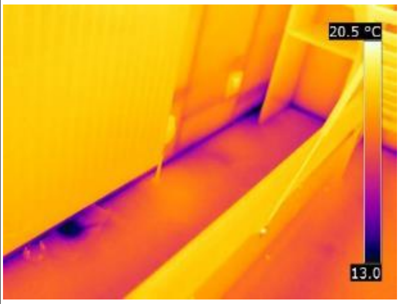
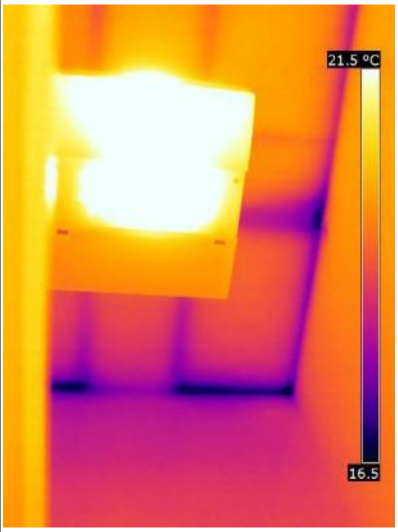
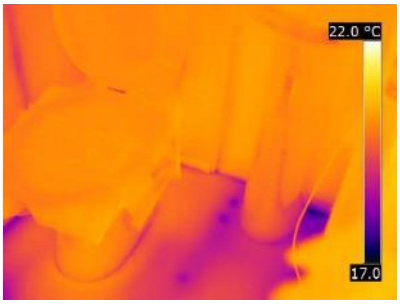
		Room – End Bedroom Span – 5 °C
		Room – End Bedroom Span – 5 °C
		Room – En-Suite Span – 5 °C
		Room – En-Suite Span – 5 °C
		Room – En-Suite Span – 5 °C

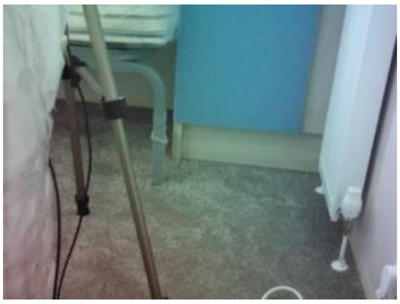
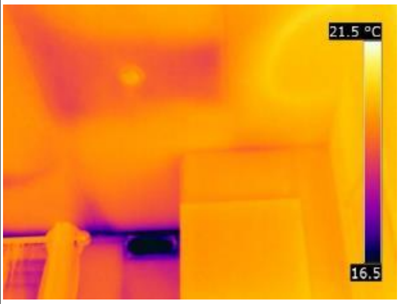
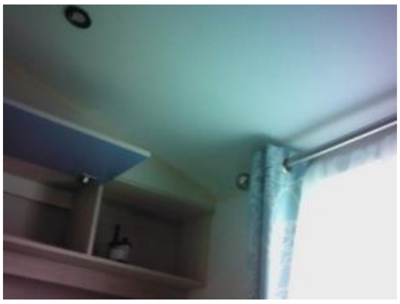
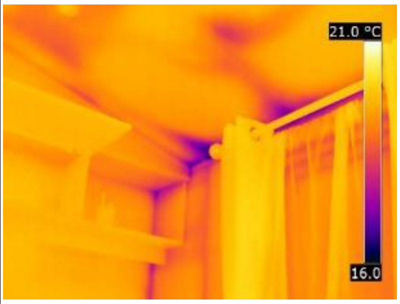
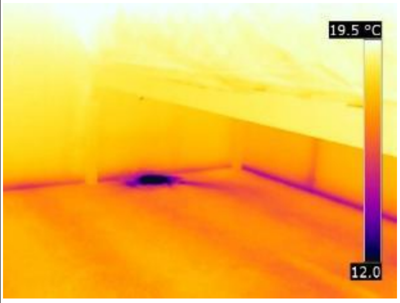
		Room – En-Suite Span – 5 °C
		Room – Side Bedroom Span – 5 °C
		Room – Side Bedroom Span – 5 °C
Caravan C External temperature 6.1 °C, Internal mean temperature 19.9 °C, ΔT ≈ 13.8 °C, f_{Rsi} < 0.75 @ 16.4 °C		
		External Span – 10 °C
		External Span – 10 °C

