Investigation into the *in situ* thermal performance of 2 static caravans - Assessing the change in heat loss behaviour due to thermally superior replacement windows.

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Introduction

The purpose of this investigation is to assess the *in situ* thermal performance of upgraded replacement windows and door installed into a static caravan located at the Blue Dolphin Holiday Park, Filey, North Yorkshire.

Two static caravans were supplied by Camden Group to the research team within the Centre for the Built Environment (CeBE) Group at Leeds Beckett University for an initial 1 week period. One caravan (Unit 10) was to be tested over the entire period as a control, with no interventions made to the van; the second van (Unit C05) was due to be tested for 2 nights in its original state followed by a further 2 nights with its original windows and door replaced with higher specification replacements. Supply issues with the door resulted in this test programme being extended and a 3-stage test being performed. Details of the tests are outlined below in Table 1.

Table 1: Test Programme

Date	Action
16-Mar-2015	Install & set-up test equipment Initial airtightness tests Commence coheating stage 1
18-Mar-2015	Replacement of windows in Unit C05 Thermal imaging Airtightness test of C05 with replacement windows Download coheating stage 1 data Commence coheating stage 2
20-Mar-2015	Replacement of door in Unit C05 Thermal imaging Airtightness test of C05 with replacement door Download coheating stage 2 data Commence coheating stage 3
24-Mar-2015	Download coheating stage 3 data Uninstall test equipment

During the test period measurements of the internal and external temperatures were recorded, along with the power consumption required to maintain that temperature difference. These measurements enabled a metric for the whole caravan heat loss to be determined, namely the heat loss coefficient (HLC) in W/K. Additionally, the heat flow through a number of different fabric elements (glazed elements, roof, walls and floor) was also measured in W/m^2. The value of undertaking both sets of measurements is that a comparison can be made between the two datasets. Consequently, any changes in performance pre- and post-intervention should be reflected in both sets of measurements (power consumption and aggregate elemental heat flow), thus providing a degree of cross-validation between the two sets of results obtained.

Thermal Imaging

Method

Thermal imaging was performed at various stages throughout the investigation using a Flir B620 Infra-Red Thermal Imaging Camera. Images contained within this section were captured under a natural pressure differential between the inside and outside of the caravans. A selection of thermal images captured under depressurisation is included in the Airtightness section of this report. A full list of all the thermal images captured during this investigation can be found in Appendix 2 - Images 16-Mar-2015 3 & 4.

Discussion

Figure 1 & Figure 2 show the original and replacement windows in C05. In both examples the thermal images were captured on arrival at the site (on the 18th and 20th March respectfully) prior to any other access being gained to the caravan that morning. Additionally, both sets of thermal images were set to a temperature span of 5 °C to allow better direct comparisons to be made between them. The difference in surface temperature, and hence heat loss, due to the replacement glazing is stark; the surface temperatures of the original glazing were the lowest observable temperatures in the images, indicating the maximum heat loss and the first or most likely areas to foster surface condensation.

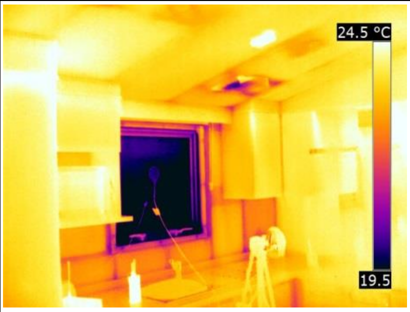
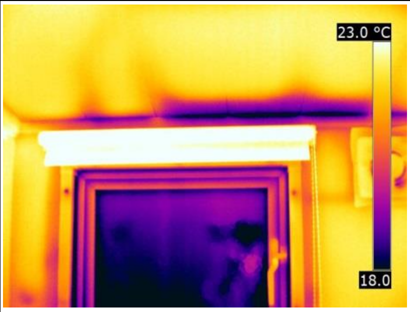
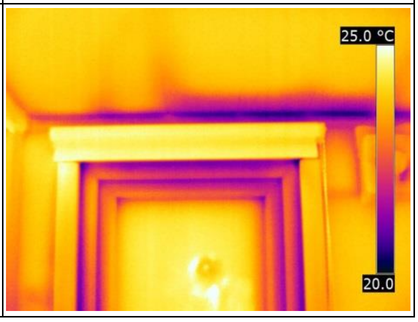
	Original Window 18-Mar-2015	Replacement Window 20-Mar-2015
		

Figure 1: C05 Kitchen window – original and replacement

	Original Window 18-Mar-2015	Replacement Window 20-Mar-2015
		

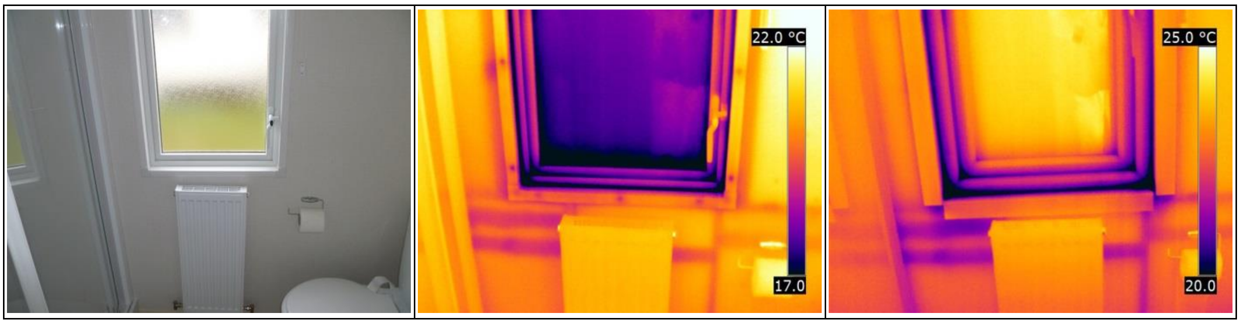


Figure 2: C05 Bathroom window – original and replacement

What is also noticeable in Figure 1 & Figure 2 is the surface temperature of the opaque elements and window frames. The window frames on the original windows are consistently cooler than the structural timber within the walls and ceiling. In contrast, the replacement frames display frame surface temperatures much closer to that of the areas of the plane elements with timber beneath.

The difference between the original window performance and the replacement glazing can be seen most clearly on caravan C05, where the window adjacent to the door was replaced prior to the door being upgraded. Figure 3 displays some difference between the 2 types of glazing when viewed from the outside, although variations in atmospheric conditions and reflection prevent any accurate analysis.

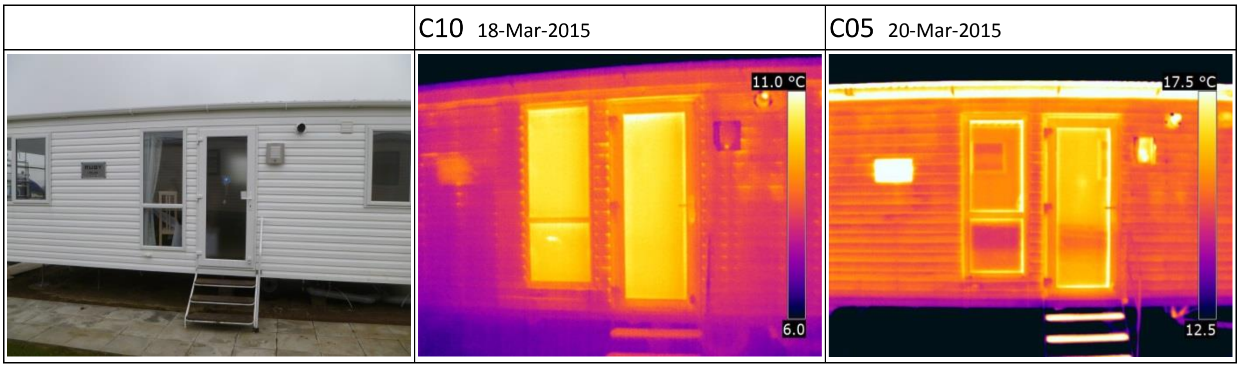


Figure 3: Doors and adjacent window showing difference in external surface temperature

Figure 4 shows the same door and adjacent window in C05, but with the images captured from within the caravan. Taken immediately after the image in Figure 3, the internally captured thermal images in Figure 4 show around a 3.5 ⁰C difference in surface temperature between the original glazing in the door and that of the replacement glazing in the adjacent window.

Figure 4: Internal images of C05 original door with adjacent window replaced – 20-Mar-2015

The thermal imaging surveys conducted throughout the investigation also indicated numerous point and repeated thermal bridges around the entire envelopes of both caravans. Analysis of these thermal anomalies do not fall within the remit of this investigation, so are not expounded upon, but provide a substantial amount of information should a more in-depth study of the thermal performance of the caravans be conducted. All the thermal images taken during this investigation are presented in Appendices 2, 3 and 4.

Airtightness

Method

Air tightness tests were performed on the caravans in accordance with the method outlined by the Airtightness Testing and Measurement Association (ATTMA) for the testing of building envelopes (ATTMA, 2010). The tests were undertaken using an Energy Conservatory Minneapolis 3 Blower Door with a DG700 dual-channel pressure gauge.

For the purposes of the tests all accessible purpose-provided ventilation, in both caravans, was temporarily sealed; some inaccessible vents (such as below the boiler and a presumed similar outlet beneath the kitchen units) were not sealed. The results were obtained using depressurisation only (rather than the usual mean of pressurisation and depressurisation), due to the door lifters in the caravan door frames making placement of the blower door frame within the narrow caravan door frame difficult. Some air leakage detection was performed under depressurisation, utilising the thermal camera to identify cooler infiltrating air.

Results

Table 2 summarises the results of the air pressurisation tests performed on both caravans.

Table 2: Airtightness test results

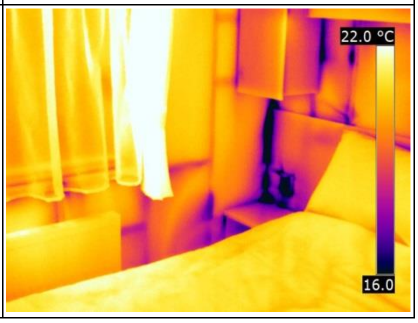
Caravan	Date	Air Permeability	Air Leakage Rate	Correlation coefficient
		$m^3/(h.m^2)$ @ 50 Pa	ach^{-1} @ 50 Pa	r^2
C05	16-Mar-2015	5.23	8.37	0.999
C05	18-Mar-2015	5.73	9.17	0.999
C05	20-Mar-2015	5.54	8.88	0.999
C10	16-Mar-2015	5.52	8.84	0.998

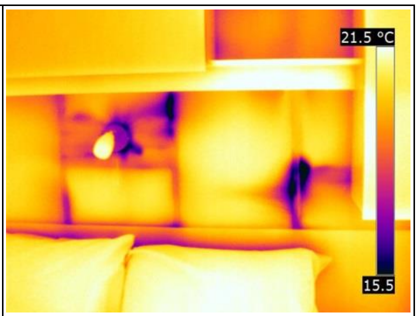
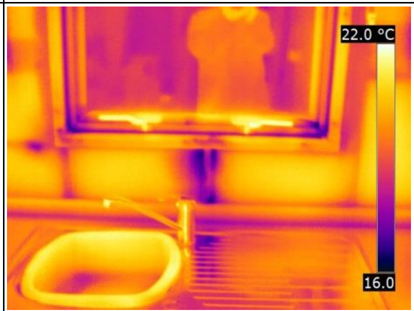
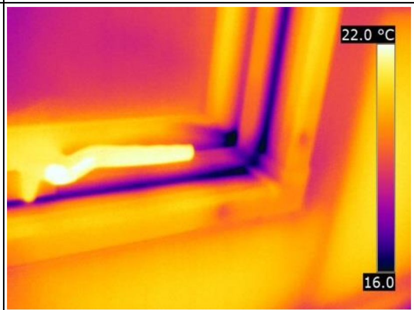
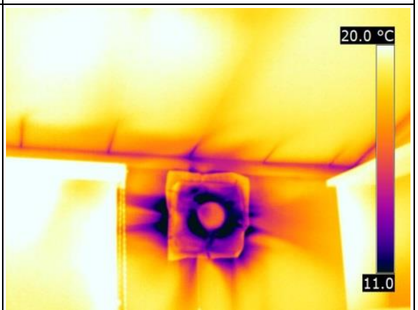
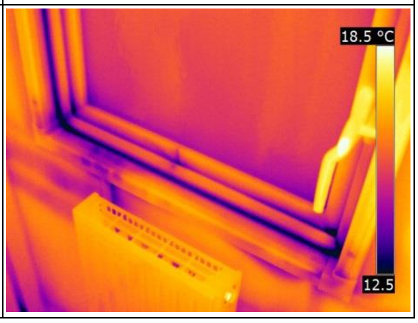
The initial increase in air leakage following the fitting of the replacement windows in C05 was partly due to difficulties in re-fitting the window surrounds, resulting in a number of these being left unfinished. During the 3rd test of C05, some of these surrounds had been re-fitted but many were still left unfinished.

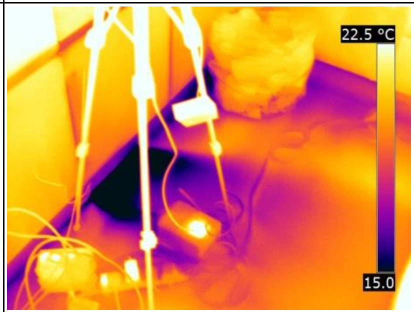
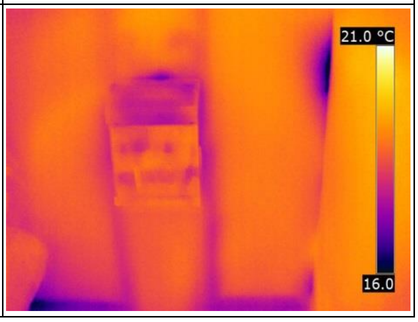
Air leakage paths

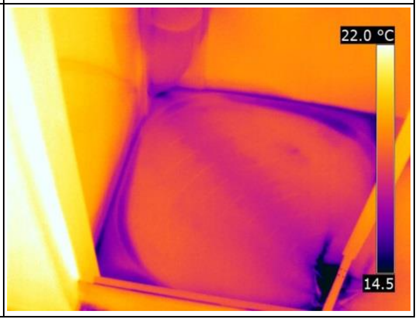
In general, both vans achieved a reasonable standard of airtightness, better than the minimum standard of 10 $m^3/(h.m^2)$ @ 50 Pa that is contained within Part L of the Building Regulations (NBS, 2013). Air leakage was detected around many junctions and penetrations, particularly those which were inaccessible or obscured from vision, with both vans displaying very similar patterns and points of air leakage. Table 3 shows just a few of the leakage paths detected and, as with the thermal imaging surveys, analysis of these do not fall within the remit of this investigation. However, they provide a substantial amount of information should a more in-depth study of the thermal performance of the caravans be conducted. All of the thermal images taken during this investigation under caravan depressurisation are presented in Appendices 2 and 4.

Table 3: Selected air leakage paths and brief descriptions

16-Mar-2015 C10 – Lounge Infiltration detected at junctions and joints between panels and around the concealed lights in the ceiling.		
		
		
16-Mar-2015 C10 – Kitchen Although the kitchen intermittent extract was temporarily sealed, the fan housing was not sealed around and leakage can be clearly observed.		
16-Mar-2015 C10 – Main Bedroom Cooler air was detected being drawn in at junctions and around electrical penetrations.		

		
16-Mar-2015 C10 – Bathroom Air leakage from the boxed-in services for the toilet was detected.		
16-Mar-2015 C05 – Kitchen Infiltration around the kitchen window was detected.		
		
16-Mar-2015 C05 – Kitchen Air leakage was detected around the sealed extract fan and around the window.		
		

20-Mar-2015 C05 – Lounge Air leakage was detected around electrical penetrations and at the wall/roof junction. One of the replacement window was also incorrectly sized and air leakage observed around the casement. This window was subsequently replaced with one that was correctly sized.	 	 
20-Mar-2015 C05 – Kitchen Substantial airflow was detected emerging from beneath the kitchen units, suggesting that there was some drainage or ventilation opening beneath the units remaining unsealed. As access to this area was not possible, no temporary seals were placed in this location.		
20-Mar-2015 C05 – Small Bedroom The wall vent had been sealed temporarily on the inside, but external air appeared to be entering the wall cavity from the outside.		
20-Mar-2015 C05 – Main Bedroom Air leakage around the consumer unit emerged at warmer temperatures than directly infiltrating air due to a longer air leakage path.		

20-Mar-2015 C05 – Bathroom Air leakage emerging from around the shower controls could be traced back down underneath the shower tray to the location where the waste pipe penetrated through the caravan floor.		
		

Actual ventilation rate

Although pressurisation tests provide a value for air permeability or air leakage, the value obtained does not represent a real background ventilation rate, since under normal conditions the internal/external pressure differential will be far less than 50 Pa and in buildings is typically around 3 to 6 Pa (Modera et al., 2009). Furthermore, the blower-door test is a single measurement, whereas background ventilation varies with pressure, temperature and wind conditions, and so is most usefully quoted as an annual average figure. In dwellings, the air leakage rate 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). As this *'rule of thumb'* was originally devised based upon a large number of results obtained in North American dwellings, the research team were sceptical whether this rule could equally be applied to caravans.

In order to be able to determine whether the n_{50}/20 *'rule of thumb'* is likely to be applicable to the test caravans, CO_2 tracer gas decay measurements were undertaken in caravan C05 during test period 1. Instead of introducing CO_2 artificially into the caravans using some type of CO_2 dispersion device, as is usual in domestic properties, the measurements were undertaken following a period when the researchers had been working in the van for some time (during this period CO_2 levels will have been elevated above the external background level). The actual air change rate was then determined using the CO_2 decay method described within Roulet and Foradini (2002). The results obtained using this method, illustrated by Figure 5 and Table 4, suggest that in the test caravans a figure of n/40 is more applicable to approximate the actual ventilation rate during the tests. This figure has also been used to determine the heat loss attributable to ventilation and has been used in subsequent energy calculations contained within this report (for instance, see Table 7).

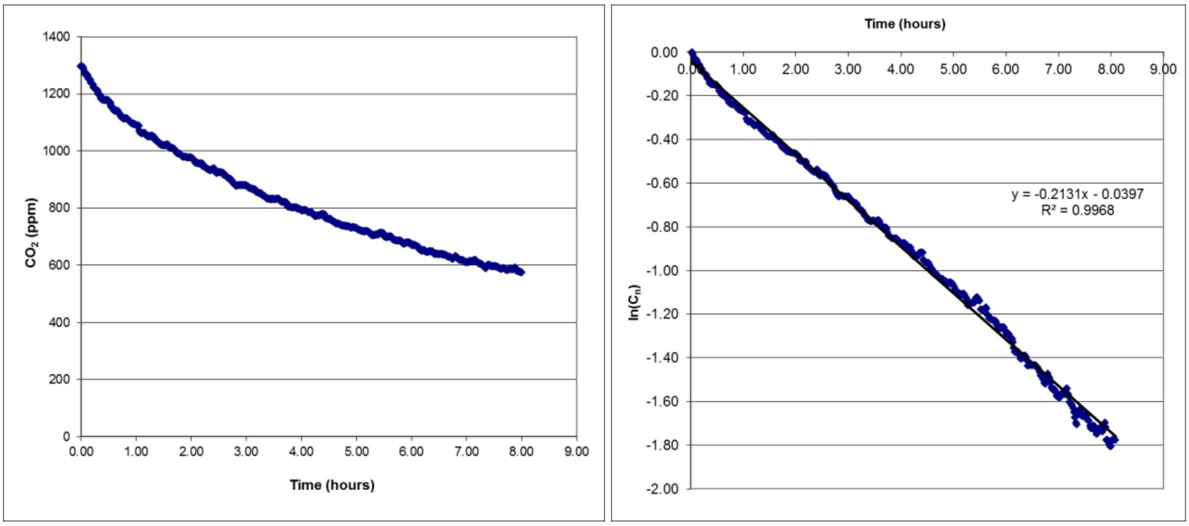


Figure 5: CO_2 decay curves for caravan CO5 stage 1 test

Table 4: Comparison of ventilation rates obtained through pressurisation testing and CO_2 decay for C05

	Based on pressure test (n/20)	Based on CO_2 decay
Approximated background ventilation rate (ach^{-1})	0.42	0.21
Ventilation heat loss (W/K)	11.6	5.8

Coheating Tests

Method

A simplified version of a coheating test was used to obtain an estimate of the steady-state aggregate fabric and ventilation heat loss from a whole dwelling. The metric which quantifies this heat loss is the heat loss coefficient (HLC), which is the power input in Watts required to maintain a one Kelvin temperature difference between the internal and external environment (ΔT). The HLC is expressed in units W/K.

A modified version of Leeds Beckett University's Coheating Test Method (Johnston et al., 2013) was used to measure the heat loss from the entire thermal envelope of caravans C05 and C10. The coheating test method was modified to account for the short time period that was available to the research team. Typically, coheating tests are undertaken during a time period of 10 – 21 days. This enables the analysis procedure to more confidently account for thermal storage and release due to the building's thermal mass, external power input resulting from solar radiation, and the effect of wind speed.

As the test caravans have low thermal mass it is reasonable to assume that a coheating test can be undertaken over a shorter time period than that of typical dwellings. However the shorter time period precludes an accurate estimation of the contribution of solar radiation to the heating power input to the caravan using multiple regression analysis. Thus, data used in the estimation of the HLC is from a time period thought not to be influenced by direct or previously stored solar radiation (22:00 – 05:59 inclusive). In addition, the data points used in a coheating regression analysis are usually the mean of a 24 hour time period. However, due to the limited test period and the fact that any thermal lag between a change in ΔT and resultant change in heating power is likely to be minimal (due to the low thermal mass of the caravans), coheating data was aggregated into hourly mean time intervals.

Each caravan was heated using electric resistance point heaters controlled by thermostatic temperature controllers. The temperature controllers in both caravans were set to maintain an internal temperature of 22 ^{o}C. Power input to the heaters was measured as well as the internal and external temperature and net radiation. Data was recorded at one minute intervals throughout the entire testing period.

Results

Caravan C05

Test period 1 (original glazing)

Figure 6 shows the hourly mean power and environmental conditions measured during test period 1 for caravan C05. The decrease in power input to the caravan observed in the first day of testing (16/03/15) is due to a reduction in power required to charge the thermal mass of the caravan following the commencement of heating (approximately 4 hours prior to the start of data logging); thus data from the first night of test period 1 (16/03/15) is excluded from the HLC analysis. The result is only one night of data available for the coheating analysis (17/03/15). The suppression of power input resulting from solar radiation and higher external temperatures is highly evident and justifies the use of overnight data in the coheating analysis. It can also be seen that overnight any change in ΔT results in a change in power input during the same one hour time period; this indicates low thermal mass and suggests that the use of one hour aggregated data in the coheating analysis is both appropriate and acceptable.

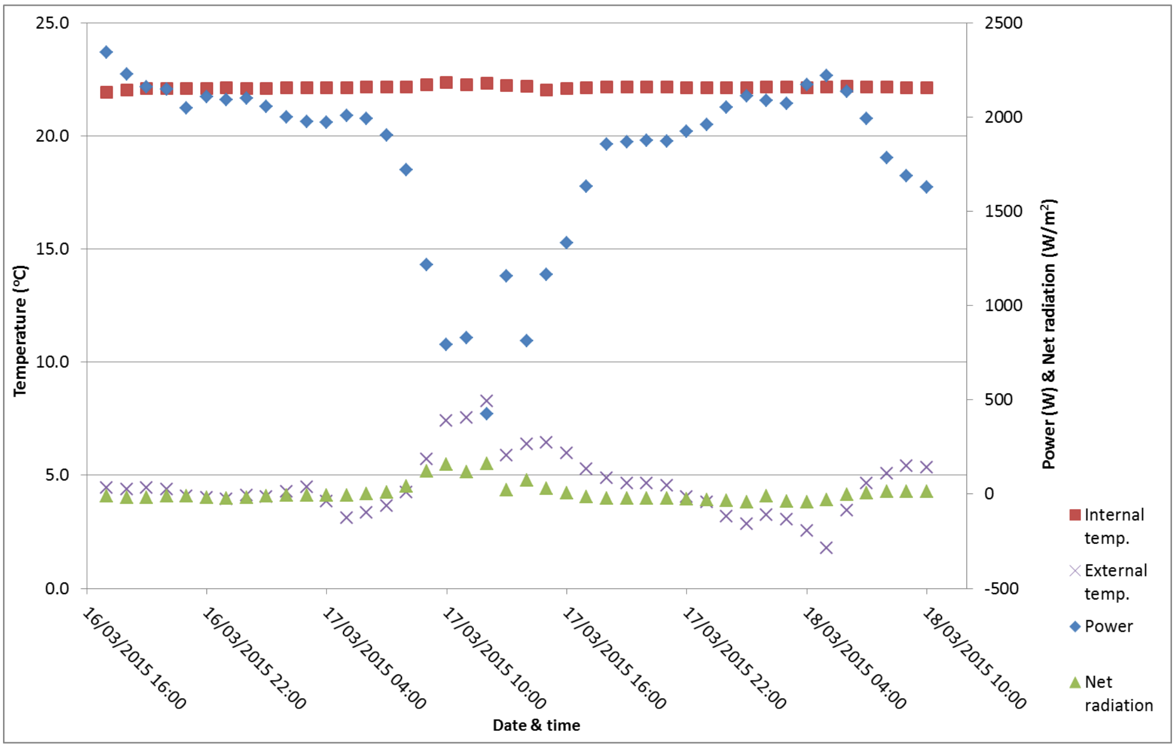


Figure 6: Caravan C05 power and environmental conditions measured during test period 1 (hourly means)

Figure 7 illustrates the power input and environmental conditions during the coheating analysis of test period 1. It is evident that a gradual external temperature decrease results in a gradual increase in power input to the caravan to maintain the ΔT throughout the test period.