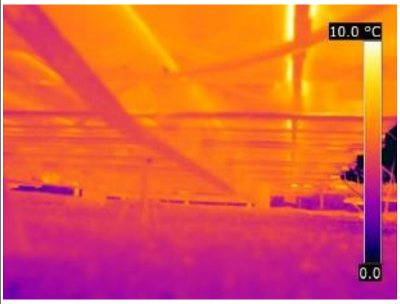
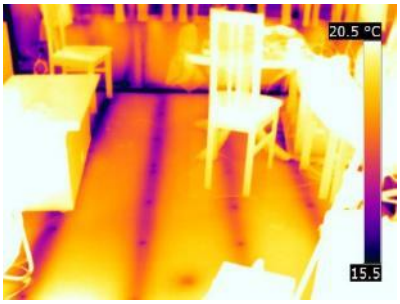
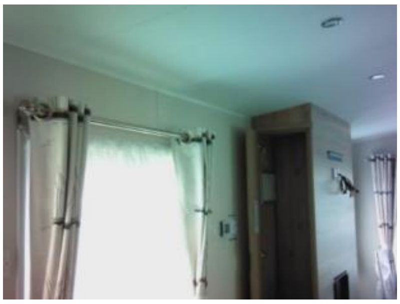
		External Span – 10 °C
		Room – Lounge/Kitchen Span – 5 °C
		Room – Lounge/Kitchen Span – 5 °C
		Room – Lounge/Kitchen Span – 5 °C
		Room – Lounge/Kitchen Span – 5 °C

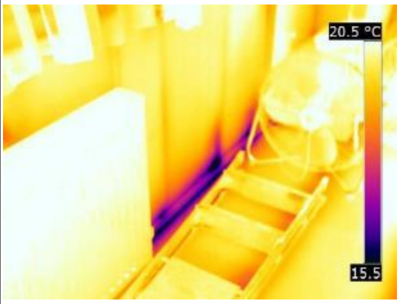
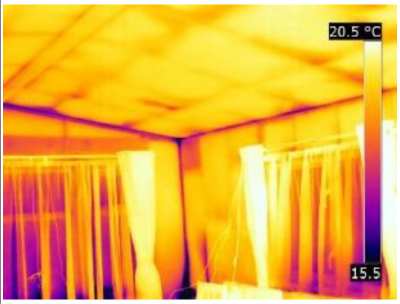
		Room – Lounge/Kitchen Span – 7.5 °C
		Room – Lounge/Kitchen Span – 5 °C
		Room – Lounge/Kitchen Span – 7.5 °C
		Room – Corridor Span – 5 °C
		Room – Bathroom Span – 5 °C

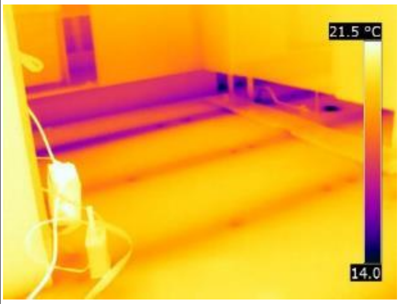
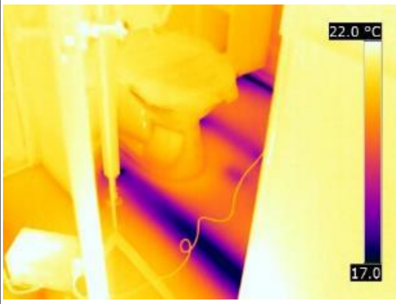
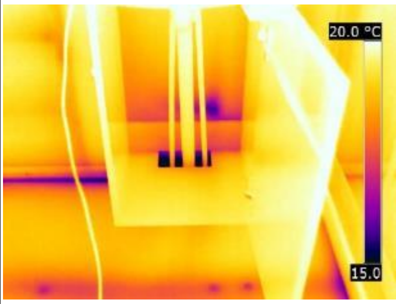
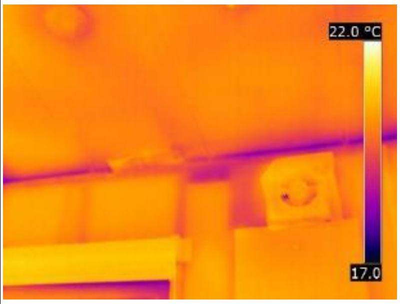
		Room – Bathroom Span – 7.5 °C
		Room – Bathroom Span – 5 °C
		Room – End Bedroom Span – 5 °C
		Room – End Bedroom Span – 5 °C
		Room – End Bedroom Span – 5 °C

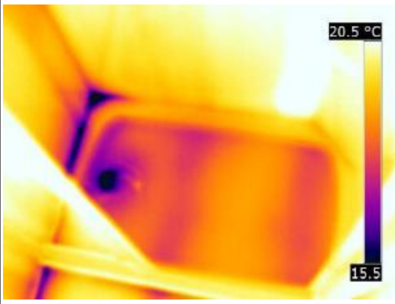
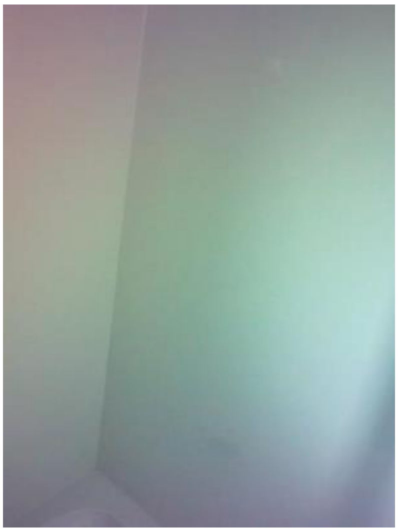
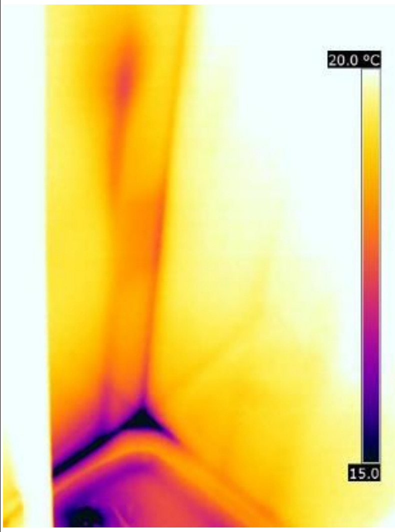
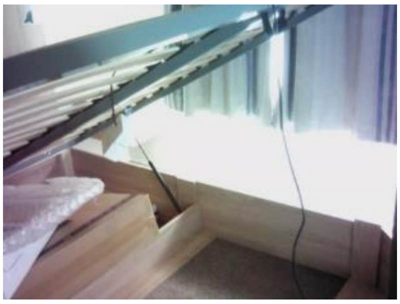
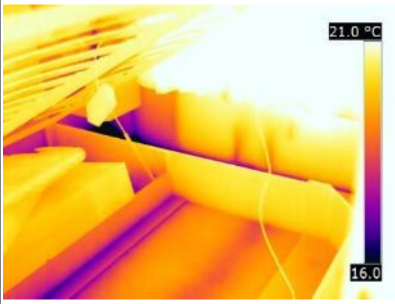
		Room – End Bedroom Span – 7.5 °C
		Room – End Bedroom Span – 5 °C
		Room – En-Suite Span – 5 °C
		Room – En-Suite Span – 5 °C
		Room – En-Suite Span – 5 °C