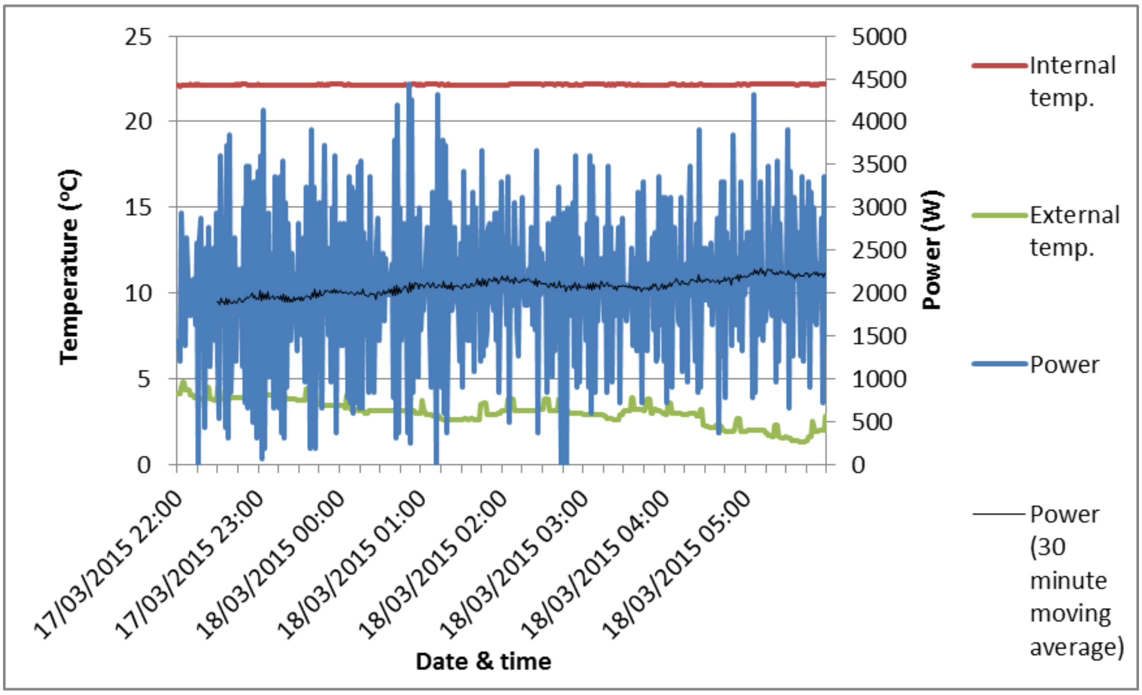


Figure 7: Power and temperatures measured throughout coheating test 1 of caravan C5

Figure 8 provides the coheating analysis of caravan C05 during test period 1. The coheating test produced an estimate of the HLC of 108.7 (±0.5) W/K (slope of the regression line). The low thermal mass of the caravan is evident by the strong relationship between mean hourly power demand and ΔT (r^2 of 0.91). This relationship provides confidence that reasonable estimate of the HLC can be obtained over a short time period.

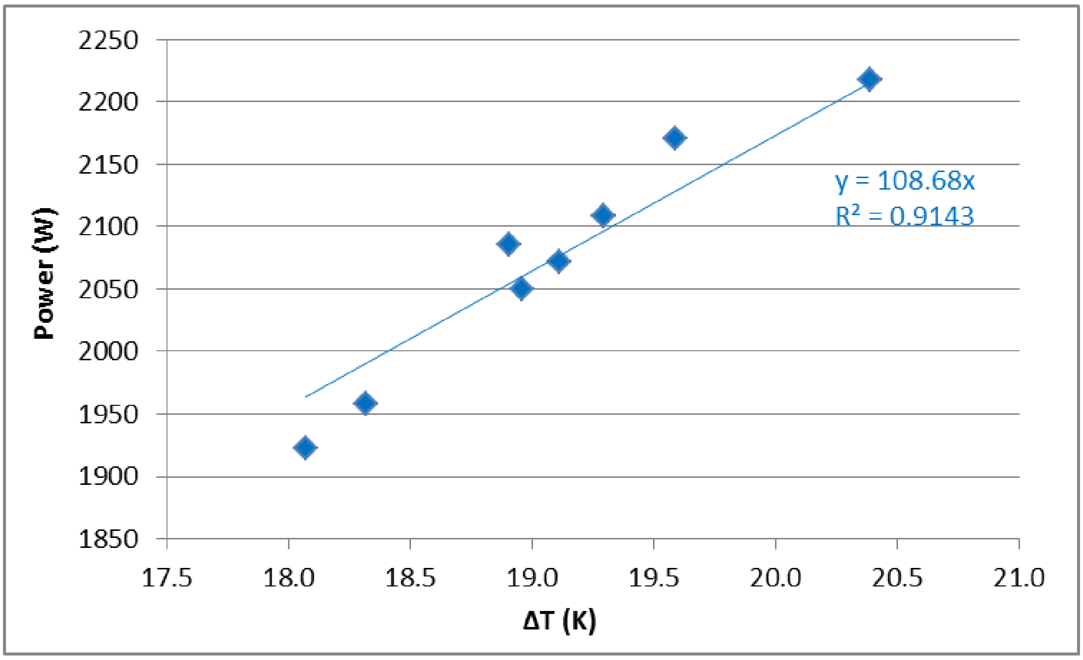


Figure 8: Coheating test 1 analysis for caravan C5 (regression forced through origin)

Test period 2 (replacement windows)

Figure 9 shows the hourly mean power and environmental conditions measured during test period 2 of caravan C05. As the fabric of the caravan remained heated throughout the period of the window replacement on 18/03/15, charging of the thermal mass was complete prior to the first night coheating analysis period. As a result, two nights of coheating data were available for analysis (18 & 19/03/15). It can be seen in Figure 9 that power input into the caravan remained reasonably stable during the coheating analysis periods. There was a reduction in internal temperature in the daytime of 19/03/15 as minor alterations to the internal window trims of the caravan were made. A partial solar eclipse caused the temporary reduction in net radiation measured on the morning of 20/03/15.

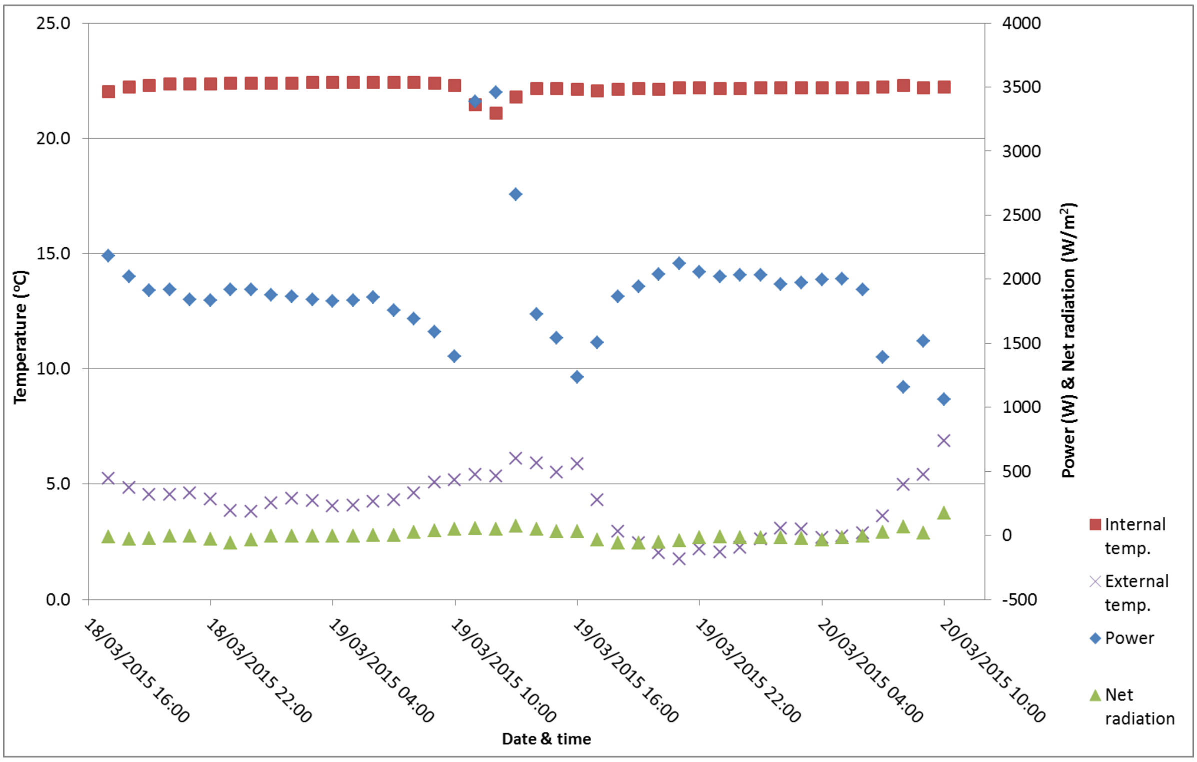


Figure 9: Caravan C05 power and environmental conditions measured during test period 2 (hourly means)

Figure 10 shows the coheating analysis for the two successive nights during test period 2. It can be seen that there is good consistency between the HLC measured on successive nights. The HLCs measured suggest that the minor alterations did not have a measureable difference on the thermal performance of the caravan. The cause of the outliers during night 1 corresponds with a reduction in wind speed during the final two hours of the test.

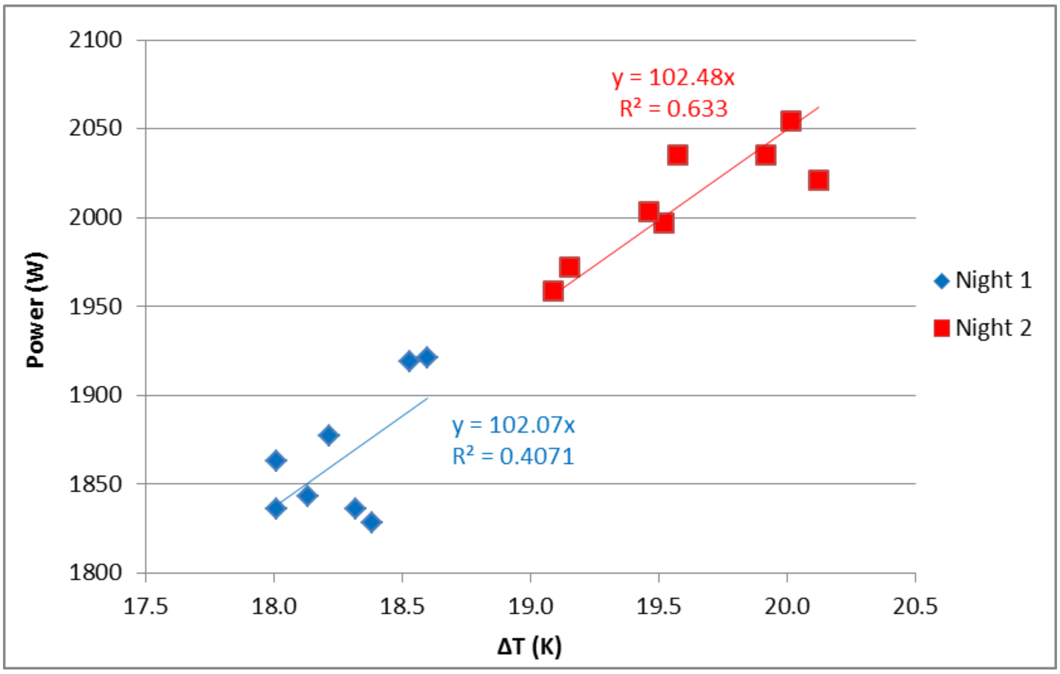


Figure 10: Individual nights coheating test 2 analysis for caravan C05 (regression forced through origin)

To increase the power of the coheating test analysis, both nights' data are included in the regression analysis to produce the HLC for test period 2; this is displayed in Figure 11.

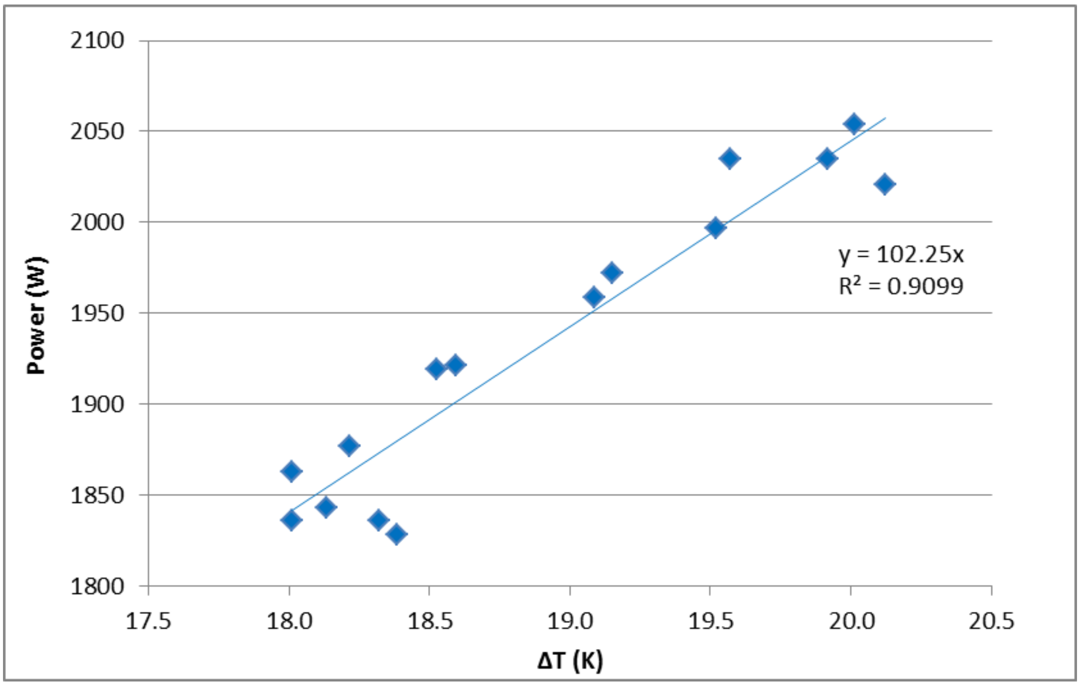


Figure 11: Coheating test 2 analysis for caravan C5 (regression forced through origin)

Figure 11 provides the coheating analysis of caravan C05 during test period 2. It is clear that there is a strong relationship between the mean hourly power demand and ΔT (r^2 of 0.91). The coheating test produced an estimate of the HLC of 102.3 (±0.3) W/K. This represents a reduction in HLC of 6.5 W/K (5.9%) from test period 1. As the airtightness of the caravan remained almost unchanged following test period 1, this reduction can primarily be attributed to the installation of the replacement windows.

Test period 3 (replacement windows and door)

Figure 12 shows the hourly mean power and environmental conditions measured during test period 3 of caravan C05. As the fabric of the caravan remained heated throughout the period of the door replacement on 20/03/15, charging of the thermal mass was complete prior to the first night coheating analysis period. As a result, four nights coheating data were available for analysis (20, 21, 22 & 23/03/15). Test period 3 was characterised by the greatest diurnal fluctuations in external temperature and the greatest changes in net radiation. The influence that these changes in external temperature and net radiation have on the power input to the caravan to maintain the ΔT can be clearly seen in Figure 12.

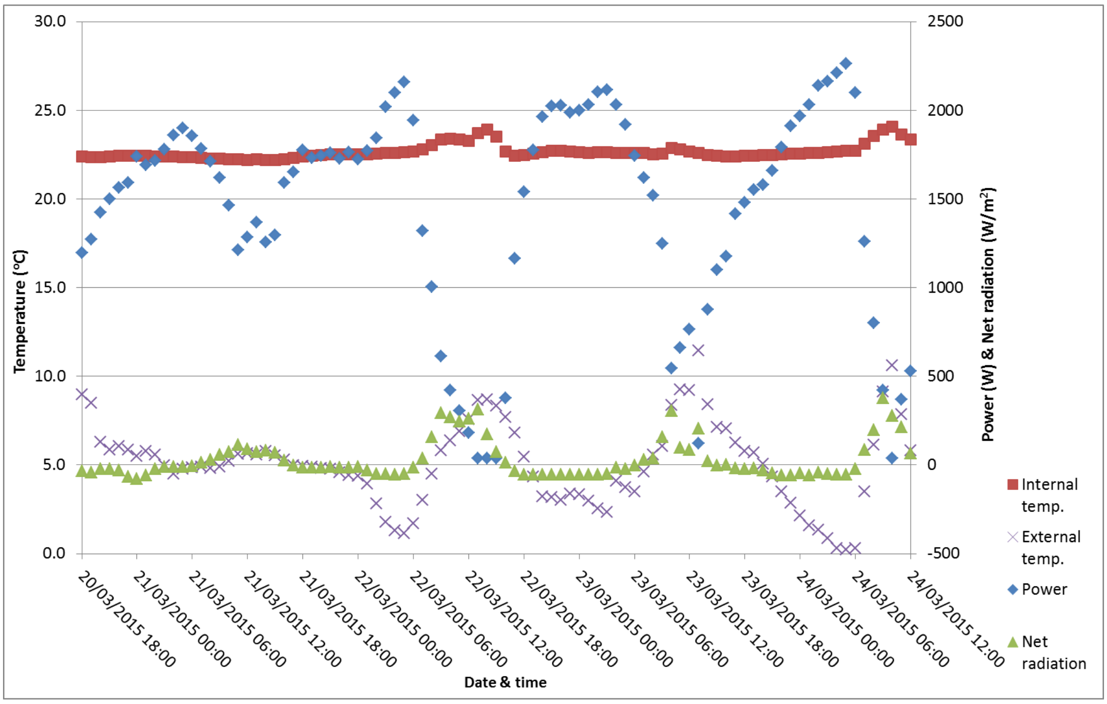


Figure 12: Caravan C05 power and environmental conditions measured during test period 3 (hourly means)

Figure 13 shows the coheating analysis for the four successive nights during test period 3. It can be seen that there is poor consistency between the HLC measured across the test period.

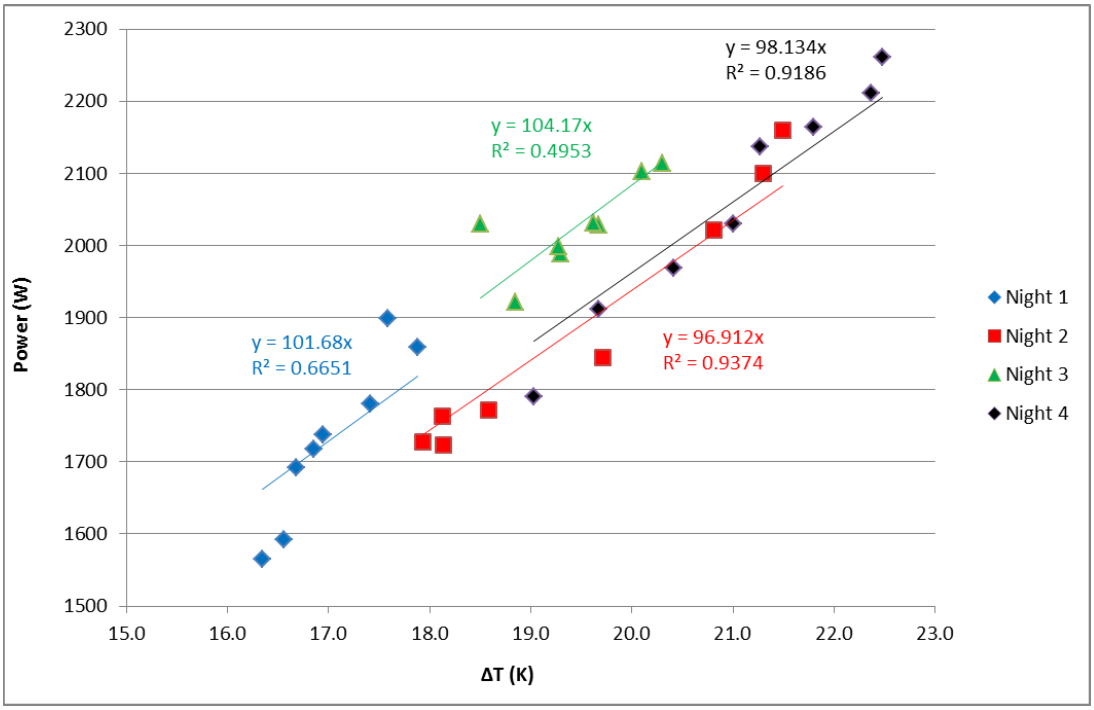


Figure 13: Individual nights coheating test 3 analysis for caravan C05 (regression forced through origin)

Figure 14 shows the relationship between nightly HLC estimates and mean wind speed measured[1] during the test period. The higher wind speed measured during night 1 and night 3 correlate with the higher HLCs measured and the poorer relationship between power input and ΔT measured (lower r^2 value). It is reasonable to assume that the many ventilation points through the caravan structure mean that it is susceptible to increased ventilation heat loss and wind-washing of the insulation during periods of high wind speeds.

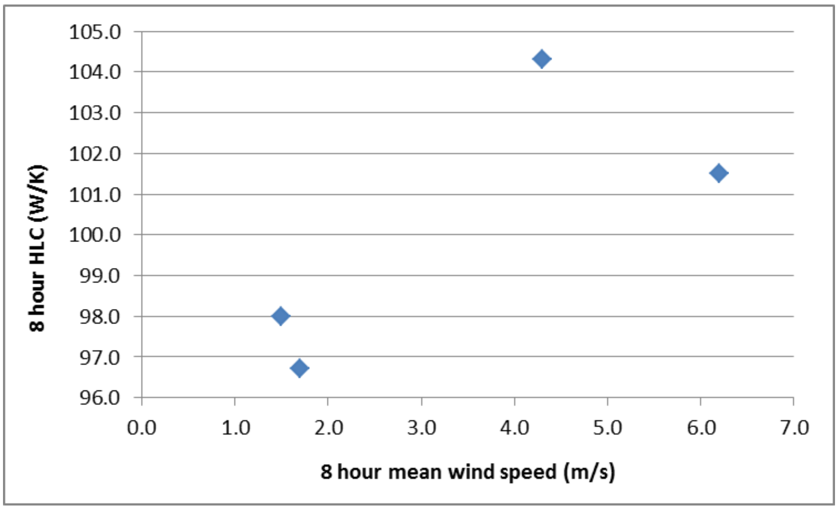


Figure 14: Wind speed vs. nightly HLC for caravan C05 during test period 3

Figure 15 shows the mean wind speed measured during each nightly coheating test period throughout the test programme. The wind speeds measured during night 1 and night 3 of test period 3 were in excess of the other two test periods. To ensure a more suitable comparison between previous test periods these nights have been excluded from the coheating analysis of test period 3.

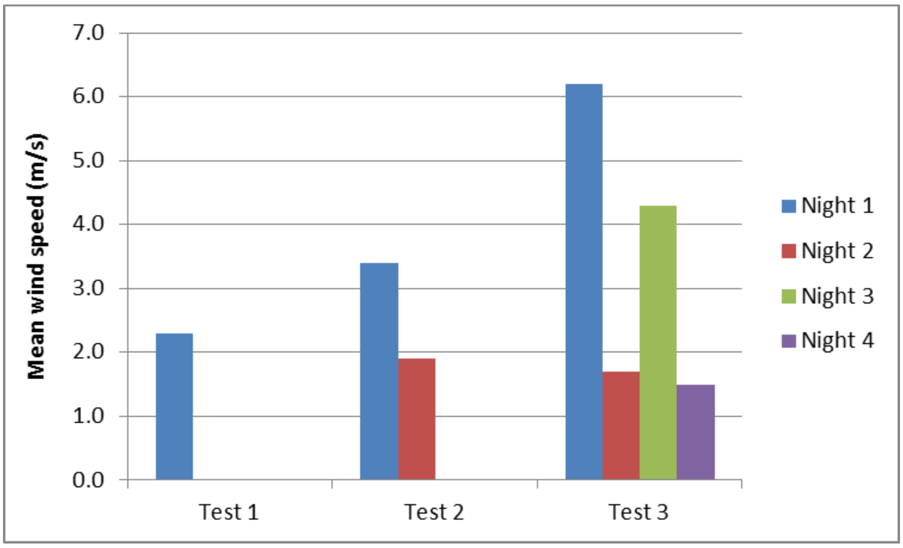


Figure 15: Mean wind speed during each nightly coheating test throughout the test programme

[1] Wind speed data obtained from Weather Underground (http://www.wunderground.com/) at RAF Topcliffe, North Yorkshire; 73 km WSW from test location. This location was the closest to the test site with trustworthy hourly wind speed measurements available. As this data is secondary, its veracity cannot be verified. In addition the distance from the location means that its suitability for use in analysis should be treated with caution.