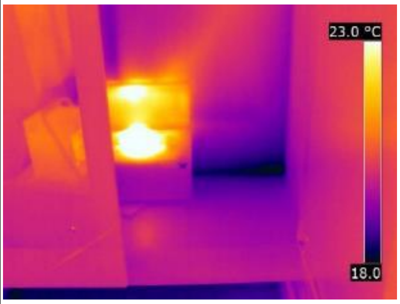
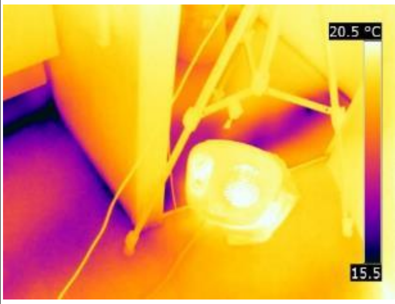
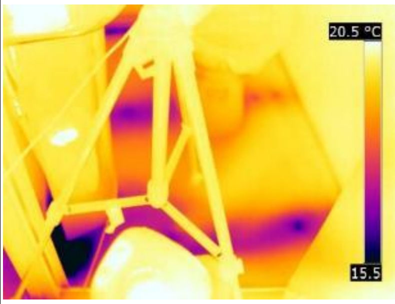
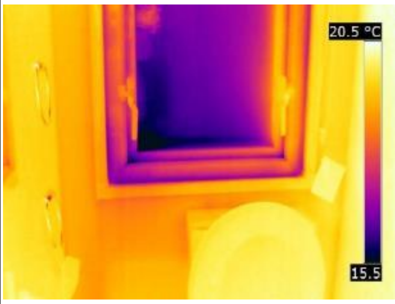
		Room – Side Bedroom Span – 5 °C
		Room – Side Bedroom Span – 5 °C
		Room – Side Bedroom Span – 5 °C
		Room – Side Bedroom Span – 7.5 °C
Caravan D External temperature 6.0 °C, Internal mean temperature 20.2 °C, ΔT ≈ 14.2 °C, f_{Rsi} < 0.75 @ 16.6 °C		
		External Span – 10 °C

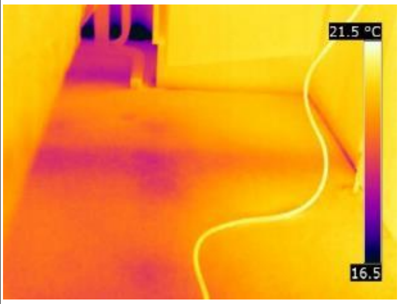
		External Span – 10 °C
		External Span – 10 °C
		Room – Lounge/Kitchen Span – 5 °C
		Room – Lounge/Kitchen Span – 5 °C
		Room – Lounge/Kitchen Span – 5 °C

		Room – Lounge/Kitchen Span – 5 °C
		Room – Lounge/Kitchen Span – 5 °C
		Room – Lounge/Kitchen Span – 7.5 °C
		Room – Lounge/Kitchen Span – 5 °C
		Room – Lounge/Kitchen Span – 5 °C

		Room – Lounge/Kitchen Span – 7.5 °C
		Room – Bathroom Span – 5 °C
		Room – Bathroom Span – 5 °C
		Room – Bathroom Span – 5 °C
		Room – Bathroom Span – 5 °C

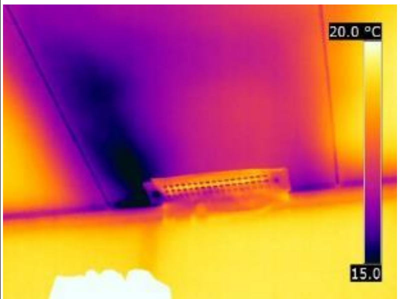
		Room – Bathroom Span – 5 °C
		Room – Bathroom Span – 5 °C
		Room – End Bedroom Span – 5 °C
		Room – End Bedroom Span – 5 °C
		Room – End Bedroom Span – 5 °C