Figure 16 provides the coheating analysis of caravan C05 during test period 3 using data obtained from night 2 and night 4 only. The coheating test produced an estimate of the HLC of 97.6 (±0.6) W/K. This represents a reduction in HLC of 11.1 W/K (11.4%) from test period 1. There is a high degree in confidence with the HLC estimate due to the very strong correlation between power input and ΔT (r^2 of 0.94). Unfortunately, it was not possible to measure change in airtightness that may have occurred following the installation of the new door. Assuming that the airtightness of C05 did not significantly change when the door was replaced, the reduction in HLC from test period 1 can primarily be attributed to the installation of the replacement windows and door.

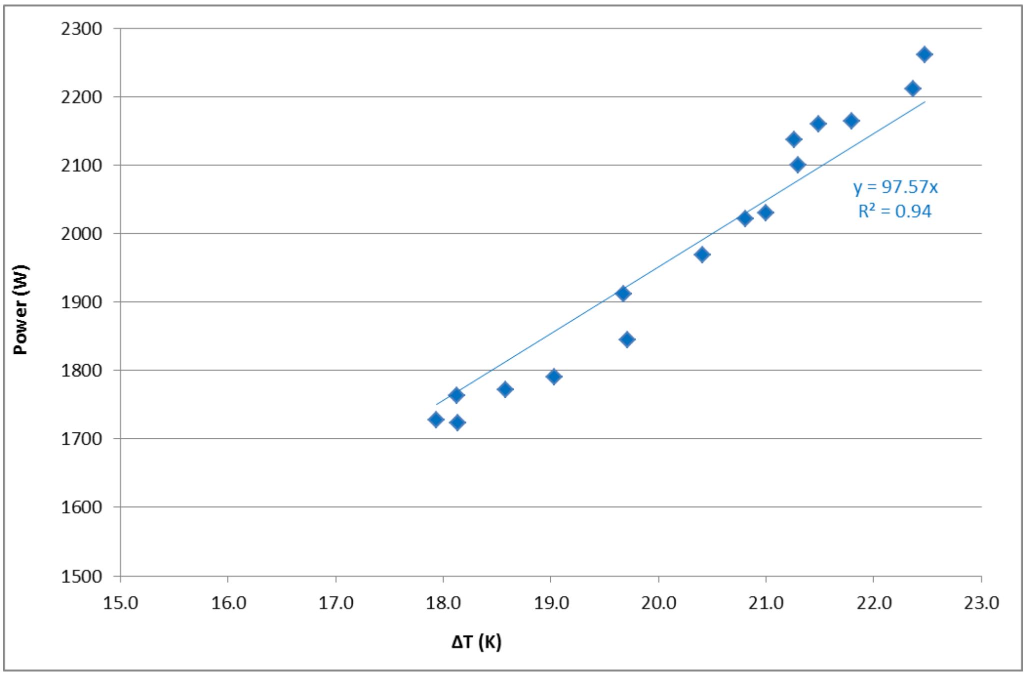


Figure 16: Coheating test 3 analysis for caravan C05 (regression forced through origin)

Caravan C10

Due to a malfunction of the energy metering equipment in caravan C10, it was not possible to estimate a HLC for test period 1; the issue with the logging equipment was resolved prior to test period 2. Caravan C10 did not have any glazing replaced, thus the HLC estimate for test period 2 is for the caravan in its original condition. The coheating analysis for caravan C10 is provided in Figure 17. The coheating test produced an estimate of the HLC of 116 (±0.6) W/K. There is a reasonable degree in confidence with the HLC estimate due to the correlation between power input and ΔT (r^2 of 0.79).

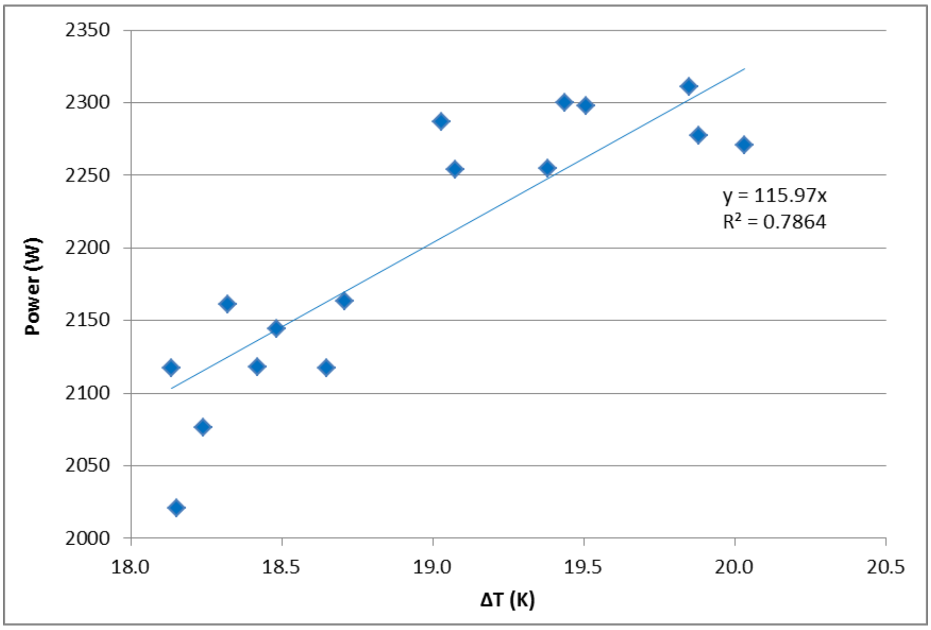


Figure 17: Coheating test analysis for caravan C10 (regression forced through origin)

Coheating test summary and conclusions

Table 5 summarises the coheating test results from the test programme. The installation of replacement windows and door to caravan C05 resulted in a HLC reduction of 11.1W/K, which equates to 10.2%. As no significant change in airtightness was measured, the improvement is primarily attributed to an improvement in the fabric thermal performance of the caravan; this is supported by the *in situ* U-value measurements presented in the following section of this report.

Table 5: Summary of coheating test results

Caravan	HLC (W/K)		
	Original glazing	Replacement windows	Replacement windows & door
C05	108.7 ± 0.5	102.3 ± 0.3	97.6 ± 0.6
C10	116 ± 0.6	n/a	n/a

The change in HLC is measured against a baseline HLC estimated with data from only one night; however there is a reasonably high degree of confidence that the HLC is reasonably accurate as successive test phases demonstrated good agreement between HLC estimates over differing nights (excluding nights of high wind speed). The coheating tests suggest that the caravans are highly susceptible to wind-washing and increased ventilation heat loss (even with all accessible purpose provided ventilation sealed). The limited data available meant that it was not possible to normalise the HLCs for wind speed. It is suggested that future testing of caravans should involve greater monitoring of wind conditions and be undertaken over a substantially longer time period. Due to the mobile nature of caravans it could be feasible to conduct fabric performance testing within a controlled environment. By undertaking fabric tests within a controlled environment it would allow faster, more accurate and more precise measurements of fabric heat loss to be obtained. Such testing could also be used to develop fabric integrity standards or a fabric performance labelling scheme for such caravans.

In situ U-value Measurement

The primary purpose of the thermal performance measurements was to measure the change in fabric heat loss of caravan C05 resulting from the installation of replacement windows and door. To confidently ascribe any change in thermal performance of the caravan to a change in thermal performance of the windows and door, rather than due to a change in the thermal performance of any other thermal element, *in situ* U-value measurements of the caravan's thermal elements were undertaken.

Method

The thermal transmittance of a building element (U-value) is defined in ISO 7345 as the *"Heat flow rate in the steady-state divided by area and by the temperature difference between the surroundings on each side of a system"* (ISO, 1987, p.3). U-values are expressed in units W/m^2K. ISO 9869 (ISO, 2014) describes the method in which *in situ* U-value measurements of thermal elements are typically undertaken. For a lightweight thermal element the minimum measurement period to comply with ISO 9869 is three successive nights where the U-value does not differ by more than ± 5%. Due to the short test duration, it was not possible to continue measurement until this condition was met; thus the values presented are not to the ISO 9869 standard. Despite this, other aspects relating to the measurement and analysis of the *in situ* U-values were undertaken in accordance with ISO 9869.

To reduce the influence of solar radiation on the results and provide a valid comparison with the coheating tests, *in situ* U-values were calculated from measurements of heat flux density and ΔT obtained overnight (22:00 – 05:59 inclusive) using Equation 1 contained within ISO 9869.

$$U = \frac{\sum_{j=1}^{n} q_j}{\sum_{j=1}^{n} (T_{ij} - T_{ej})} \qquad \text{Equation 1}$$

Where: U= *in situ* U-value (W/m^2K)

q = heat flux density (W/m^2)

$T_{(i)}$ = internal air temperature (K)

$T_{(e)}$ = external air temperature (K)

The U-values presented are the mean of the U-values measured during each night of each test period. The error associated with each *in situ* U-value presented is considered to be ± 10%.

In situ measurements of heat flux density, from which *in situ* U-values are derived, were obtained using Hukseflux HFP01 heat flux plates (HFPs) installed on the following thermal elements of each test caravan:

- Window glazing centre pane (4 no.)
- Door glazing centre pane
- External wall
- Roof
- Floor

Results

Table 6 provides a summary of the *in situ* U-value measurements obtained during each test period.

Table 6: *In situ* U-values measured in each caravan during each test period

Location	Caravan	*In situ* U-value (W/m²K)		
		Test 1	Test 2	Test 3
Window 1 (centre pane)	C5	2.61	1.39	1.41
	C10	2.66	2.82	n/a
Window 2 (centre pane)	C5	2.54	1.33	1.34
	C10	2.51	2.50	n/a
Window 3 (centre pane)	C5	2.55	1.33	1.36
	C10	2.63	2.70	n/a
Window 4 (centre pane)	C5	2.57	1.32	1.36
	C10	2.57	2.76	n/a
Door (centre pane)	C5	2.61	2.74	1.41
	C10	2.72	2.74	n/a
Wall	C5 (stud)	0.76	0.73	0.74
	C10	0.44	0.41	n/a
Roof	C5	0.26	0.24	0.24
	C10	0.26	0.29	n/a
Floor	C5	0.56	0.58	0.55
	C10	0.76	0.75	n/a

There was a high level of consistency between *in situ* glazing centre pane U-values measured across both caravans (mean 2.60 W/m²K, SD 0.06 W/m²K) in test period 1. The *in* situ U-values of non-glazed thermal elements in each caravan remained reasonably consistent across each of the test periods, this supports the assertion made in the coheating analysis that the reduction in HLC of caravan C05 is primarily due to the installation of replacement glazing and door. In addition, the mean *in situ* window centre pane U-value in caravan C05 reduced from 2.57 W/m²K to 1.37 W/m²K following the installation of the replacement windows. Figure 18 illustrates the reduction in mean *in situ* window centre pane U-value that was measured across the test periods.

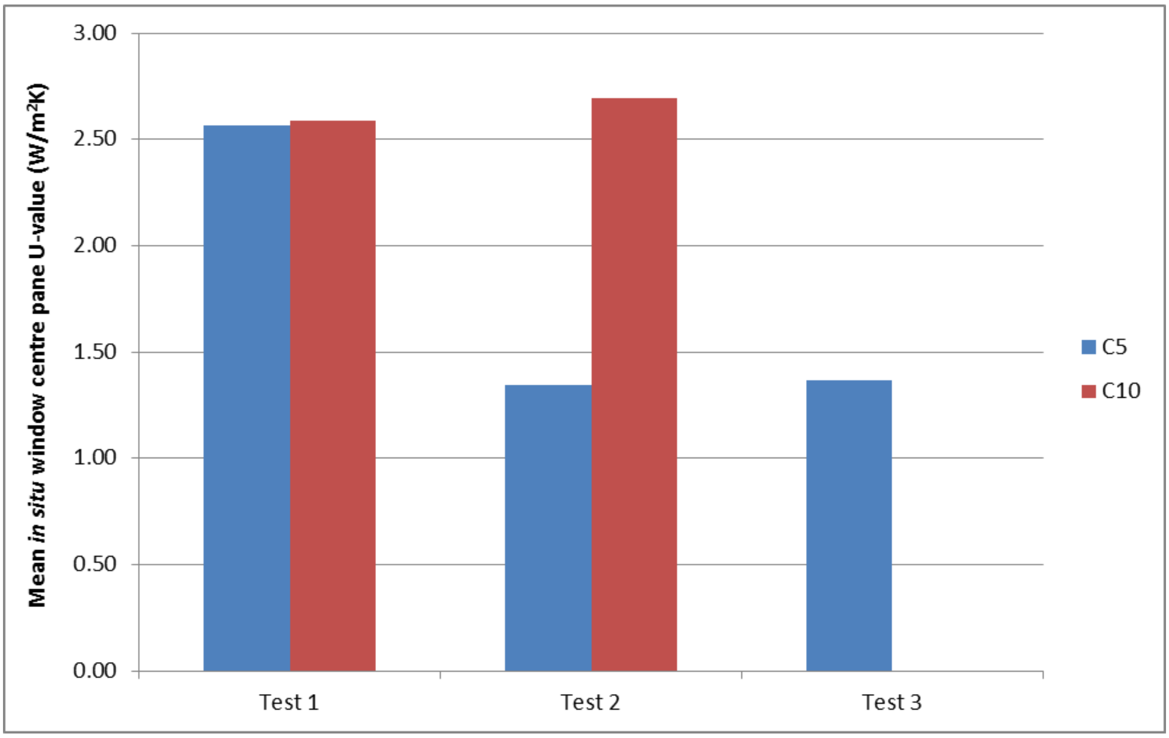


Figure 18: Mean *in situ* window centre pane U-value for each caravan during the 3 test periods (windows only).

Table 7 provides very approximate estimates of the total heat loss from the caravans for each stage of testing based on the values listed in Table 6 and a number of additional assumptions, not least that the elemental *in situ* U-values obtained were only based on single placements of heat flux sensors. Unfortunately, extending the heat flux measurement to provide fully representative samples of each individual thermal element in each caravan was beyond the scope of this project. The assumptions used in calculating the total heat loss are detailed below.

- The external wall U-value used is based on the assumption that the stud fraction is 10% of the overall external wall area.
- The window/door U-values used are based upon the measured centre-pane values.
- The values used for thermal bridging equate to the default values used with Part L of the Building Regulations for timber- frame housing.
- The heat loss due to ventilation has been calculated based upon the measured pressurisation test results of each caravan, rather than an actual ventilation rate over the test periods.

The results obtained from undertaking the heat loss calculations are detailed within Table 7. In all of the tests, the total heat loss coefficient values listed in Table 7 show a reasonable and consistent correlation with the measured whole caravan heat loss detailed within Table 5. Both sets of results appear to verify the measurements made using the alternative technique. It should be noted that it is the general trend that is of importance here, rather than the estimated values.

Table 7: Approximate HLC based on *in situ* U-value measurement and estimates of thermal bridging and ventilation heat loss.

		C10		C05 - Stage 1		C05 - Stage 2		C05 - Stage 3	
Detail	**Area**	**Apparent U-value**	**Heat Loss**	**Apparent U-value**	**Heat Loss**	**Apparent U-value**	**Heat Loss**	**Apparent U-value**	**Heat Loss**
	m^2	W/m^2K	W/K	W/m^2K	W/K	W/m^2K	W/K	W/m^2K	W/K
Ground Floor	38.4	0.76	29.0	0.56	21.5	0.58	22.3	0.55	21.1
Roof	37.6	0.28	10.5	0.26	9.8	0.24	9.2	0.24	9.2
Walls	47.2	0.48	22.9	0.48	22.9	0.48	22.9	0.48	22.9
Windows	9.9	2.62	26.0	2.57	25.5	1.37	13.6	1.37	13.6
Door	1.3	2.73	3.4	2.61	3.3	2.74	3.5	1.41	1.8
Total	**134.5**		**91.8**		**82.9**		**71.4**		**68.5**
Thermal Bridging	m	W/mK		W/mK		W/mK		W/mK	
Openings	75.9	0.15	11.4	0.15	11.4	0.15	11.4	0.15	11.4
Junctions	47.6	0.15	7.1	0.15	7.1	0.15	7.1	0.15	7.1
Total	**123.5**		**18.5**		**18.5**		**18.5**		**18.5**
		ach^{-1}@50Pa		ach^{-1}@50Pa		ach^{-1}@50Pa		ach^{-1}@50Pa	
Ventilation Heat Loss		8.84	**5.6**	8.37	**5.3**	9.17	**5.8**	8.88	**5.7**
Total (Heat Loss Coefficient)			**116.0**		**106.8**		**95.7**		**92.7**

Conclusions

The magnitude of the HLC reduction calculated from the *in situ* U-value measurements is comparable to that measured by the coheating tests. The *in situ* U-value measurements also support the findings obtained from the coheating tests, where the reduction in the measured HLC can be attributed to the installation of the replacement glazing and doors, rather than due to any change in thermal performance of the other thermal elements.

The installation of the replacement windows in caravan C05 resulted in a reduction of mean *in situ* window centre pane U-value (for the 4 windows and door investigated) from 2.57 W/m^2K to 1.37 W/m^2K.

Summary

This report has outlined the results of a number of fabric performance tests that were undertaken on two static caravans located at the Blue Dolphin Holiday Park, Filey, North Yorkshire. The tests were undertaken in order to assess the impact that the installation of upgraded replacement windows and doors would have on the *in situ* thermal performance of the caravans.

Due to slight differences in the orientation of the two caravans, it is to be expected that there will be some natural variation between the measured fabric thermal performance of each caravan. The coheating test measurements indicate a small difference in fabric thermal performance between the caravans prior to any upgrade measures, with caravan C10 obtaining an HLC of 116 ± 0.6 W/K and caravan C10 obtaining an HLC of 108.7 ± 0.5 W/K. This small difference in performance is also reflected in the pressurisation test results, with caravan C10 obtaining an air permeability of 5.52 $m^3/(h.m^2)$ @ 50 Pa compared to 5.23 $m^3/(h.m^2)$ @ 50 Pa for caravan C05. The observed difference in air permeability between the caravans will account for some of the observed difference in the coheating test results. Following replacement of the original windows and door installed in caravan C05 with higher performance glazing and door units, the heat loss coefficient of this caravan reduced to 97.6 ± 0.6 W/K. This equates to an absolute difference in heat loss coefficient of 11.1 W/K, representing a reduction in heat loss coefficient in excess of 10%.

The results of the coheating tests also suggest that both caravans are highly susceptible to wind washing and increased ventilation heat loss (even when all of the accessible purpose provided ventilation openings are sealed). It is suggested that any future testing of caravans should involve greater monitoring of wind conditions and be undertaken over a substantially longer time period. Due to the mobile nature of caravans it could be feasible to conduct fabric performance testing within a controlled environment. By undertaking fabric tests within a controlled environment it would allow faster, more accurate and more precise measurements of fabric heat loss to be obtained and add to any evaluation of interventions (such as this investigation). Such testing could also be used to develop fabric integrity standards or a fabric performance labelling scheme for such caravans.

A series of *in situ* heat flux density measurements was also undertaken on the caravans. These measurements revealed that there was a high level of consistency between *in situ* glazing centre pane U-values measured across both caravans in test period 1 (mean 2.60 W/m^2K, SD 0.06 W/m^2K), whilst the *in* situ U-values of the non-glazed thermal elements in each caravan remained reasonably consistent across each of the test periods. These results confirm that the reduction in the HLC of caravan C05 measured during the coheating tests is primarily due to the installation of the replacement glazing and door. In addition, the *in situ* heat flux density measurements undertaken in caravan C05 revealed a significant reduction in the mean *in situ* window centre pane U-value following the installation of the replacement windows. From test period 1 to test period 3, the centre pane U-value reduced by almost 50%, from 2.57 W/m^2K to 1.37 W/m^2K.

Thermal imaging undertaken internally also revealed that the replacement window surfaces were noticeably warmer than the original windows. As moisture generation within the caravans will condense most rapidly on the coolest surfaces, this raised window surface temperature is likely to result in a reduction in formation of surface condensation on the glazing units. It is suspected that there is also a reduction in thermal bridging around the window frames, due to the removal of the aluminium strip around the perimeter of the original window frames. However, additional work would be required to be undertaken to confirm this.

The results obtained from the *in situ* heat flux density measurements were also used to determine a whole van heat loss coefficient using an *in situ* U-value methodology. If this methodology is compared with the whole van *in situ* heat loss measurement method, comparable results are obtained.

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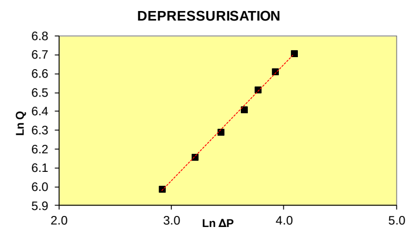
Appendix 1 - Blower door spread sheets

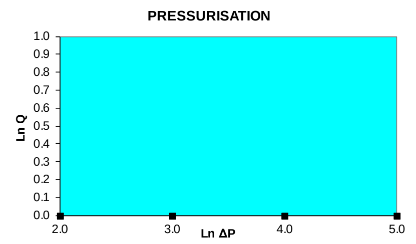
MINNEAPOLIS BLOWER DOOR DATA INPUT AND CALCULATION

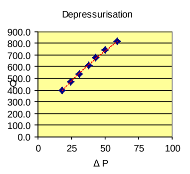
date:	16/03/2015		Version 16c	04 November 2014	
test house address:	C10 Blue Dolphin				
company:	Camden Group				
house type:	Mobile home				
tester:	DMS, DF				
test reference number:	Filey1a		Blower Door & Gauge Used	Model 3 with DG700	
outdoor temp (°C)	9	°C	Note: ENSURE THAT FLOW SETTINGS ARE IN m3/h - When using the DG700 gauge run baseline pressure adjustment for minimum 30s with fan switched on but not rotating		
indoor temp (°C)	16	°C			
outdoor humidity (%rh)	66	%RH			
indoor humidity (%rh)	53	%RH			
outdoor barometric pressure	1014.6	mbar or hPa	Calculated Outdoor Air Density	1.25	kg/m^3
indoor barometric pressure	1014.6	mbar or hPa	Calculated Indoor Air Density	1.22	kg/m^3
temperature corr. fact. depress.	0.976		description of main construction details:		
temperature corr. fact. press.	1.025		Static Van C10 - pre window upgrade		
wind speed (m/s):	0.3				
baseline pressure diff (Pa) (+/-)		Pa			
house width:	3.575	m			
house depth:	10.75	m			
house height:	2.38	m			
floor area:	38.43	m^2			
volume:	84	m^3			
envelope area including floor:	134.5	m^2			
Pressure Difference for ELA	10	Pa			
RESULTS:					
Q50 Mean Flow at 50Pa =		m^3/h			
Mean Air Leakage at 50Pa =		h^{-1}			
Mean Air Permeability at 50 Pa =		m/h or m^3h/m^2			
Equivalent Leakage Area =		m^2 at	10	Pa	

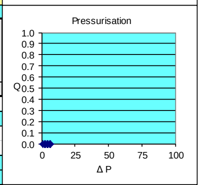
DEPRESSURISATION	RING - O,A,B,C,D,E for BD3 0,1,2,3 for DuctBB	MEASURED FAN PRESSURE (Pa)	MEASURED FLOW (m^3/h)	ADJUSTED FLOW (m^3/h)	FLOW RANGE OK FOR SELECTED RING?	Adjusted Pressure (Pa)	Ln delta P	Ln Q	Q50 Calculated Flow at 50Pa (m^3/h)	Permeability Depressurisation Only ($m^3/(h.m^2)$)	Air Leakage Depressurisation Only (h^{-1})
Approx 65 Pa	1	59.6	839	818.1	OK	59.6	4.088	6.707	742.86	5.52	8.84
Approx 57 Pa	1	50.4	762	743.0	OK	50.4	3.920	6.611	r^2	0.998	
Approx 49 Pa	1	43.4	692	674.7	OK	43.4	3.770	6.514	C_{env}	65.030	$m^3/h.Pa^n$
Approx 41 Pa	1	38.2	624	608.4	OK	38.2	3.643	6.411	n	0.619	
Approx 33 Pa	1	31.2	553	539.2	OK	31.2	3.440	6.290			
Approx 25 Pa	1	24.7	485	472.9	OK	24.7	3.207	6.159	C_L (corrected)	66.033	$m^3/h.Pa^n$
Approx 20 Pa	1	18.5	410	399.8	OK	18.5	2.918	5.991			

PRESSURISATION	RING - O,A,B,C,D,E for BD3 0,1,2,3 for DuctBB	MEASURED FAN PRESSURE (Pa)	MEASURED FLOW (m^3/h)	ADJUSTED FLOW (m^3/h)	FLOW RANGE OK FOR SELECTED RING?	Adjusted Pressure (Pa)	Ln delta P	Ln Q	Q50 Calculated Flow at 50Pa (m^3/h)	Permeability Pressurisation Only ($m^3/(h.m^2)$)	Air Leakage Pressurisation Only (h^{-1})
Approx 65 Pa											
Approx 57 Pa									r^2		
Approx 49 Pa									C_{env}		$m^3/h.Pa^n$
Approx 41 Pa									n		
Approx 33 Pa											
Approx 25 Pa									C_L (corrected)		$m^3/h.Pa^n$
Approx 20 Pa											







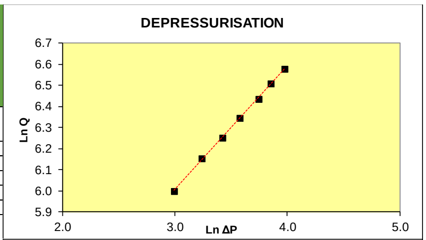


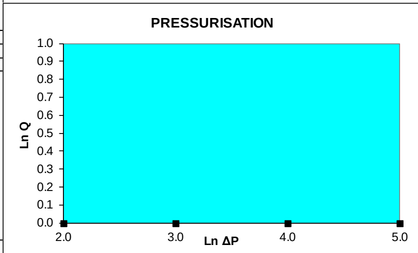
MINNEAPOLIS BLOWER DOOR DATA INPUT AND CALCULATION

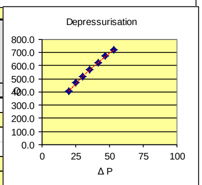
date:	16/03/2015		Version 16c	04 November 2014	
test house address:	C5 Blue Dolphin				
company:	Camden Group				
house type:	Atlas Static Van				
tester:	DMS DF				
test reference number:			Blower Door & Gauge Used	Model 3 with DG700	
outdoor temp (°C)	9.3	°C	Note: ENSURE THAT FLOW SETTINGS ARE IN m3/h - When using the DG700 gauge run baseline pressure adjustment for minimum 30s with fan switched on but not rotating		
indoor temp (°C)	19.1	°C			
outdoor humidity (%rh)	66	%RH			
indoor humidity (%rh)	51	%RH			
outdoor barometric pressure	1014.6	mbar or hPa	Calculated Outdoor Air Density	1.25	kg/m^3
indoor barometric pressure	1014.6	mbar or hPa	Calculated Indoor Air Density	1.20	kg/m^3
temperature corr. fact. depress.	0.966		description of main construction details:		
temperature corr. fact. press.	1.035		Static Van C05 - pre window upgrade		
wind speed (m/s):	0.2				
baseline pressure diff (Pa) (+/-)		Pa			
house width:	3.575	m			
house depth:	10.75	m			
house height:	2.38	m			
floor area:	38.43	m^2			
volume:	84	m^3			
envelope area including floor:	134.5	m^2			
Pressure Difference for ELA	10	Pa			
RESULTS:					
Q50 Mean Flow at 50Pa =		m^3/h			
Mean Air Leakage at 50Pa =		h^{-1}			
Mean Air Permeability at 50 Pa =		m/h or m^3h/m^2			
Equivalent Leakage Area =		m^2 at	10	Pa	

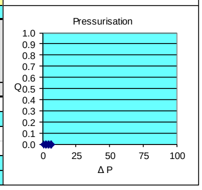
DEPRESSURISATION	RING - O,A,B,C,D,E for BD3 0,1,2,3 for DuctBB	MEASURED FAN PRESSURE (Pa)	MEASURED FLOW (m^3/h)	ADJUSTED FLOW (m^3/h)	FLOW RANGE OK FOR SELECTED RING?	Adjusted Pressure (Pa)	Ln delta P	Ln Q	Q50 Calculated Flow at 50Pa (m^3/h)	Permeability Depressurisation Only ($m^3/(h.m^2)$)	Air Leakage Depressurisation Only (h^{-1})
Approx 65 Pa	1	53.3	744	718.1	OK	53.3	3.976	6.577	703.01	5.23	8.37
Approx 57 Pa	1	47.3	696	671.8	OK	47.3	3.857	6.510	r^2	0.999	
Approx 49 Pa	1	42.3	646	623.5	OK	42.3	3.745	6.435	C_{env}	69.799	$m^3/h.Pa^n$
Approx 41 Pa	1	35.8	590	569.5	OK	35.8	3.578	6.345	n	0.586	
Approx 33 Pa	1	30.7	537	518.3	OK	30.7	3.424	6.251			
Approx 25 Pa	1	25.5	487	470.0	OK	25.5	3.239	6.153	C_L (corrected)	70.935	$m^3/h.Pa^n$
Approx 20 Pa	1	20	417	402.5	OK	20	2.996	5.998			

PRESSURISATION	RING - O,A,B,C,D,E for BD3 0,1,2,3 for DuctBB	MEASURED FAN PRESSURE (Pa)	MEASURED FLOW (m^3/h)	ADJUSTED FLOW (m^3/h)	FLOW RANGE OK FOR SELECTED RING?	Adjusted Pressure (Pa)	Ln delta P	Ln Q	Q50 Calculated Flow at 50Pa (m^3/h)	Permeability Pressurisation Only ($m^3/(h.m^2)$)	Air Leakage Pressurisation Only (h^{-1})
Approx 65 Pa											
Approx 57 Pa									r^2		
Approx 49 Pa									C_{env}		$m^3/h.Pa^n$
Approx 41 Pa									n		
Approx 33 Pa											
Approx 25 Pa									C_L (corrected)		$m^3/h.Pa^n$
Approx 20 Pa											



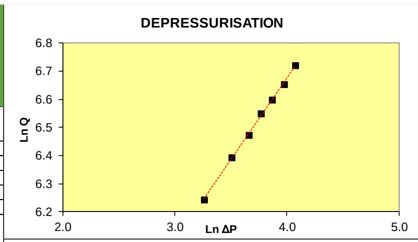


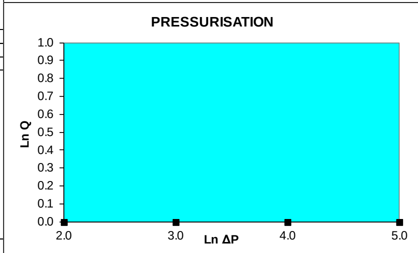




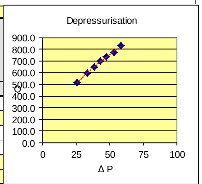
MINNEAPOLIS BLOWER DOOR DATA INPUT AND CALCULATION

date:	18/03/2015		Version 16c 04 November 2014
test house address:	C5 Blue Dolphin		
company:	Camden Group		
house type:	Atlas Static Van		
tester:	DMS DF		
test reference number:	FileyC5(2)		Blower Door & Gauge Used: Model 3 with DG700
outdoor temp (°C)	6.9	°C	Note: ENSURE THAT FLOW SETTINGS ARE IN m3/h - When using the DG700 gauge
indoor temp (°C)	17.4	°C	run baseline pressure adjustment for minimum 30s with fan switched on but not
outdoor humidity (%rh)	89.2	%RH	rotating
indoor humidity (%rh)	49.8	%RH	
outdoor barometric pressure	1023.2	mbar or hPa	Calculated Outdoor Air Density: 1.27 kg/m³
indoor barometric pressure	1023.2	mbar or hPa	Calculated Indoor Air Density: 1.22 kg/m³
temperature corr. fact. depress.	0.964	WARNING!!	description of main construction details:
temperature corr. fact. press.	1.038	Extreme Test	Static Van C05 - post window upgrade
wind speed (m/s):	2.8	Conditions	
baseline pressure diff (Pa) (+/-)		Pa	
house width:	3.575	m	
house depth:	10.75	m	
house height:	2.38	m	
floor area:	38.43	m²	
volume:	84	m³	
envelope area including floor:	134.5	m²	
Pressure Difference for ELA	10	Pa	
RESULTS:			
Q50 Mean Flow at 50Pa =		m³/h	
Mean Air Leakage at 50Pa =		h⁻¹	
Mean Air Permeability at 50 Pa =		m/h or m³h/m²	
Equivalent Leakage Area =		m² at	10 Pa

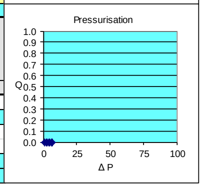




DEPRESSURISATION	RING - O,A,B,C,D,E for BD3 0,1,2,3 for DuctBB	MEASURED FAN PRESSURE (Pa)	MEASURED FLOW (m³/h)	ADJUSTED FLOW (m³/h)	FLOW RANGE OK FOR SELECTED RING?	Adjusted Pressure (Pa)	Ln delta P	Ln Q	Q50 Calculated Flow at 50Pa (m³/h)	Permeability Depressurisation Only (m³/(h.m²))	Air Leakage Depressurisation Only (h⁻¹)
Approx 65 Pa	1	58.8	860	828.6	OK	58.8	4.074	6.720	770.23	5.73	9.17
Approx 57 Pa	1	53.4	806	776.6	OK	53.4	3.978	6.655	r²	0.999	
Approx 49 Pa	1	48	762	734.2	OK	48	3.871	6.599	C_{env}	76.870	m³/h.Pa*n*
Approx 41 Pa	1	43.4	726	699.5	OK	43.4	3.770	6.550	n	0.583	
Approx 33 Pa	1	39	673	648.4	OK	39	3.664	6.475			
Approx 25 Pa	1	33.4	620	597.4	OK	33.4	3.509	6.393	C_L (corrected)	78.673	m³/h.Pa*n*
Approx 20 Pa	1	26.2	534	514.5	OK	26.2	3.266	6.243			

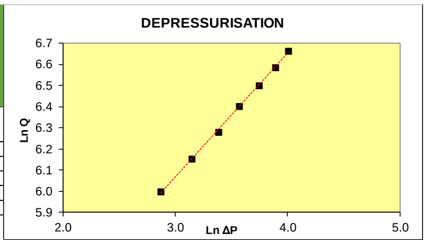


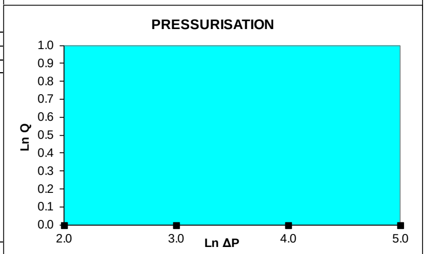
PRESSURISATION	RING - O,A,B,C,D,E for BD3 0,1,2,3 for DuctBB	MEASURED FAN PRESSURE (Pa)	MEASURED FLOW (m³/h)	ADJUSTED FLOW (m³/h)	FLOW RANGE OK FOR SELECTED RING?	Adjusted Pressure (Pa)	Ln delta P	Ln Q	Q50 Calculated Flow at 50Pa (m³/h)	Permeability Pressurisation Only (m³/(h.m²))	Air Leakage Pressurisation Only (h⁻¹)
Approx 65 Pa											
Approx 57 Pa									r²		
Approx 49 Pa									C_{env}		m³/h.Pa*n*
Approx 41 Pa									n		
Approx 33 Pa											
Approx 25 Pa									C_L (corrected)		m³/h.Pa*n*
Approx 20 Pa											



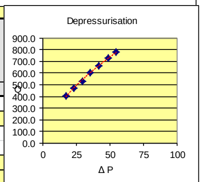
MINNEAPOLIS BLOWER DOOR DATA INPUT AND CALCULATION

date:	20/03/2015		Version 16c 04 November 2014
test house address:	C5 Blue Dolphin		
company:	Camden Group		
house type:	Atlas Static Van		
tester:	DMS DF DJ		
test reference number:	FileyC5(3)		Blower Door & Gauge Used: Model 3 with DG700
outdoor temp (°C)	10.9	°C	Note: ENSURE THAT FLOW SETTINGS ARE IN m3/h - When using the DG700 gauge
indoor temp (°C)	23.8	°C	run baseline pressure adjustment for minimum 30s with fan switched on but not
outdoor humidity (%rh)	62.2	%RH	rotating
indoor humidity (%rh)	39	%RH	
outdoor barometric pressure	1014.4	mbar or hPa	Calculated Outdoor Air Density: 1.24 kg/m³
indoor barometric pressure	1014.5	mbar or hPa	Calculated Indoor Air Density: 1.19 kg/m³
temperature corr. fact. depress.	0.957	WARNING!!	description of main construction details:
temperature corr. fact. press.	1.045	Extreme Test	Static Van C05 - post window upgrade + trims
wind speed (m/s):	2.4	Conditions	
baseline pressure diff (Pa) (+/-)		Pa	
house width:	3.575	m	
house depth:	10.75	m	
house height:	2.38	m	
floor area:	38.43	m²	
volume:	84	m³	
envelope area including floor:	134.5	m²	
Pressure Difference for ELA	10	Pa	
RESULTS:			
Q50 Mean Flow at 50Pa =		m³/h	
Mean Air Leakage at 50Pa =		h⁻¹	
Mean Air Permeability at 50 Pa =		m/h or m³h/m²	
Equivalent Leakage Area =		m² at	10 Pa

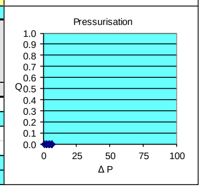




DEPRESSURISATION	RING - O,A,B,C,D,E for BD3 0,1,2,3 for DuctBB	MEASURED FAN PRESSURE (Pa)	MEASURED FLOW (m³/h)	ADJUSTED FLOW (m³/h)	FLOW RANGE OK FOR SELECTED RING?	Adjusted Pressure (Pa)	Ln delta P	Ln Q	Q50 Calculated Flow at 50Pa (m³/h)	Permeability Depressurisation Only (m³/(h.m²))	Air Leakage Depressurisation Only (h⁻¹)
Approx 65 Pa	1	55.1	819	782.5	OK	55.1	4.009	6.663	745.71	5.54	8.88
Approx 57 Pa	1	48.8	760	726.1	OK	48.8	3.888	6.588	r²	0.999	
Approx 49 Pa	1	42.2	696	665.0	OK	42.2	3.742	6.500	C_{env}	75.197	m³/h.Pa*n*
Approx 41 Pa	1	35.4	631	602.9	OK	35.4	3.567	6.402	n	0.583	
Approx 33 Pa	1	29.5	558	533.1	OK	29.5	3.384	6.279			
Approx 25 Pa	1	23.3	493	471.0	OK	23.3	3.148	6.155	C_L (corrected)	76.240	m³/h.Pa*n*
Approx 20 Pa	1	17.6	422	403.2	OK	17.6	2.868	5.999			



PRESSURISATION	RING - O,A,B,C,D,E for BD3 0,1,2,3 for DuctBB	MEASURED FAN PRESSURE (Pa)	MEASURED FLOW (m³/h)	ADJUSTED FLOW (m³/h)	FLOW RANGE OK FOR SELECTED RING?	Adjusted Pressure (Pa)	Ln delta P	Ln Q	Q50 Calculated Flow at 50Pa (m³/h)	Permeability Pressurisation Only (m³/(h.m²))	Air Leakage Pressurisation Only (h⁻¹)
Approx 65 Pa											
Approx 57 Pa									r²		
Approx 49 Pa									C_{env}		m³/h.Pa*n*
Approx 41 Pa									n		
Approx 33 Pa											
Approx 25 Pa									C_L (corrected)		m³/h.Pa*n*
Approx 20 Pa											



Appendix 2 - Images 16-Mar-2015

Camden Group: Site Visit Images 16-Mar-2015

Researchers: Dominic Miles-Shenton, David Farmer

Site Address: C05 & C10, Holly Bank
Blue Dolphin Holiday Park
Filey
North Yorkshire
YO14 9PU

C10

C05

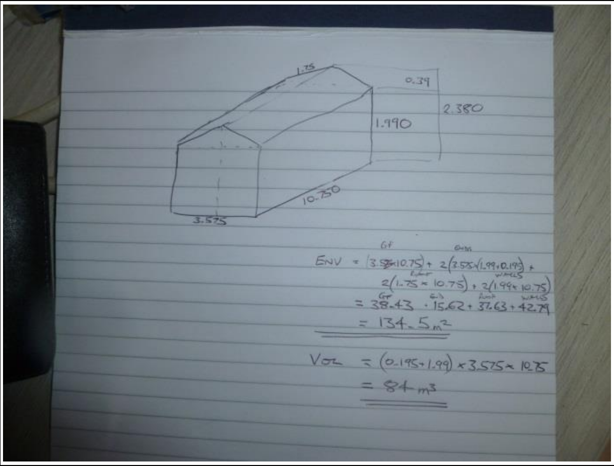
Pressurisation Test Results (depressurisation only):

	Air Permeability	Air Leakage Rate	Correlation coefficient
	$m^3/(h.m^2)$ @ 50 Pa	ach^{-1}	r^2
C05	5.23	8.37	0.999
C10	5.52	8.84	0.998

Images:

C10 on arrival

C10 internal dimensions and area/volume calculations

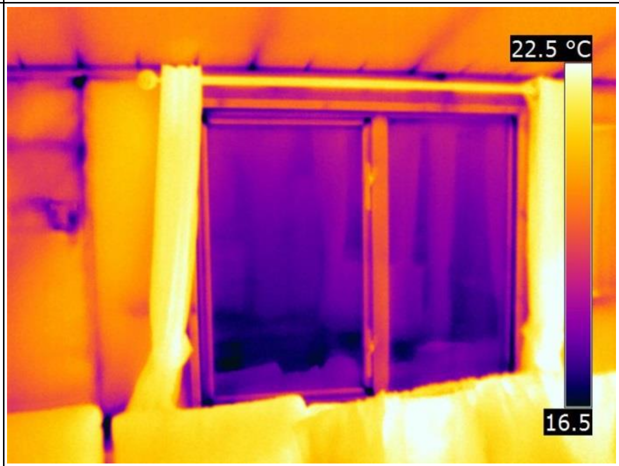


C05 on arrival

C10 prior to pressurisation test

C10 under depressurisation


22.0 °C
16.0

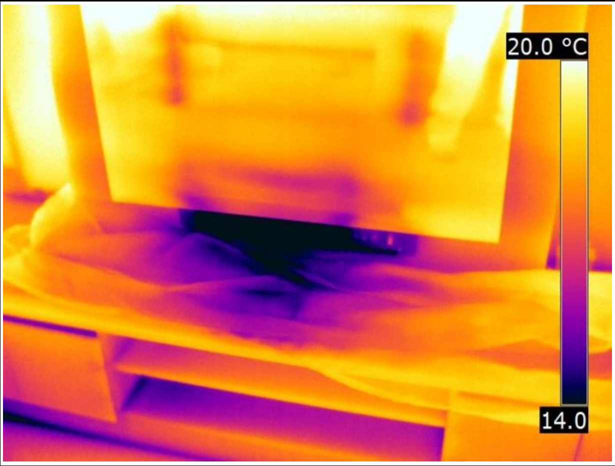

22.5 °C
16.5

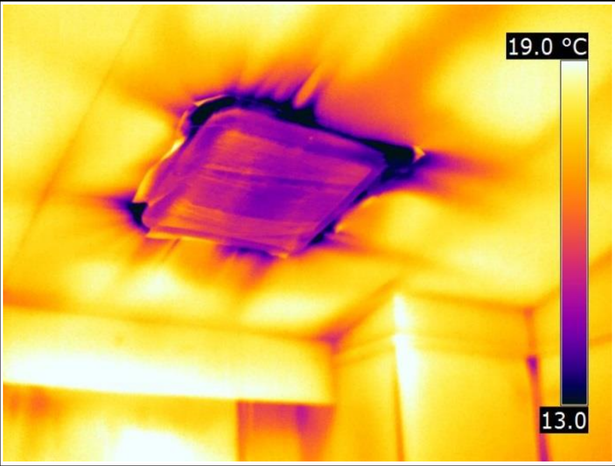

21.0 °C
15.0


22.5 °C
16.5


23.0 °C
17.0


21.5 °C
15.5

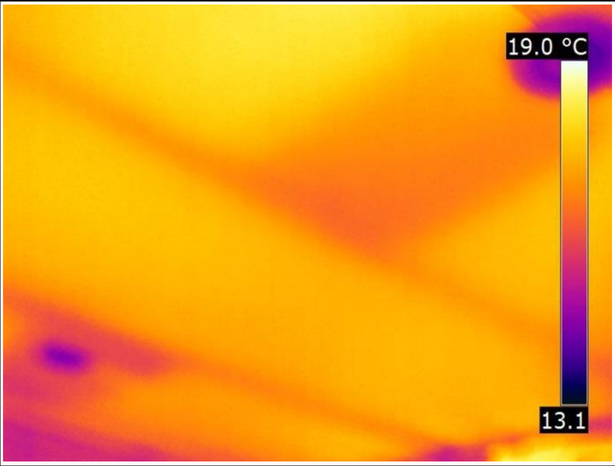

20.0 °C
14.0


19.0 °C
13.0



19.0 °C
13.0

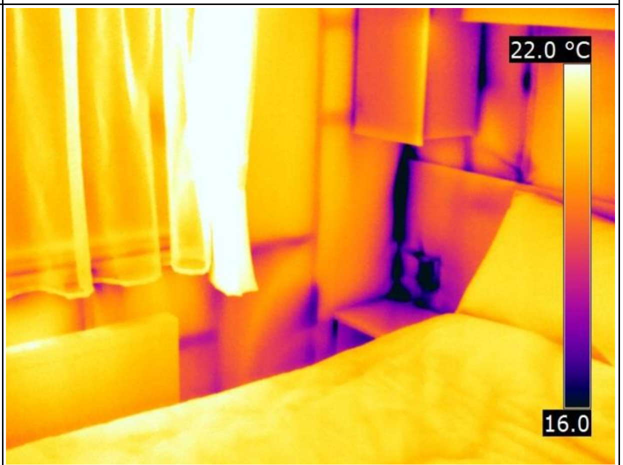

19.0 °C
13.0

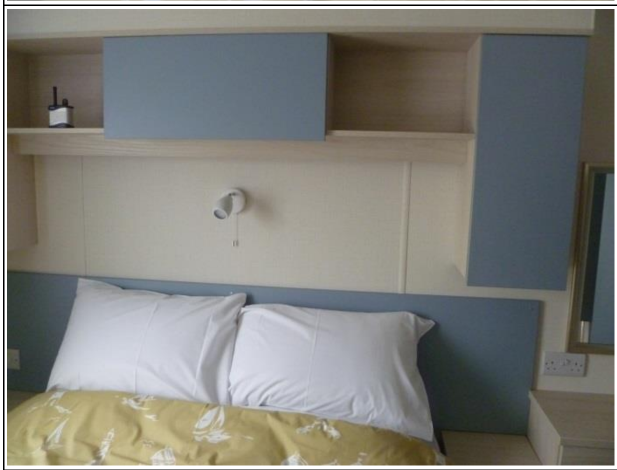

19.0 °C
13.1

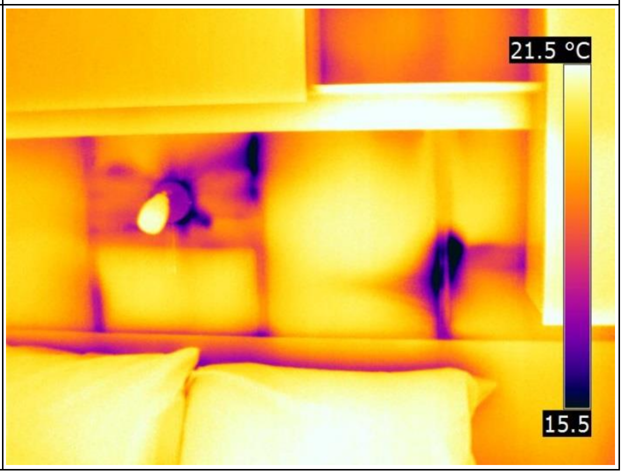

17.0 °C
11.0


22.0 °C
16.0

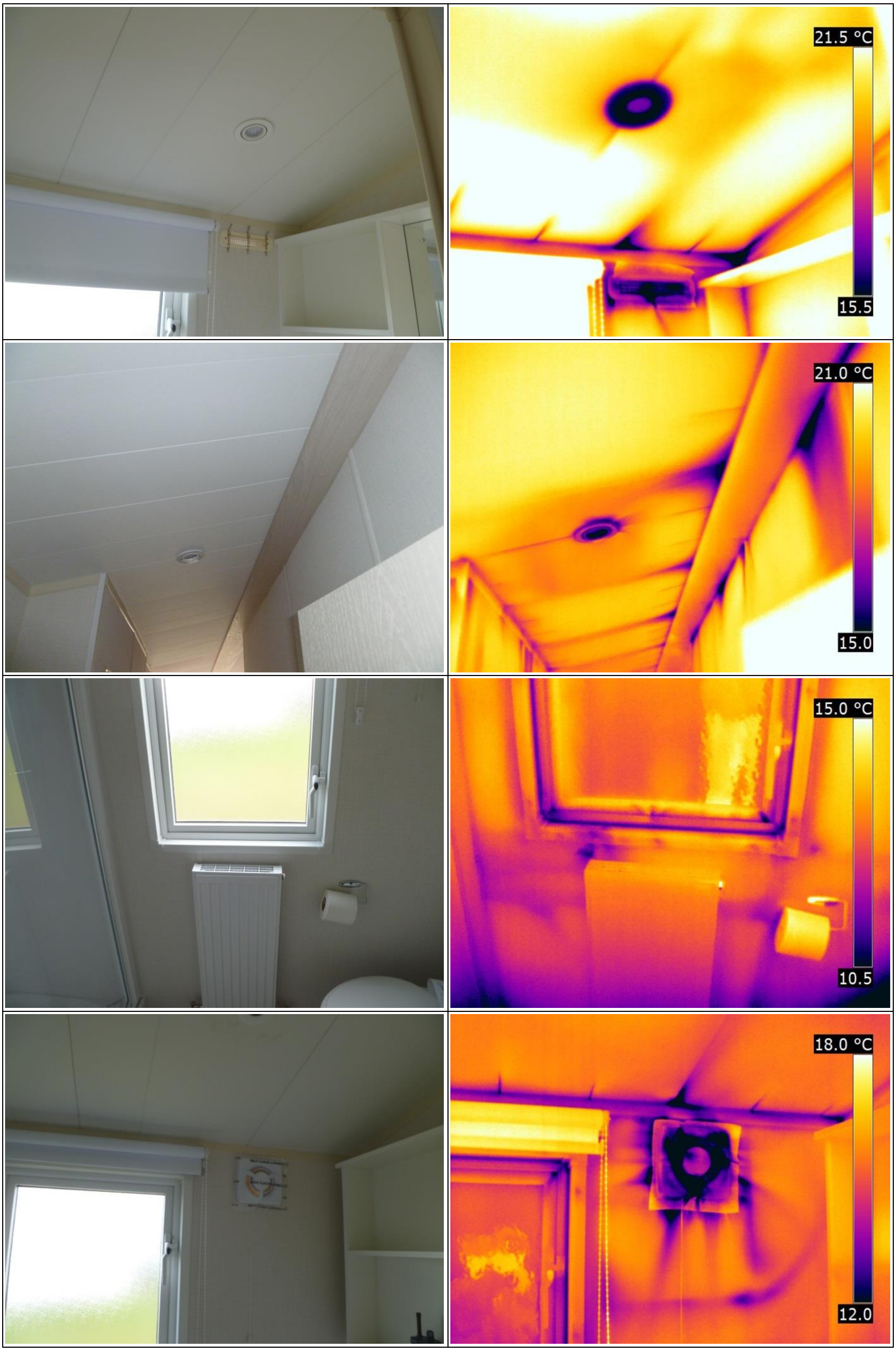

22.0 °C
16.0

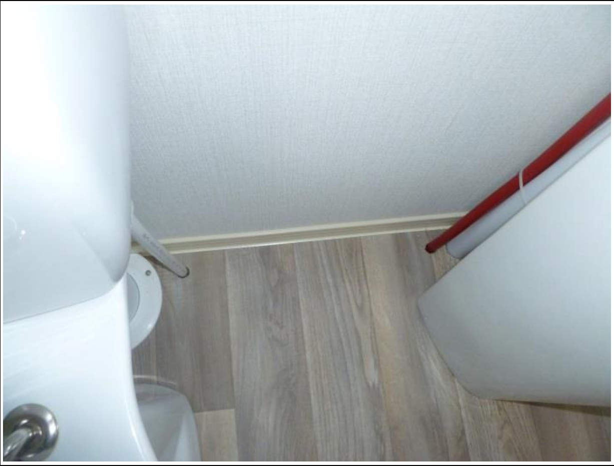

22.0 °C
16.0




21.5 °C
15.5

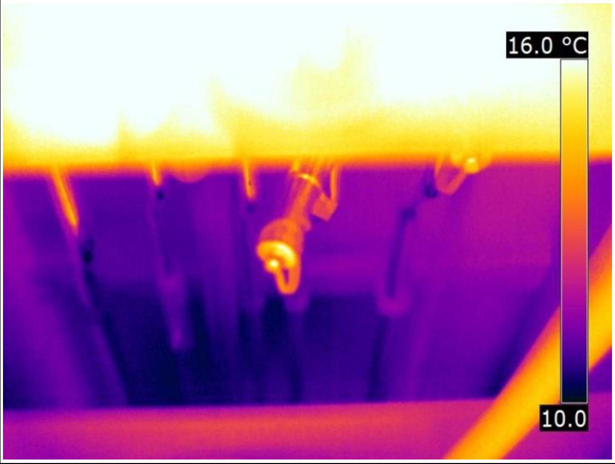

21.5 °C
15.5
18.5 °C
12.4
20.5 °C
14.5
Your toilet has been sanitised
18.0 °C
12.0

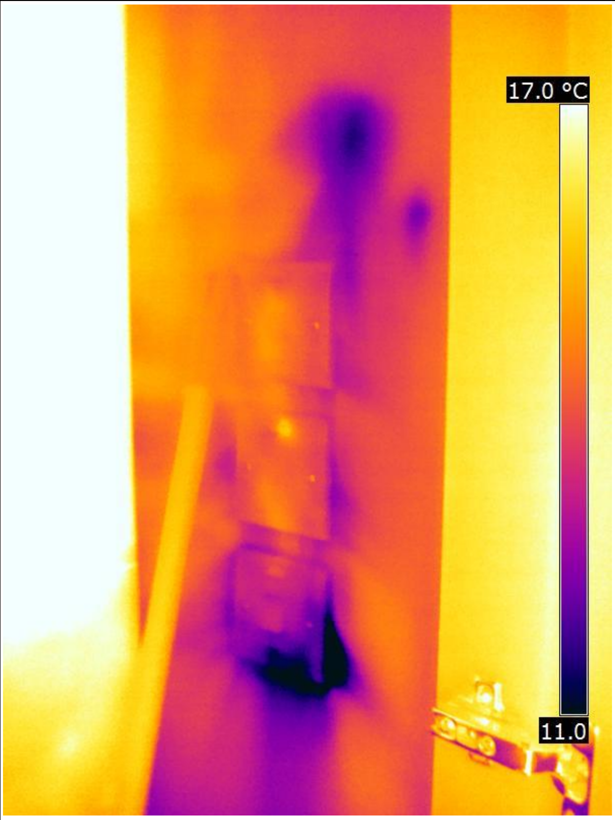

21.5 °C
15.5
21.0 °C
15.0
15.0 °C
10.5
18.0 °C
12.0




12.0 °C
7.5


AT011427/06
MORCO

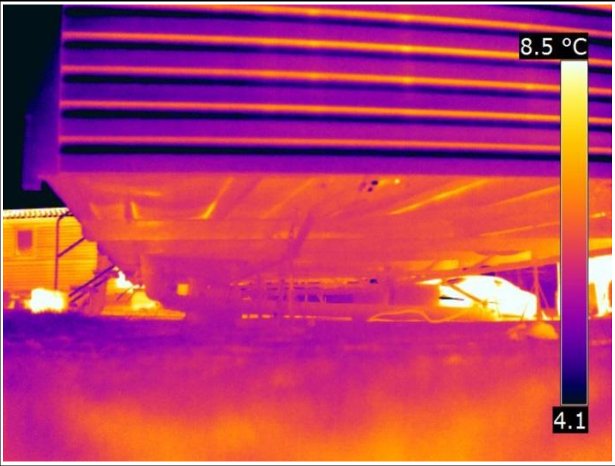

16.0 °C
10.0



C05 prior to pressurisation test

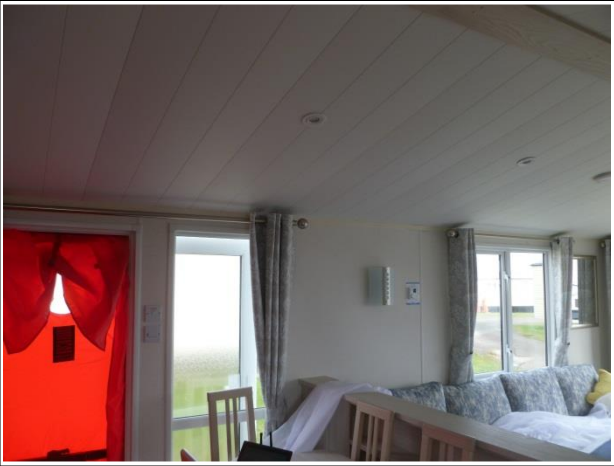
10.0 °C
4.0

10.5 °C
4.5



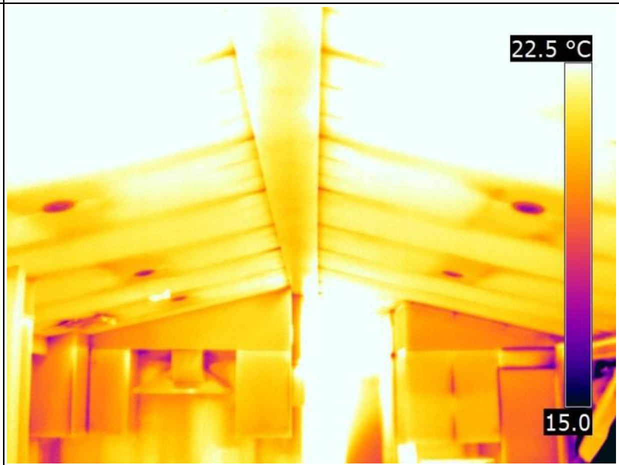
8.5 °C
4.1

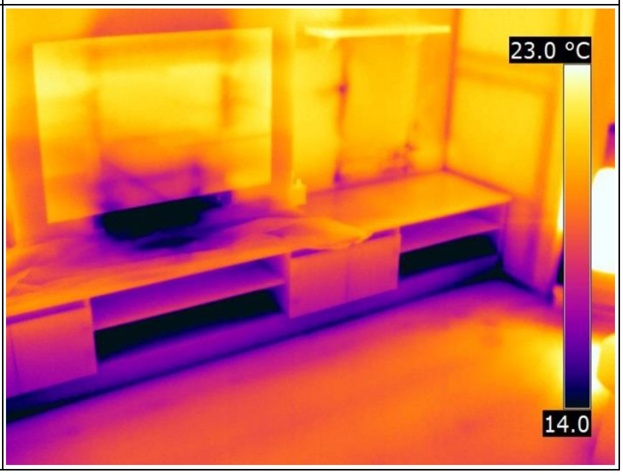
24.0 °C
15.0

C05 under depressurisation	
	
	
	