		Room – End Bedroom Span – 5 °C
		Room – En-Suite Span – 5 °C
		Room – En-Suite Span – 5 °C
		Room – En-Suite Span – 5 °C
		Room – En-Suite Span – 5 °C



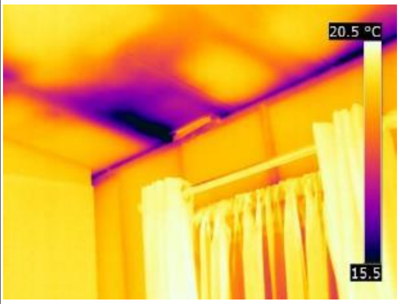
Room – Side Bedroom

Span – 5 °C



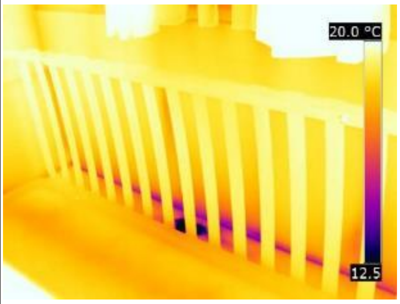
Room – Side Bedroom

Span – 5 °C



Room – Side Bedroom

Span – 5 °C

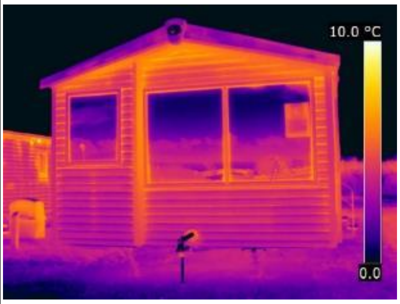
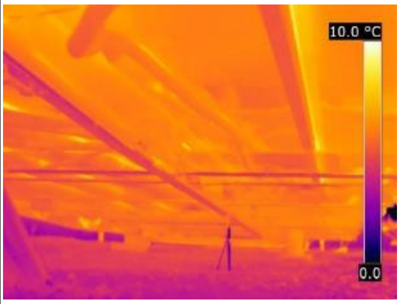
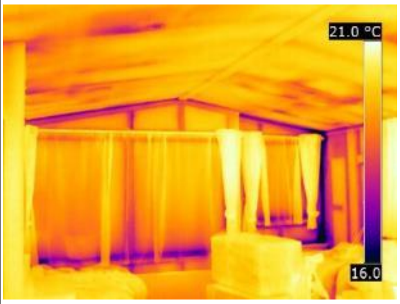
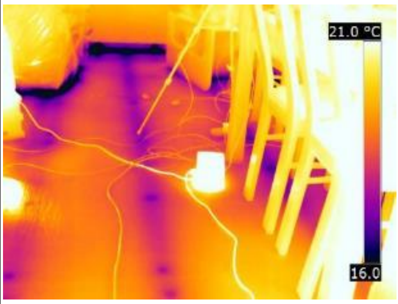


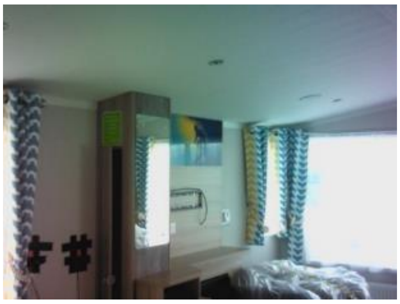
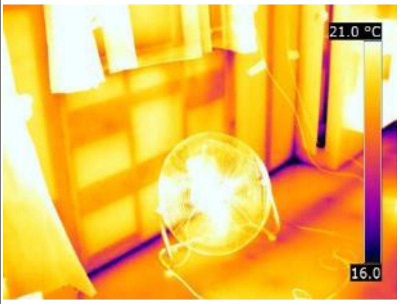
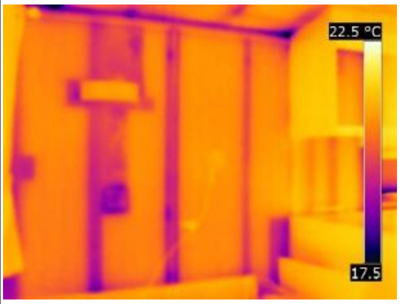
Room – Side Bedroom

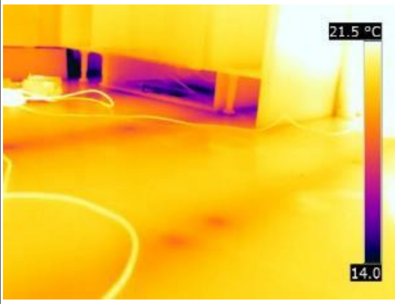
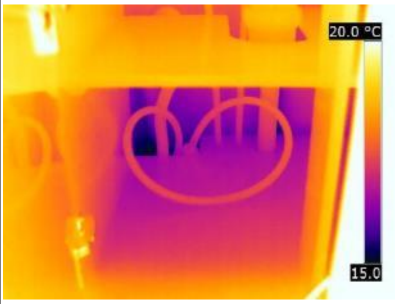
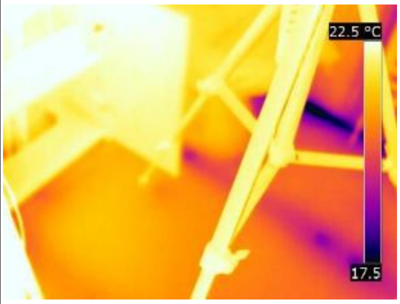
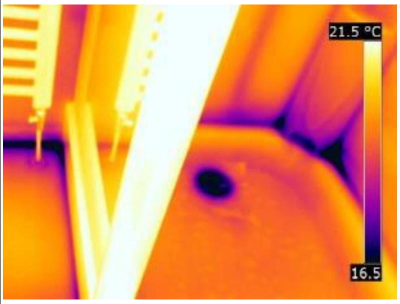
Span – 7.5 °C

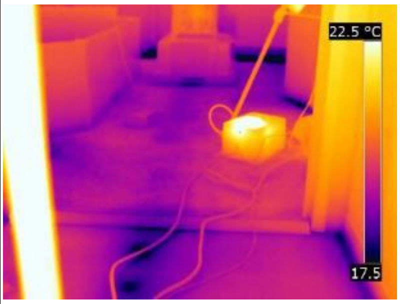
Room – Boiler

Span – 7.5 °C

Caravan E External temperature 6.1 °C, Internal mean temperature 20.7 °C, ΔT ≈ 13.6 °C, f_{Rsi} < 0.75 @ 17.0 °C		
		External Span – 10 °C
		External Span – 10 °C
		External Span – 10 °C
		Room – Lounge/Kitchen Span – 5 °C
		Room – Lounge/Kitchen Span – 5 °C

		Room – Lounge/Kitchen Span – 5 °C
		Room – Lounge/Kitchen Span – 5 °C
		Room – Lounge/Kitchen Span – 5 °C
		Room – Lounge/Kitchen Span – 5 °C
		Room – Lounge/Kitchen Span – 5 °C

		Room – Lounge/Kitchen Span – 7.5 °C
		Room – Lounge/Kitchen Span – 5 °C
		Room – Bathroom Span – 7.5 °C
		Room – Bathroom Span – 5 °C
		Room – Bathroom Span – 5 °C

		Room – End Bedroom Span – 5 °C
		Room – End Bedroom Span – 7.5 °C
		Room – End Bedroom Span – 7.5 °C
		Room – End Bedroom Span – 7.5 °C
		Room – En-Suite Span – 7.5 °C