24.0 °C
15.0


21.5 °C
14.0

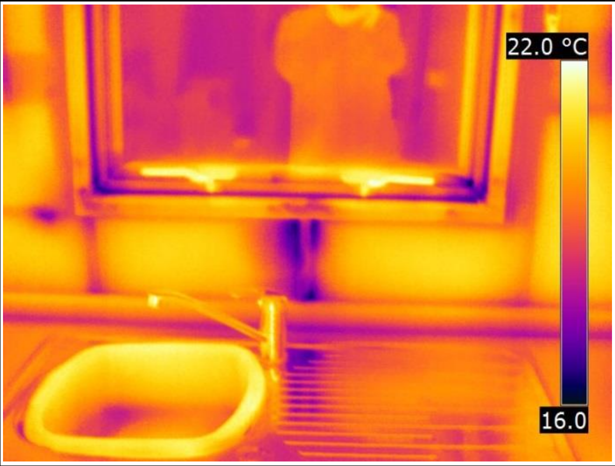

22.5 °C
15.0

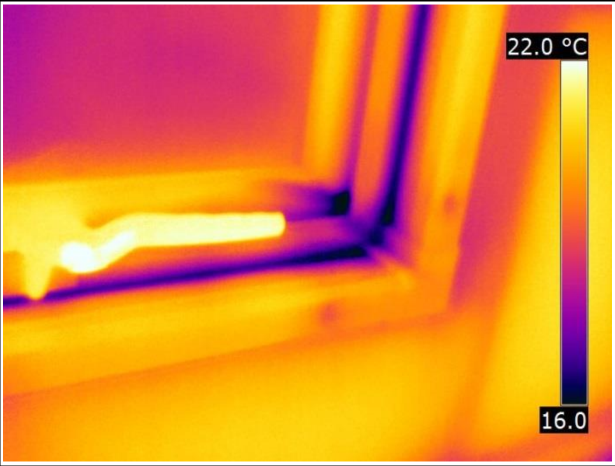

23.0 °C
14.0



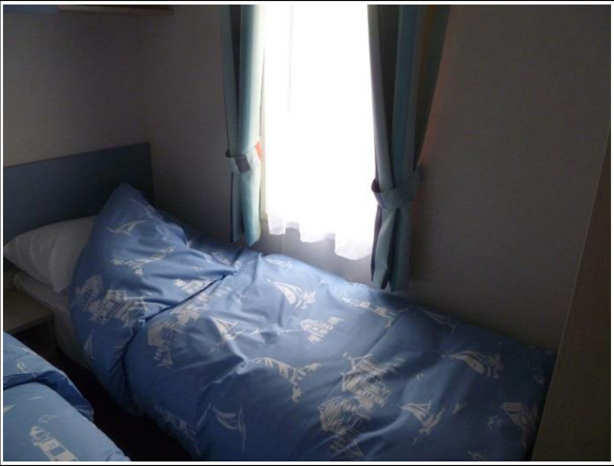
22.0 °C
16.0

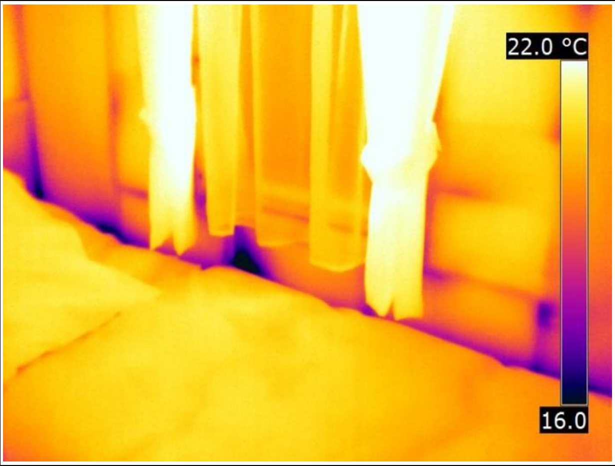

22.0 °C
16.0

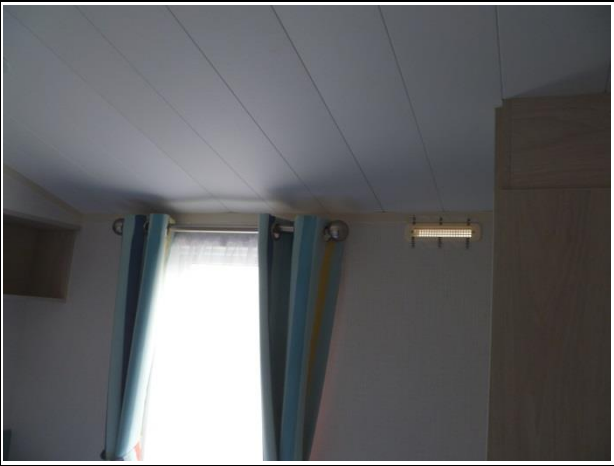

22.0 °C
16.0

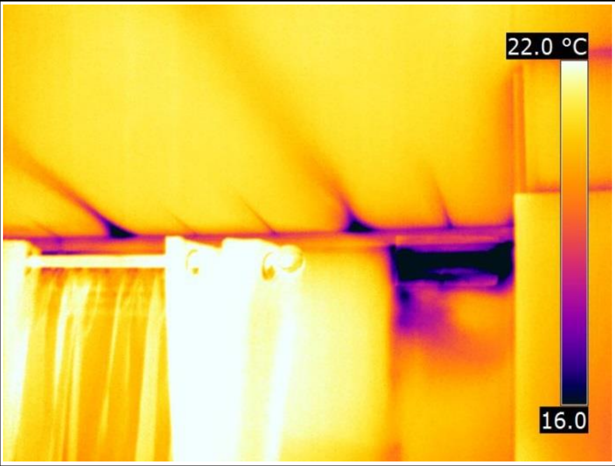

22.0 °C
16.0

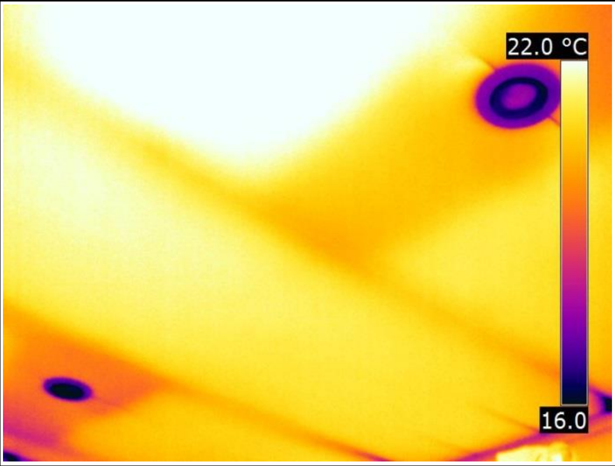

22.0 °C
16.0

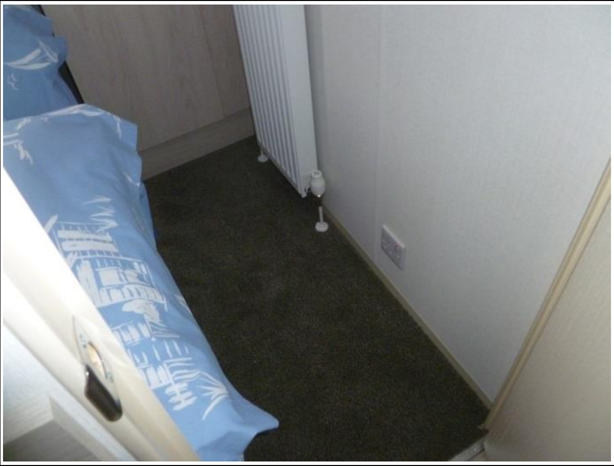


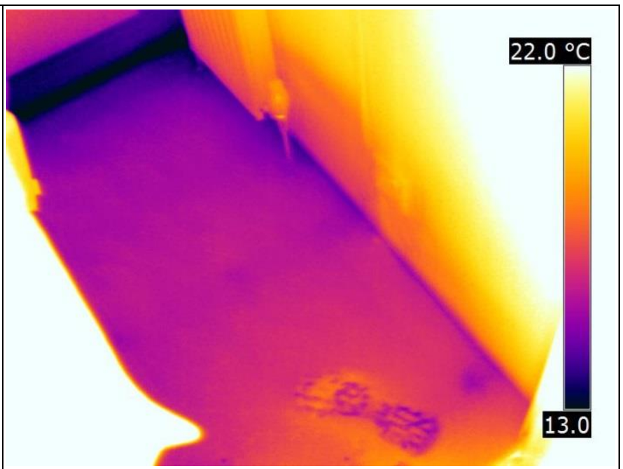

22.0 °C
16.0




22.0 °C
16.0


22.0 °C
16.0




22.0 °C
13.0

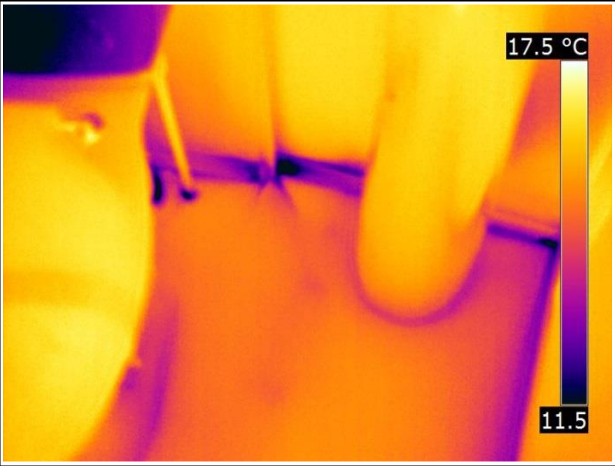

21.0 °C
15.0

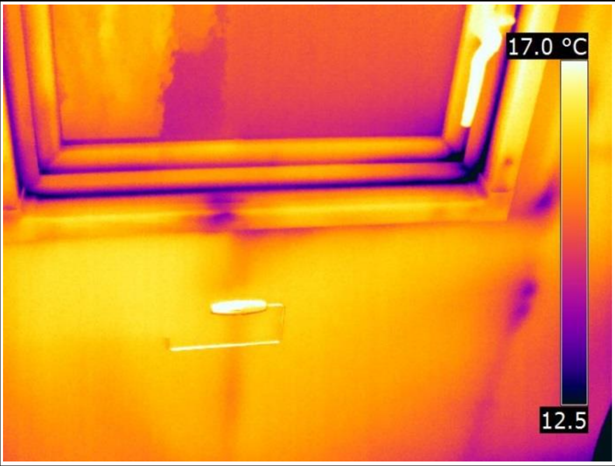

22.0 °C
16.0

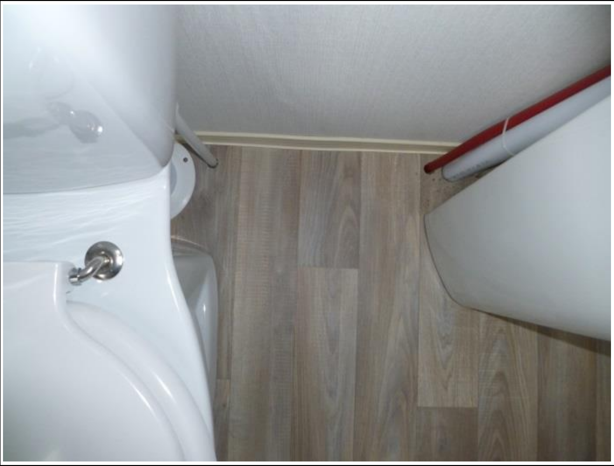

20.0 °C
14.0

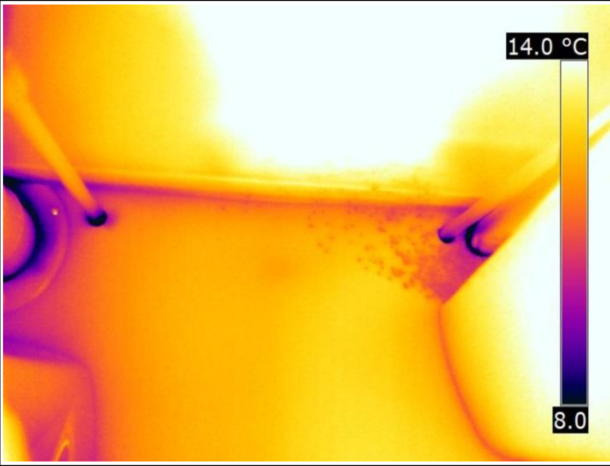

21.5 °C
15.5


19.0 °C
10.0

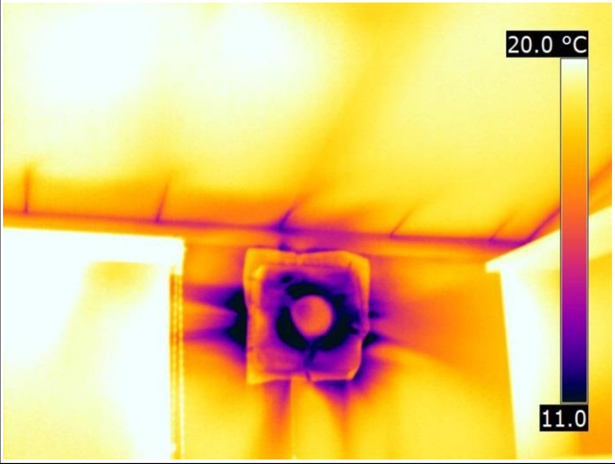

17.5 °C
11.5


17.0 °C
12.5



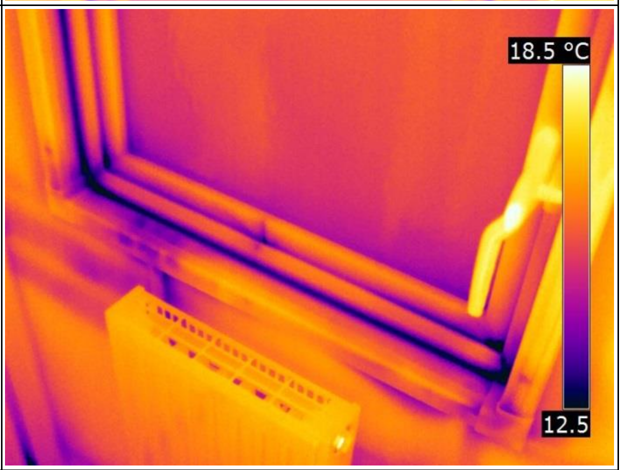


14.0 °C
8.0

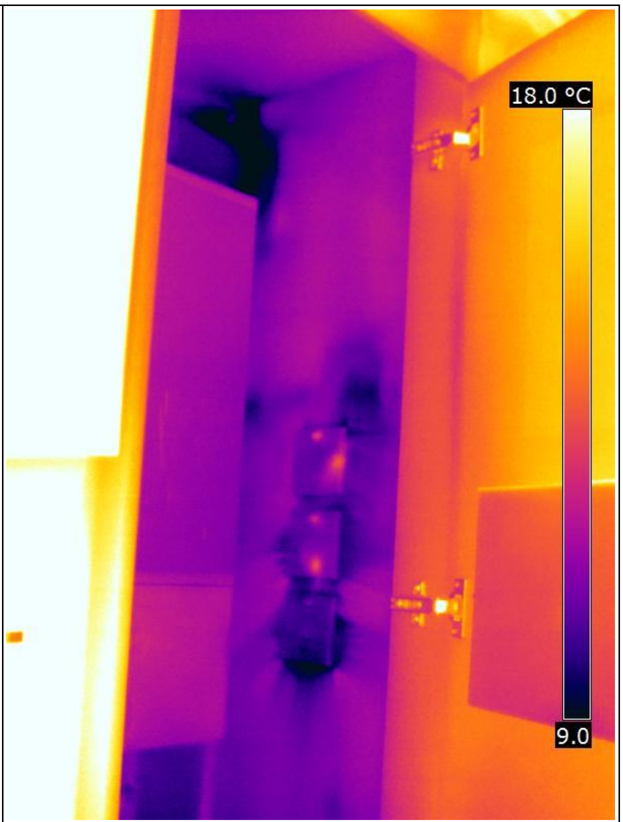


20.0 °C
11.0

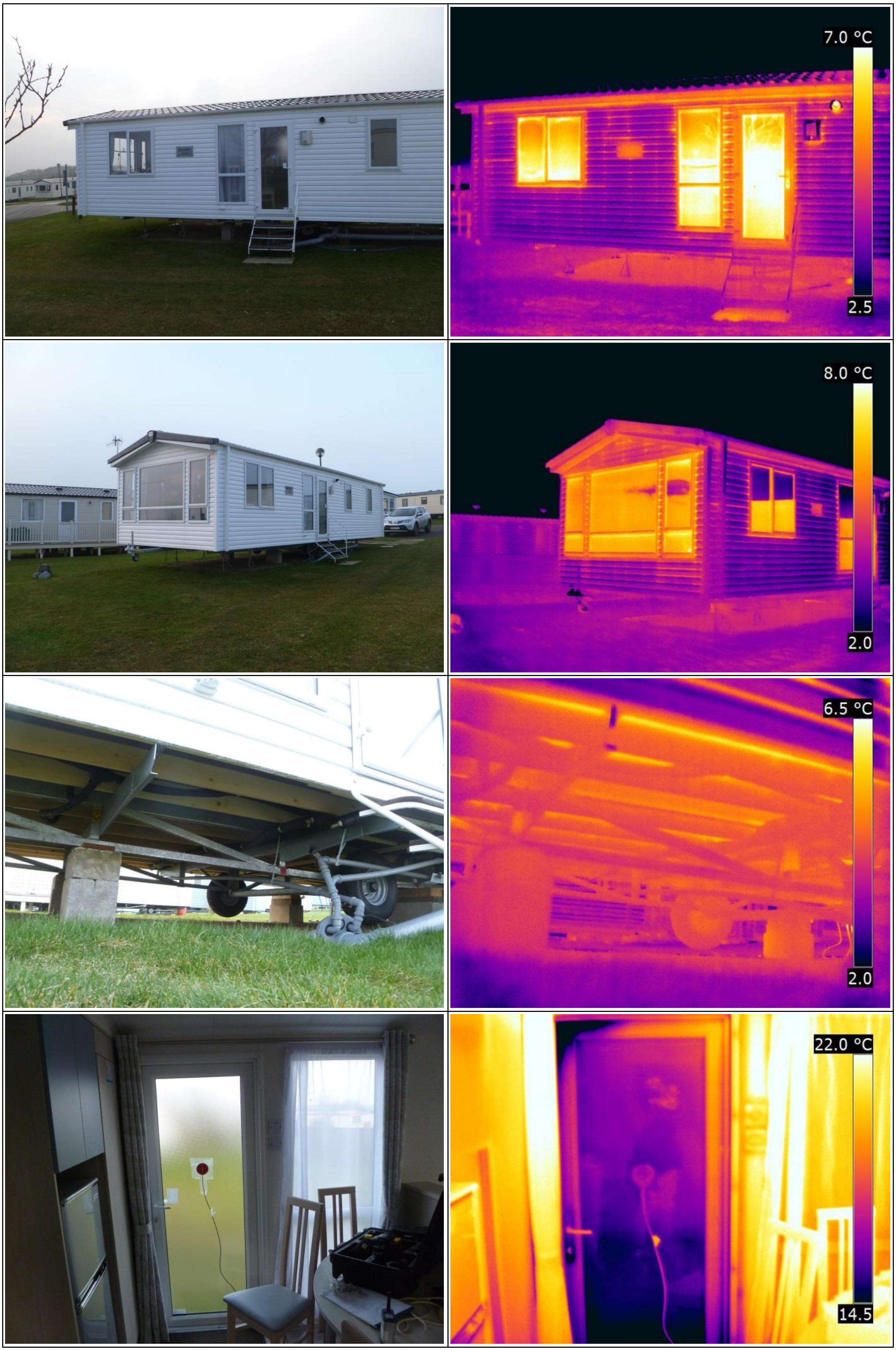
19.5 °C
13.5



18.5 °C
12.5



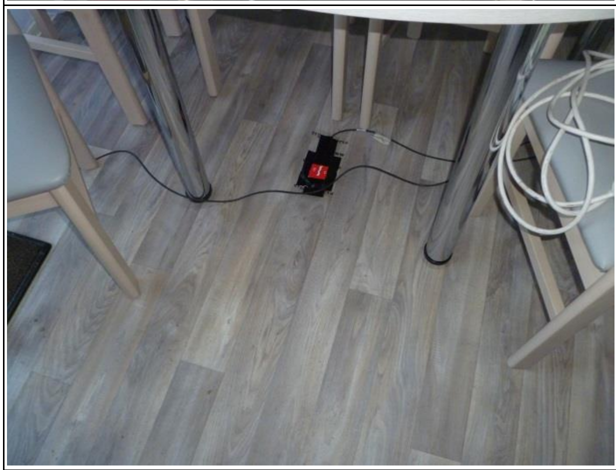
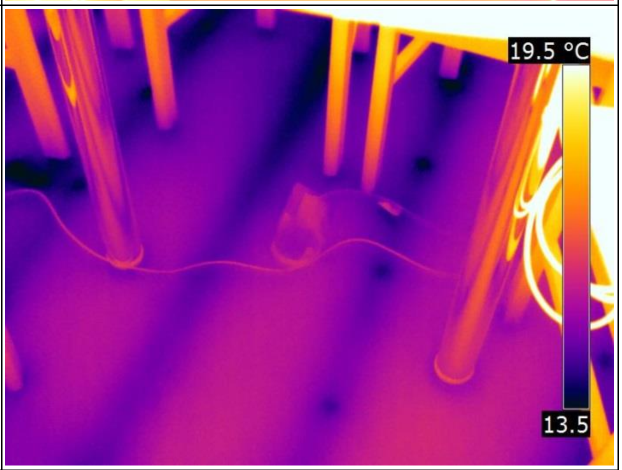
C10 Heated, following pressurisation test, with heat flux sensor placements


7.0 °C
2.5
8.0 °C
2.0
6.5 °C
2.0
22.0 °C
14.5



22.5 °C
15.0


23.5 °C
19.0


22.5 °C
16.5


19.5 °C
13.5

C05 Heat flux sensor placement

Appendix 3 - Images 18-Mar-2015

Camden Group: Site Visit Images 18-Mar-2015

Researchers: Dominic Miles-Shenton, David Farmer

Site Address: C05 & C10, Holly Bank
Blue Dolphin Holiday Park
Filey
North Yorkshire
YO14 9PU

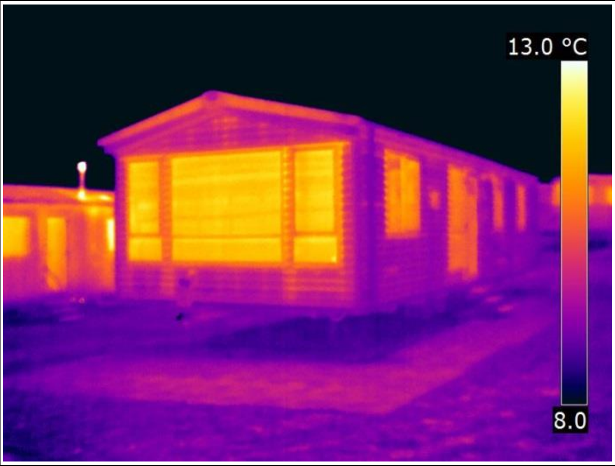
Pressurisation Test Result 18-Mar-2015 (depressurisation only):

	Air Permeability	Air Leakage Rate	Correlation coefficient
	$m^3/(h.m^2)$ @ 50 Pa	ach^{-1}	r^2
C05	5.73	9.17	0.999

Previous pressurisation Test Results 16-Mar-2015 (depressurisation only):

	Air Permeability	Air Leakage Rate	Correlation coefficient
	$m^3/(h.m^2)$ @ 50 Pa	ach^{-1}	r^2
C05	5.23	8.37	0.999
C10	5.52	8.84	0.998

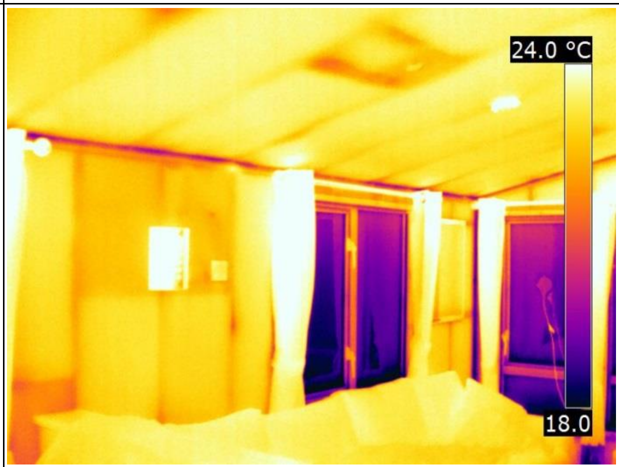
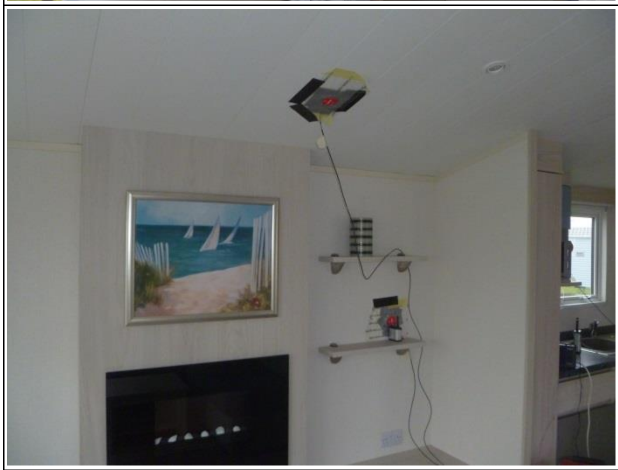
Images:

C05 on arrival	
	
	
	


12.0 °C
7.0
11.5 °C
6.5
12.0 °C
7.0
RUBY
11.0 °C
6.0

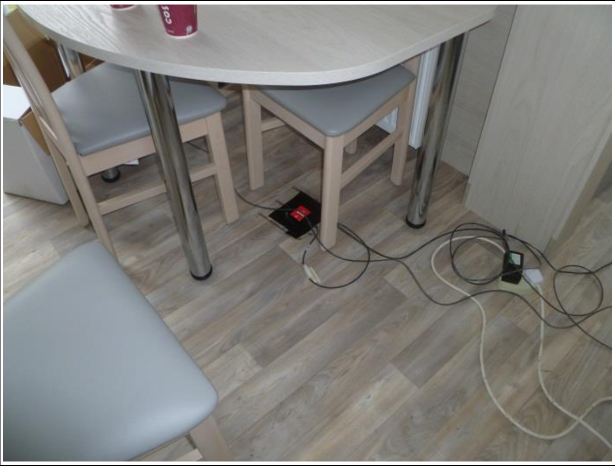
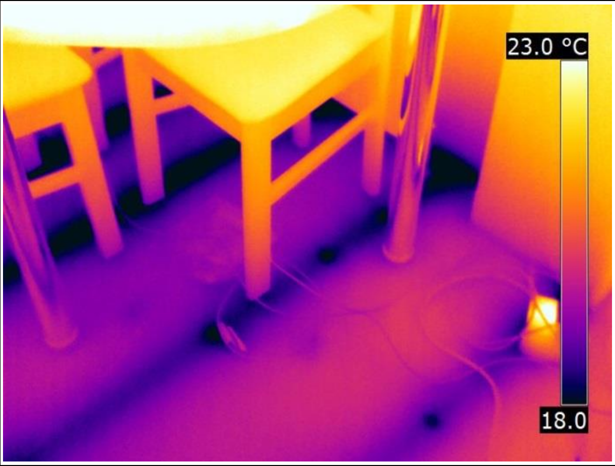