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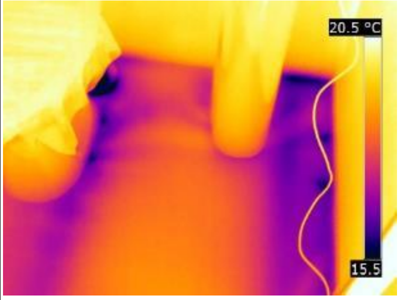
<tr><td></td><td>
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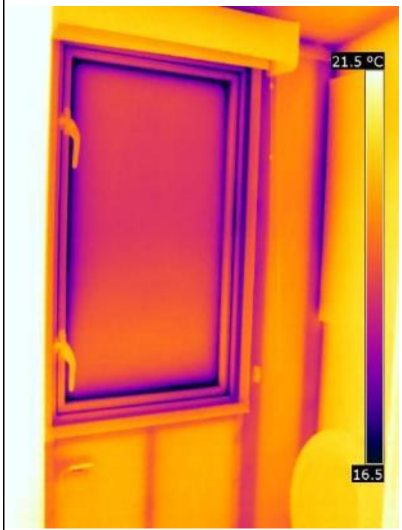
Span – 5 °C</td></tr>
<tr><td></td><td>
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</td><td>Room – En-Suite
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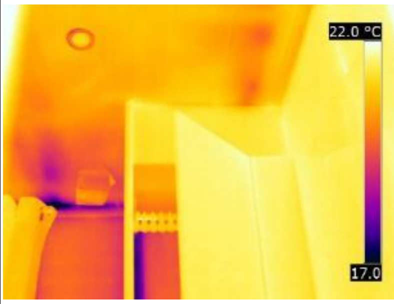
<tr><td></td><td>
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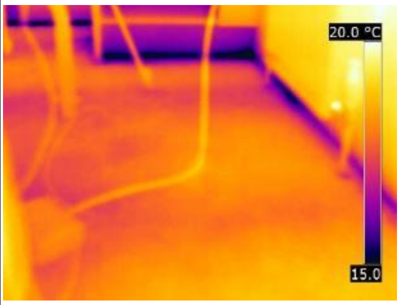
<tr><td></td><td>
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Span – 5 °C</td></tr>
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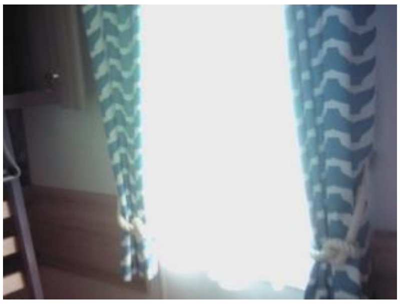
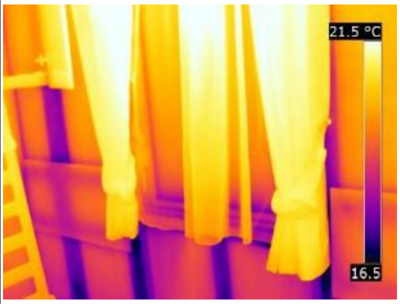
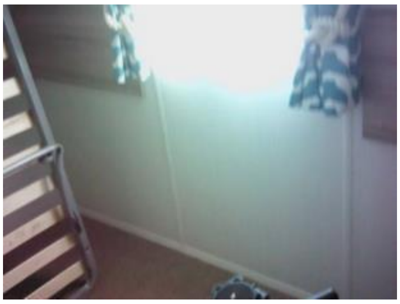
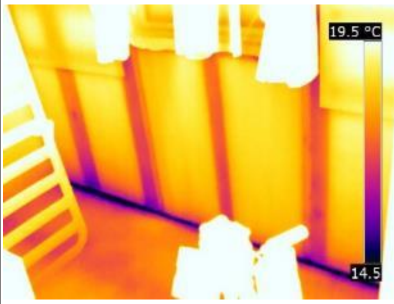
		Room – Side Bedroom Span – 5 °C
		Room – Side Bedroom Span – 5 °C
		Room – Side Bedroom Span – 5 °C