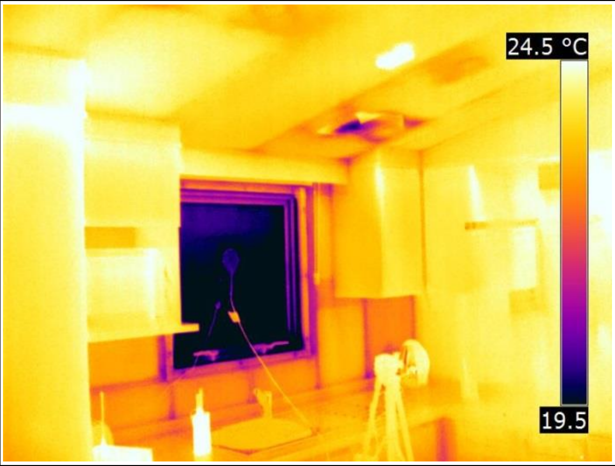
24.0 °C
18.0


24.0 °C
18.0


25.0 °C
20.0

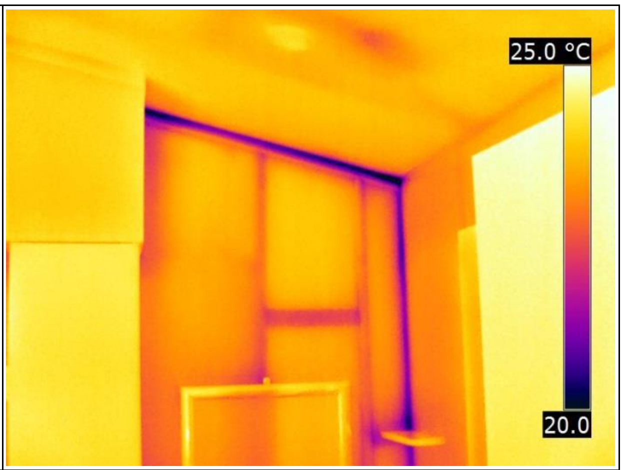

24.0 °C
19.0

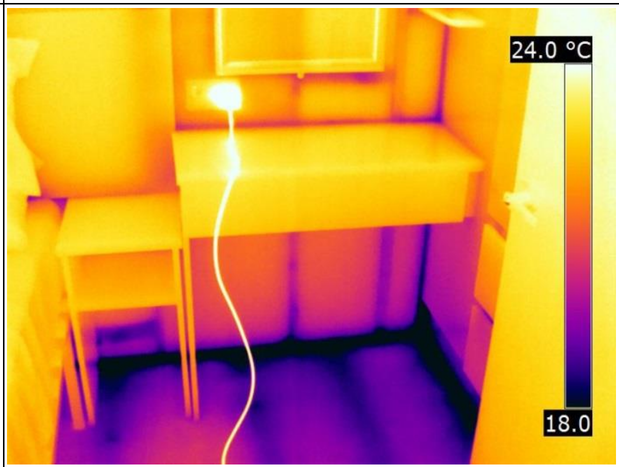


23.0 °C
18.0

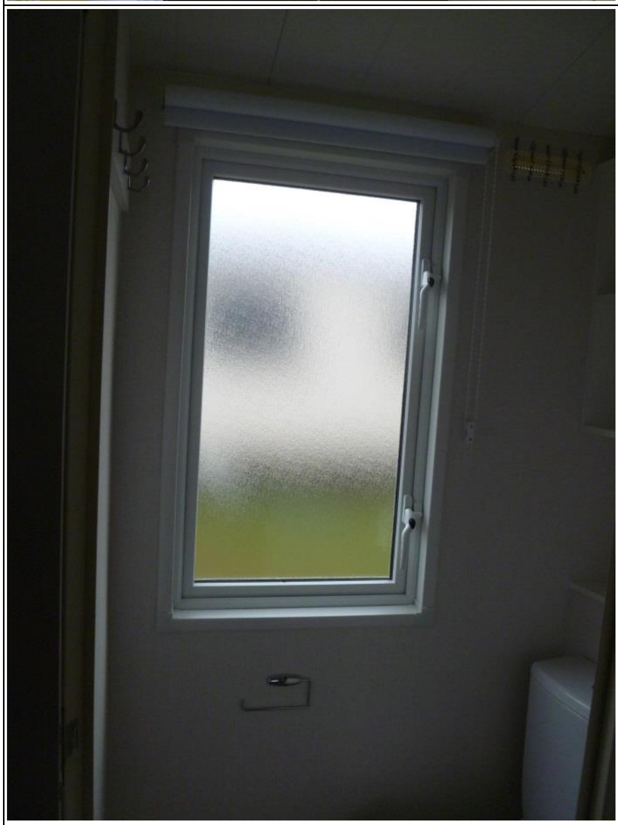

24.5 °C
19.5

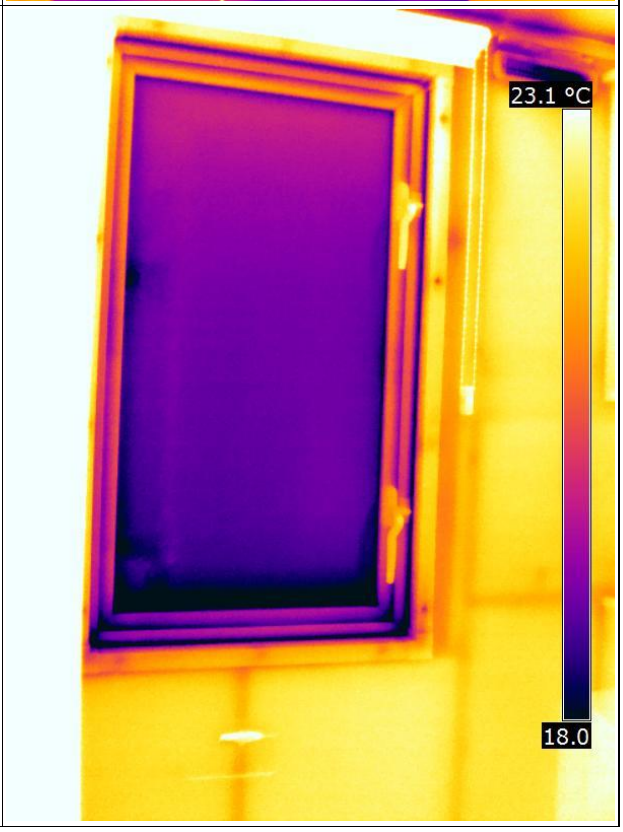

26.0 °C
20.0

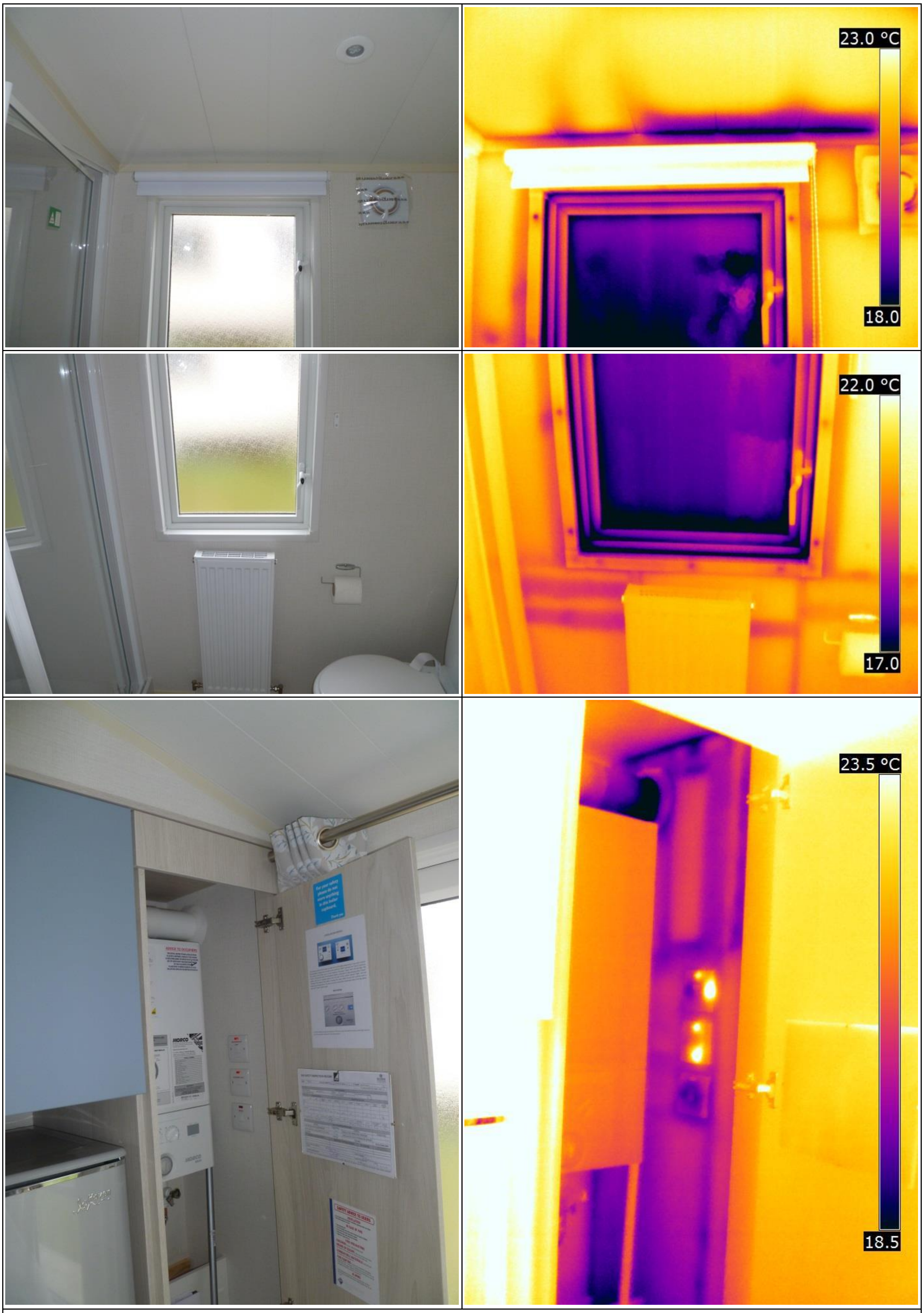

24.5 °C
18.5


25.0 °C
20.0


24.0 °C
18.0




23.1 °C
18.0

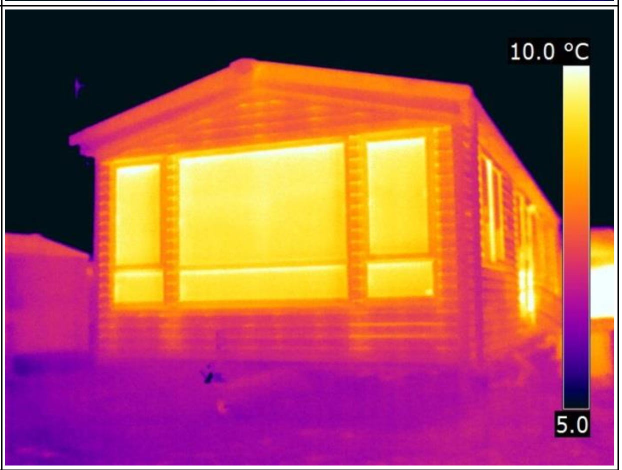


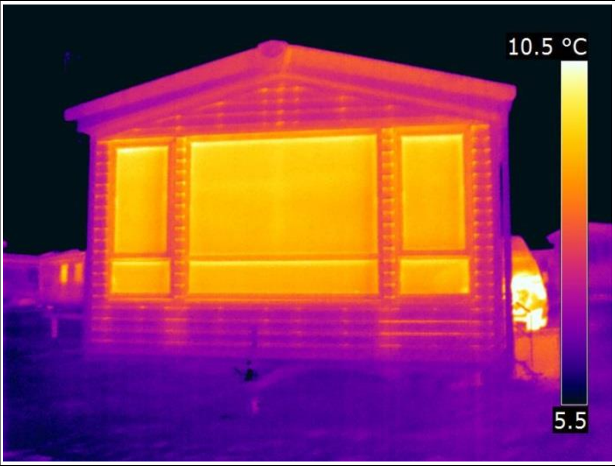
C10 on arrival


11.0 °C
6.0

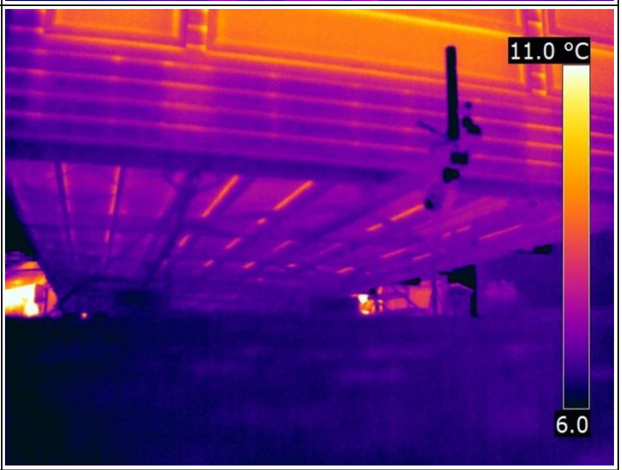

10.0 °C
5.0

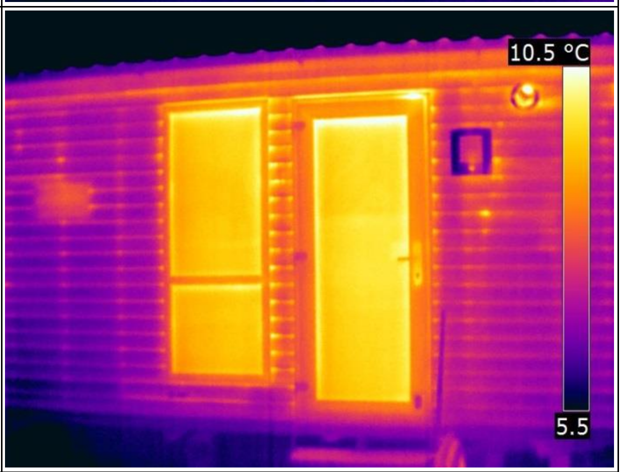

11.0 °C
6.0


10.0 °C
5.0



10.5 °C
5.5


10.5 °C
5.5

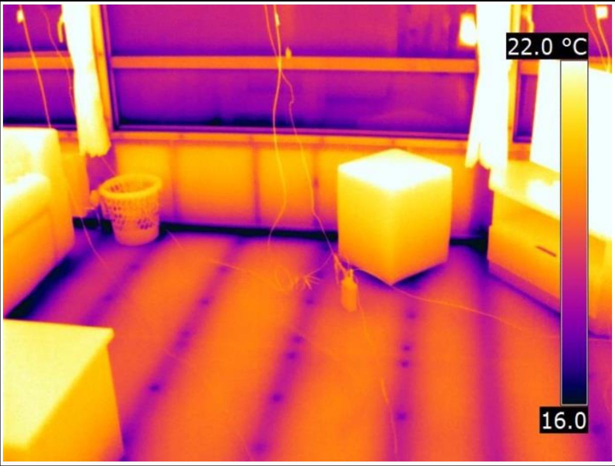

11.0 °C
6.0

RUBY

10.5 °C
5.5



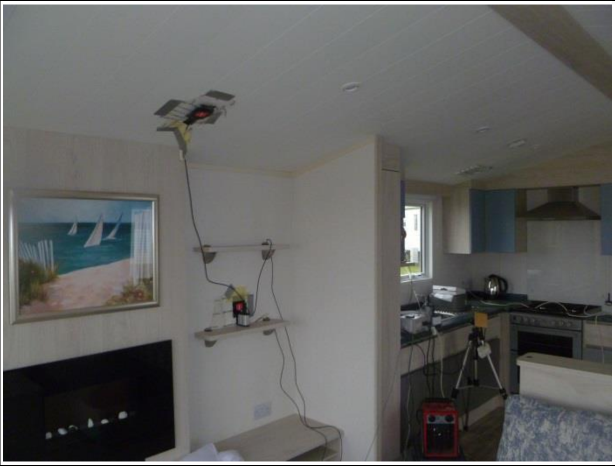
23.5 °C
17.0


23.5 °C
17.0


22.0 °C
16.0

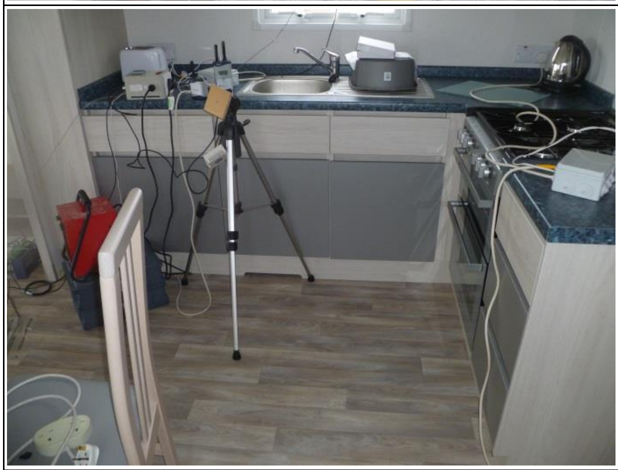

24.0 °C
18.0


22.9 °C
18.0

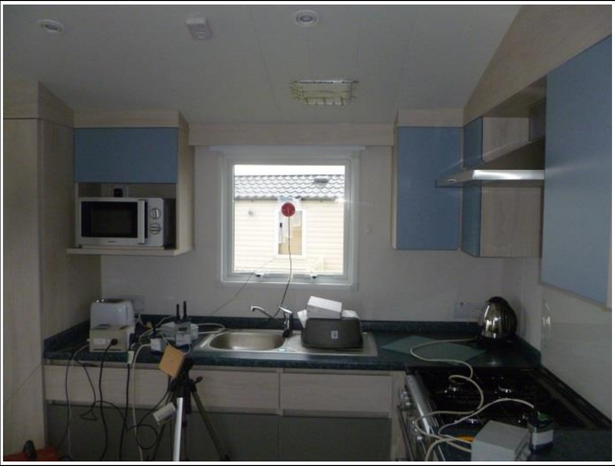


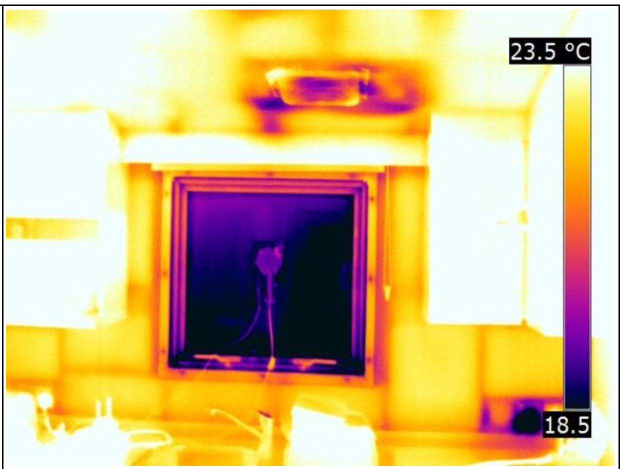

24.0 °C
19.0


26.0 °C
20.0



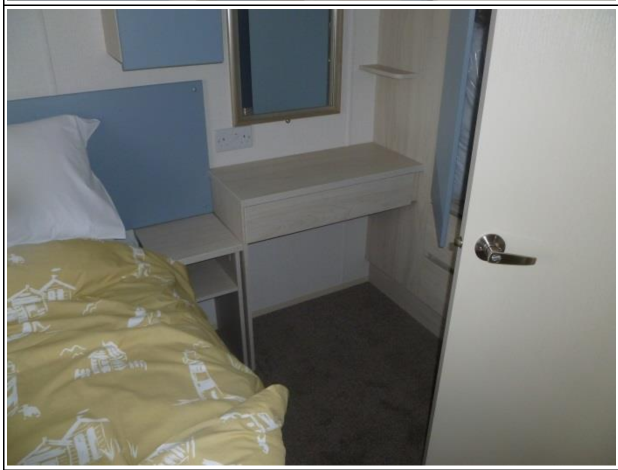

23.0 °C
14.0

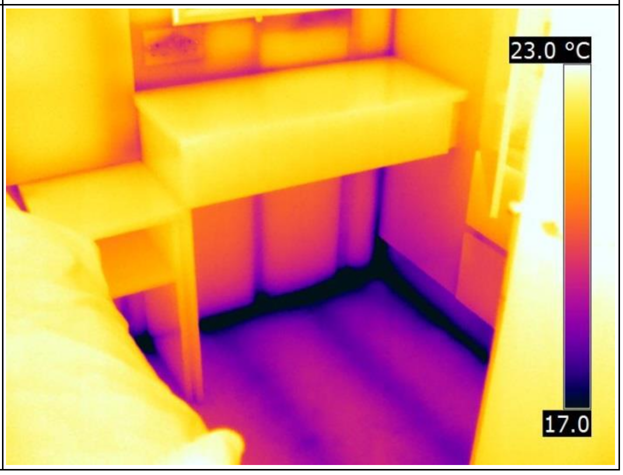



23.5 °C
18.5

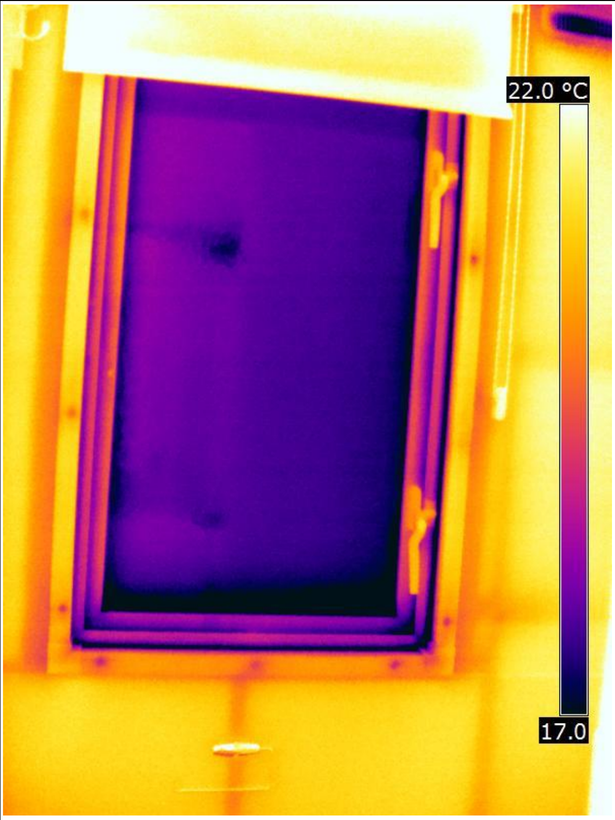

23.0 °C
18.0

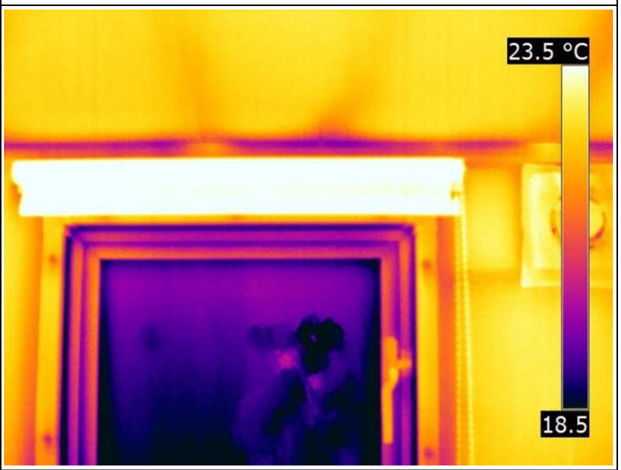

24.0 °C
19.0

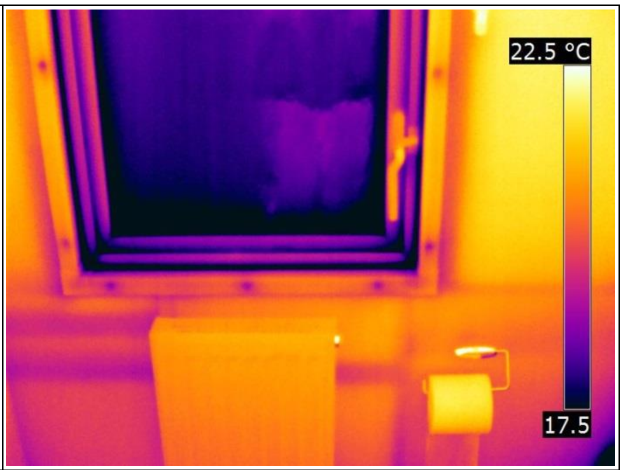


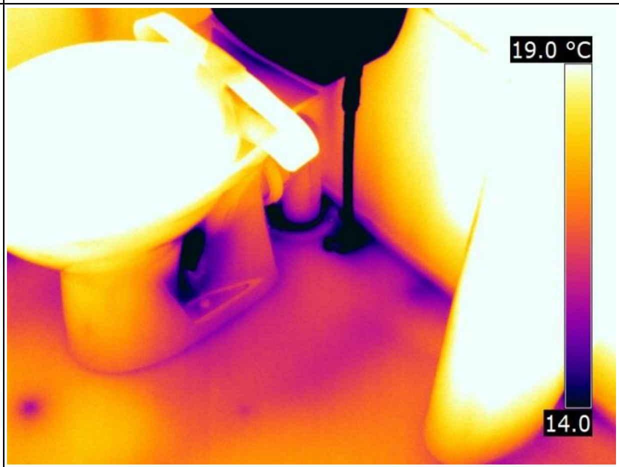

23.0 °C
17.0


24.0 °C
19.0


22.0 °C
17.0

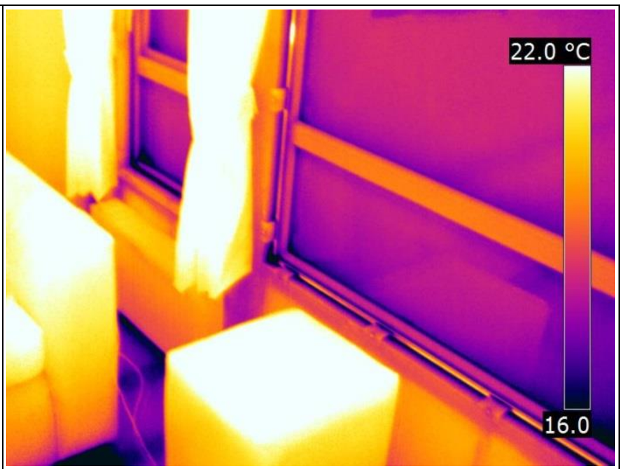

23.5 °C
18.5


22.5 °C
17.5


19.0 °C
14.0


23.0 °C
18.0

C05 window removal


22.0 °C
16.0


23.0 °C
17.5


23.5 °C
17.0

C05 window replacement


C 5

5

C 5






ATLAS LEISURE HOMES LTD
BG
Camden
Glazing
1231250


This window contains
Pilkington K Glass™ S
energy-efficient glass
This surface must face the room interior
www.pilkington.co.uk/kglass



RUBY

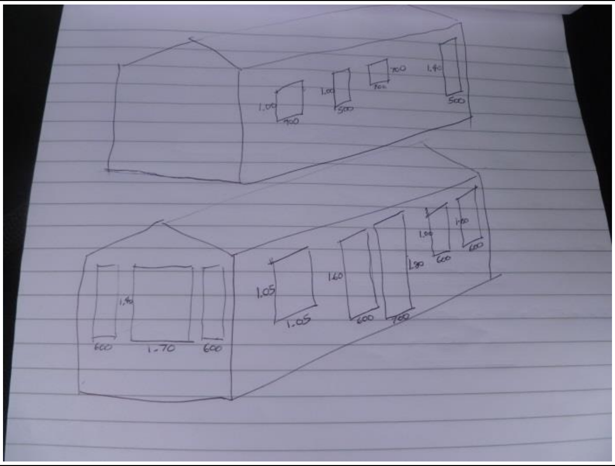




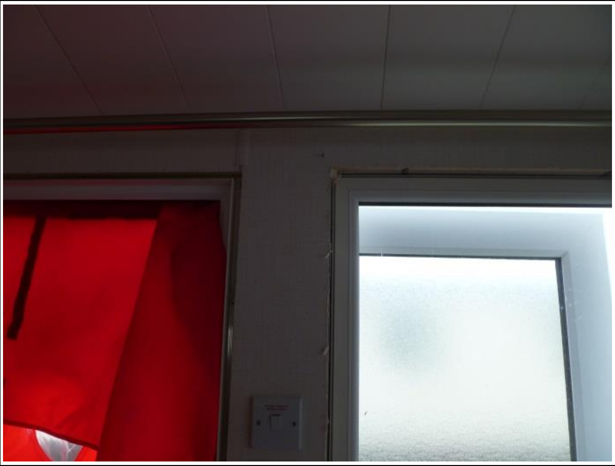

18.0 °C
12.5
17.5 °C
12.4
inliten


C05 removed window



C05 pressure test



Appendix 4 - Images 20-Mar-2015

Camden Group: Site Visit Images 20-Mar-2015

Researchers: Dominic Miles-Shenton, David Farmer, Prof. David Johnston

Site Address: C05 & C10, Holly Bank
Blue Dolphin Holiday Park
Filey
North Yorkshire
YO14 9PU

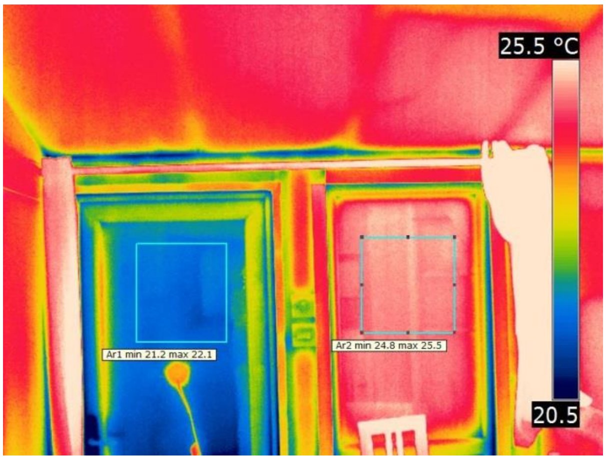
Pressurisation Test Result 20-Mar-2015 (depressurisation only):

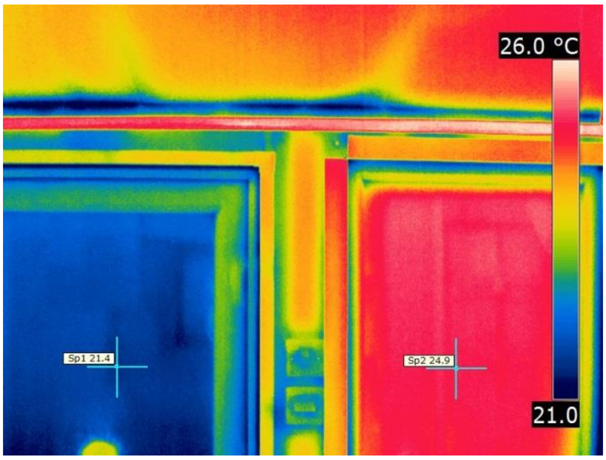
	Air Permeability	Air Leakage Rate	Correlation coefficient
	$m^3/(h.m^2)$ @ 50 Pa	ach^{-1}	r^2
C05	5.54	8.88	0.999

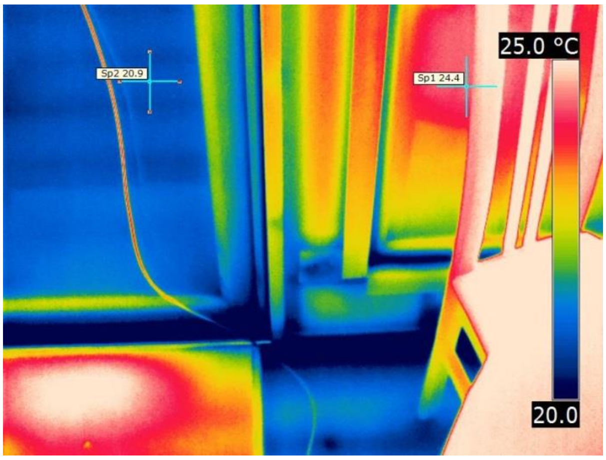
Previous pressurisation Test Results (depressurisation only):

	Date	Air Permeability	Air Leakage Rate	Correlation coefficient
		$m^3/(h.m^2)$ @ 50 Pa	ach^{-1}	r^2
C05	16-Mar-2015	5.23	8.37	0.999
C05	18-Mar-2015	5.73	9.17	0.999
C10	16-Mar-2015	5.52	8.84	0.998

Direct comparison of the original door and a replacement window in C05:

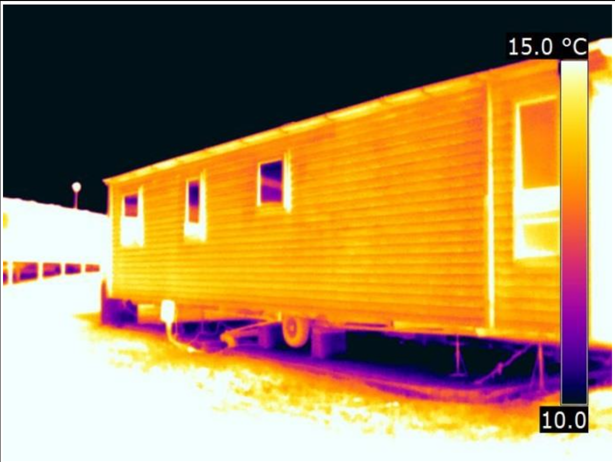


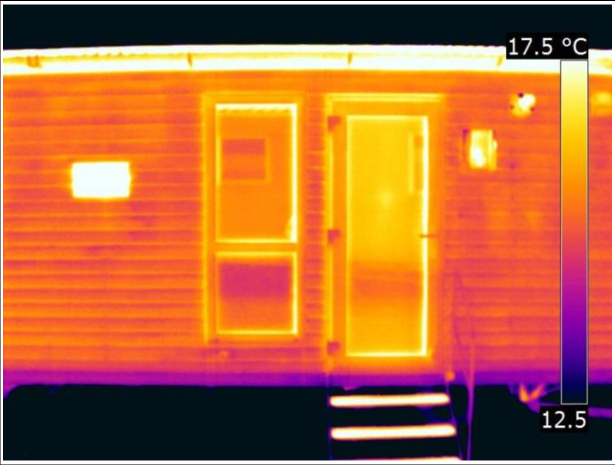




Images:

C05 on arrival







17.5 °C
10.0


29.5 °C
22.0


27.5 °C
22.5

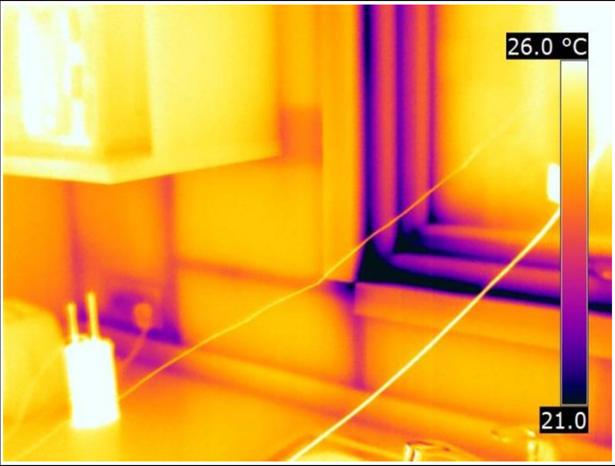

27.5 °C
22.5

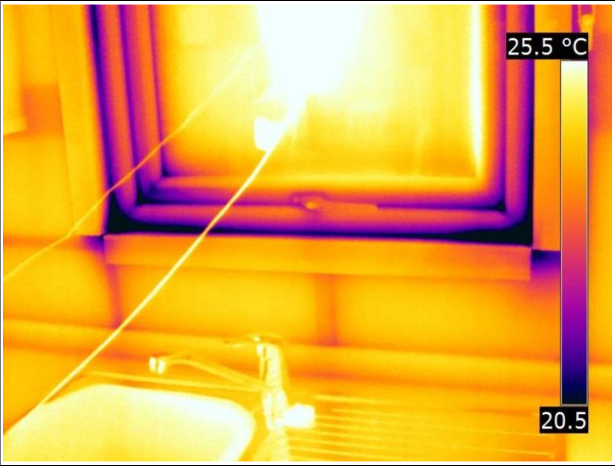

27.5 °C
20.0


27.1 °C
22.0

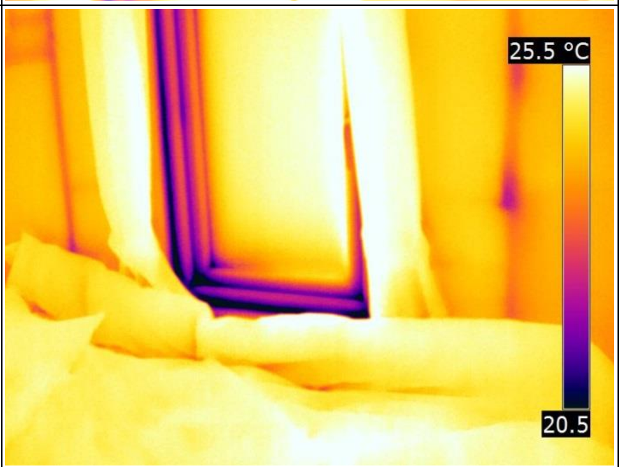

26.5 °C
21.5

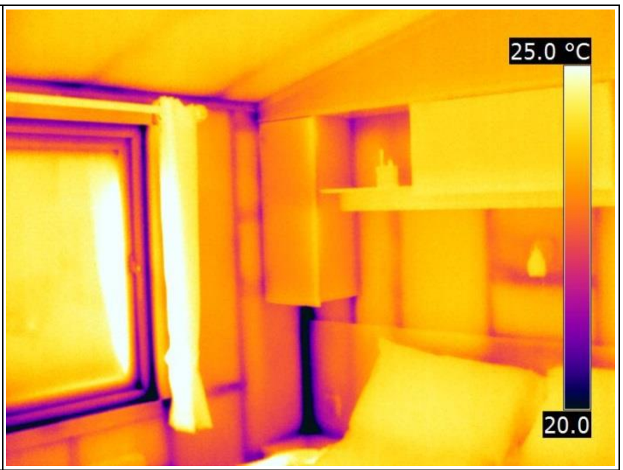

25.0 °C
17.5

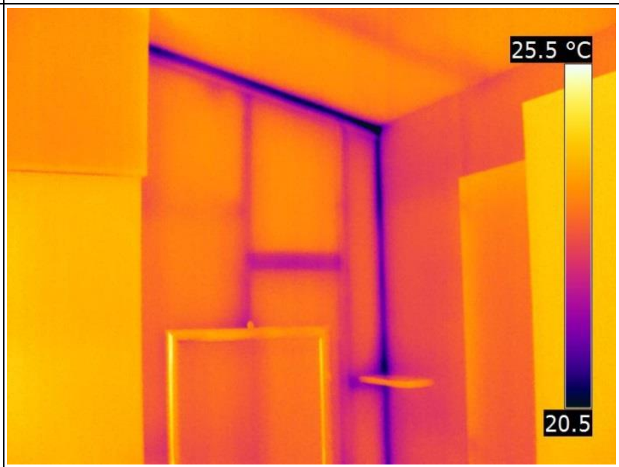


26.0 °C
21.0


25.5 °C
20.5

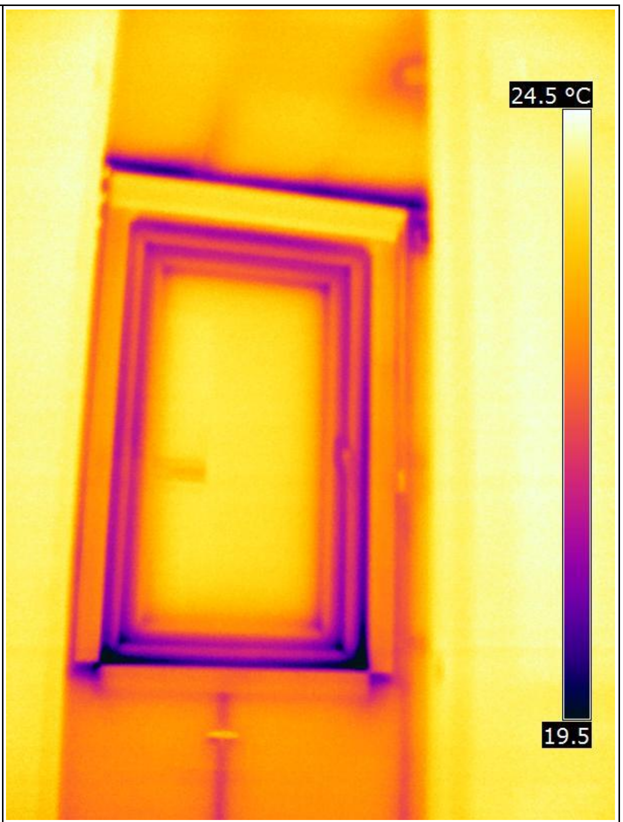

25.0 °C
20.0


25.5 °C
20.5

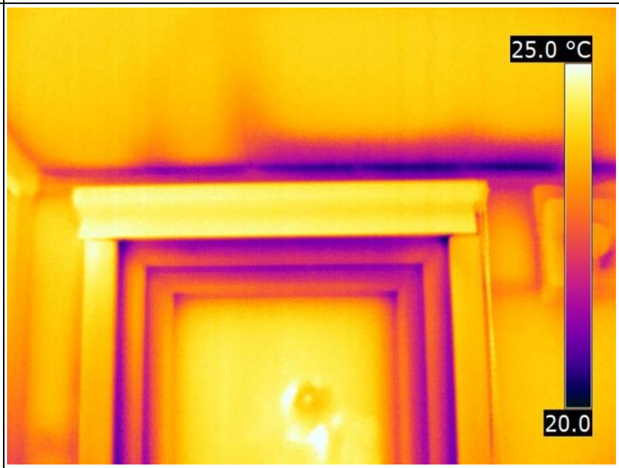

25.0 °C
20.0


25.5 °C
20.5

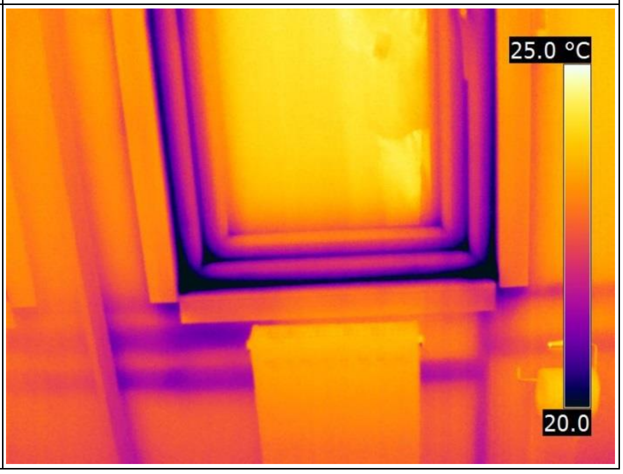

23.5 °C
18.5



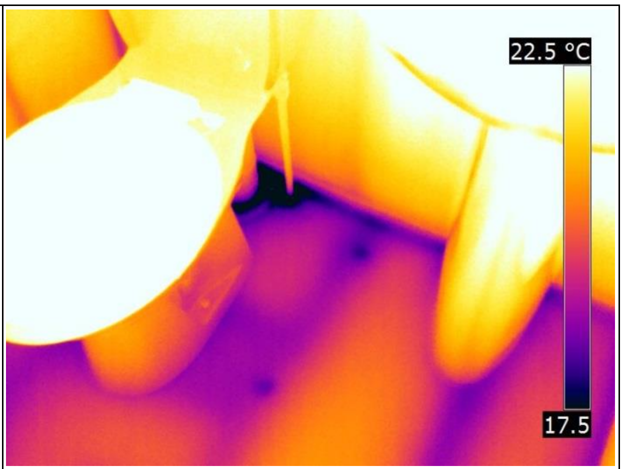
24.5 °C
19.5

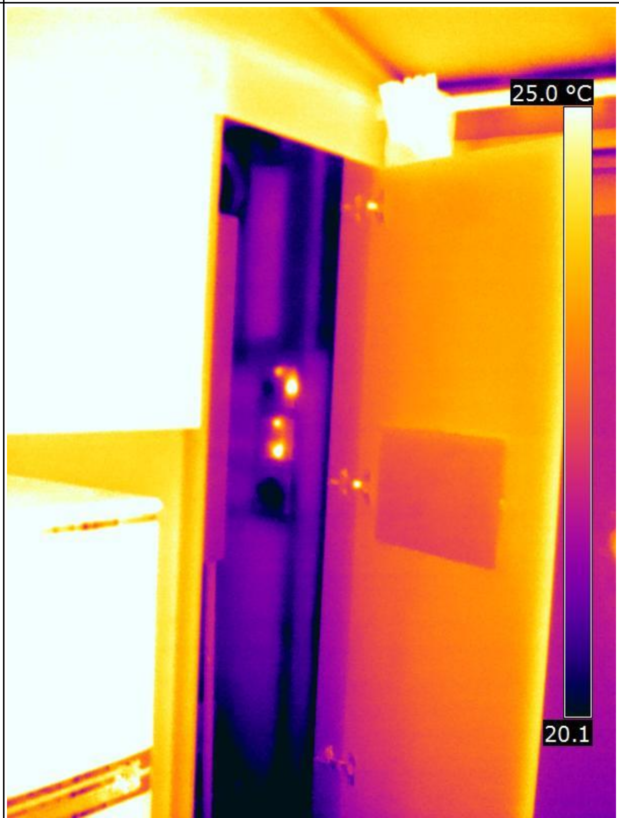


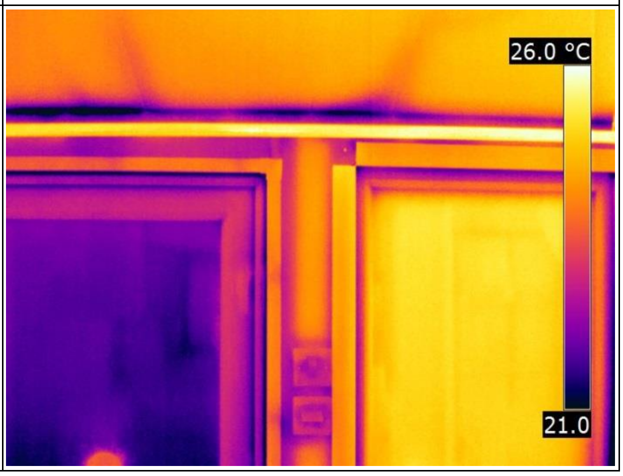
25.0 °C
20.0



25.0 °C
20.0

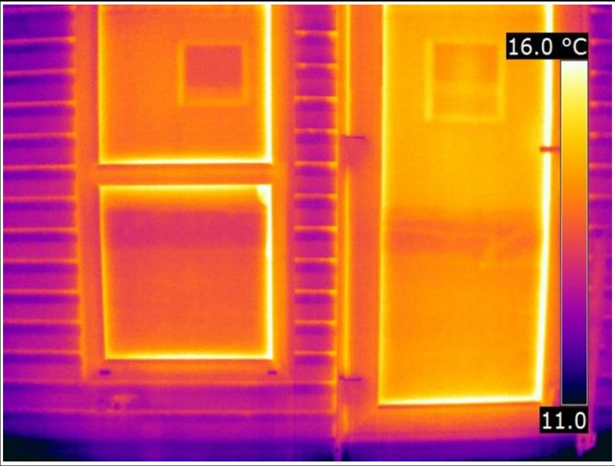

22.5 °C
17.5

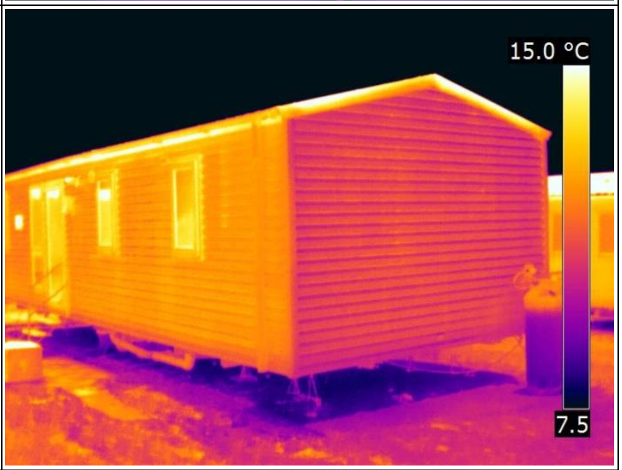

25.0 °C
20.1


26.0 °C
21.0


24.5 °C
19.5


25.5 °C
20.5

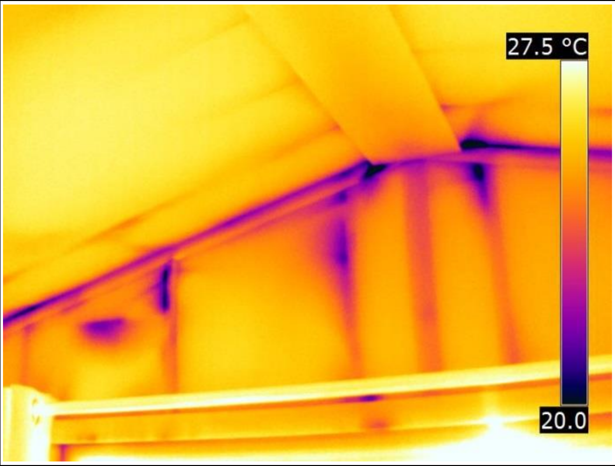

16.0 °C
11.0

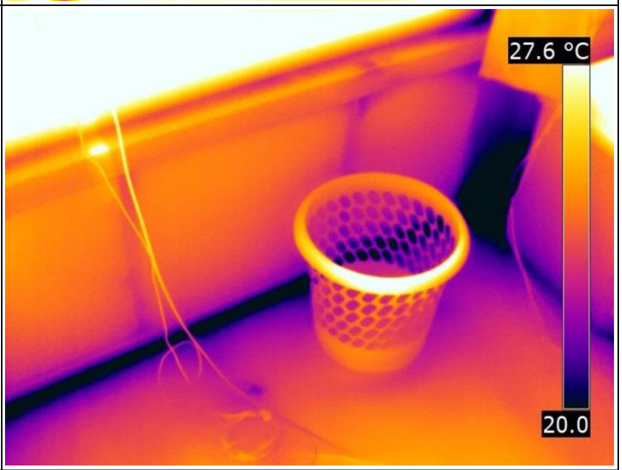

15.0 °C
7.5

C05 under depressurisation:

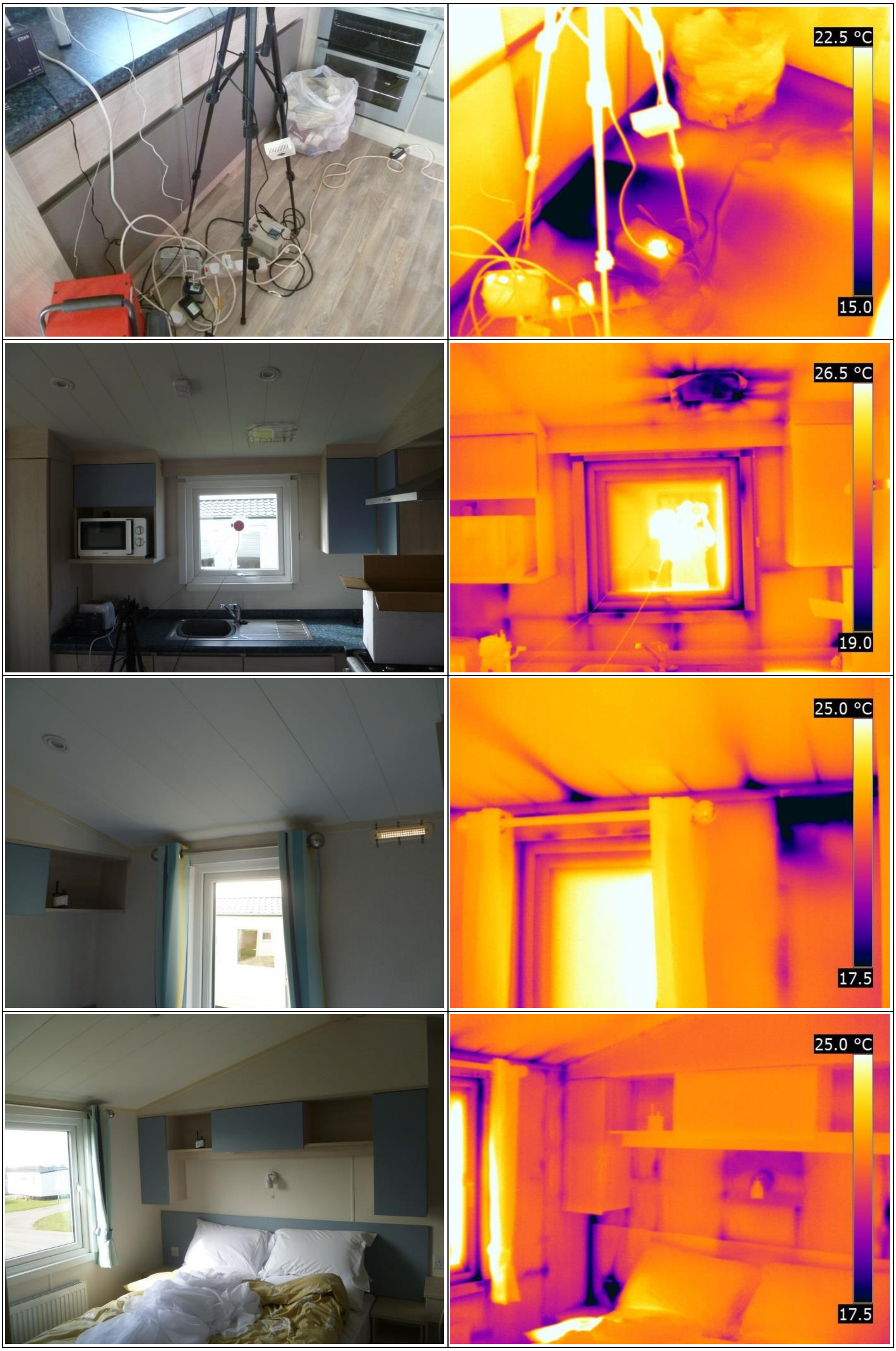


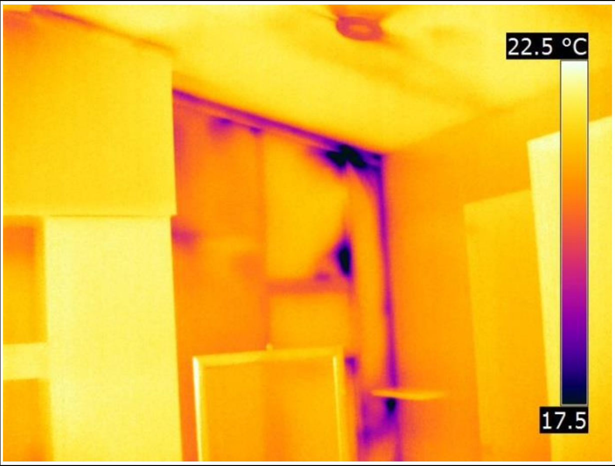
27.5 °C
20.0

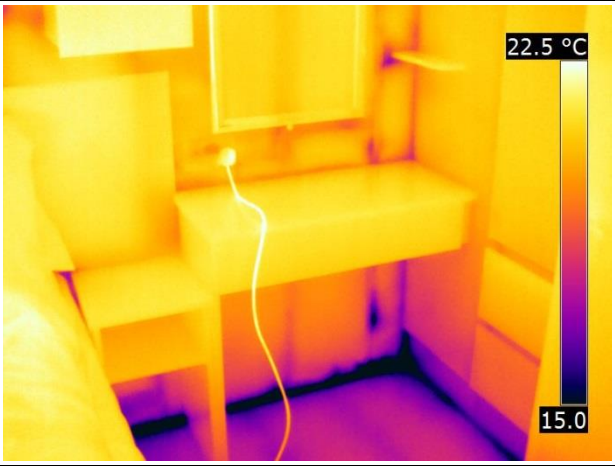

27.5 °C
20.0


27.6 °C
20.0

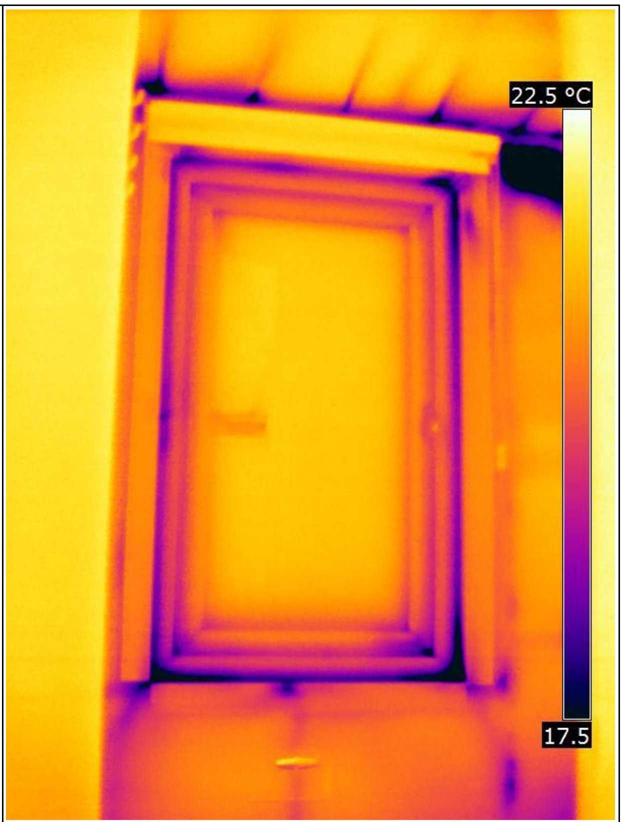

27.5 °C
20.0


22.5 °C
15.0
26.5 °C
19.0
25.0 °C
17.5
25.0 °C
17.5

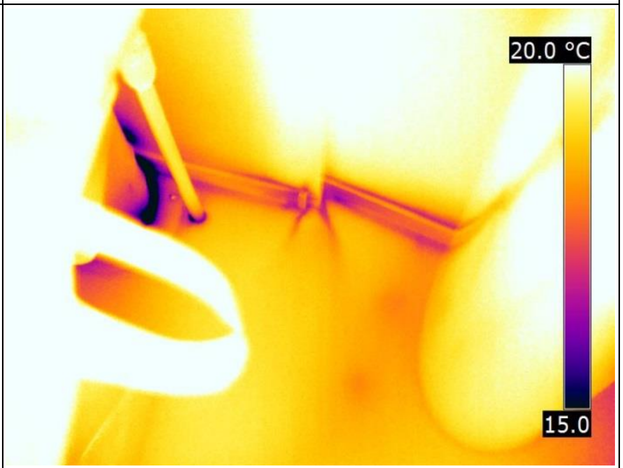

22.5 °C
17.5

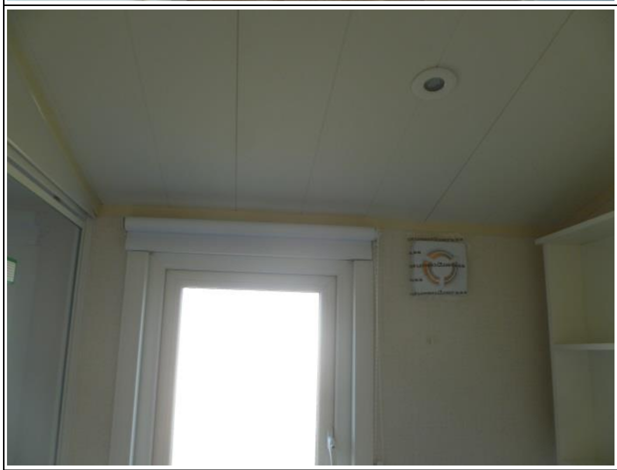

22.5 °C
15.0

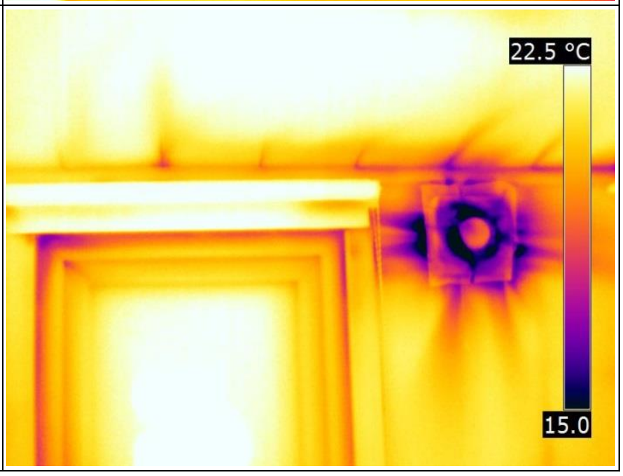

21.0 °C
16.0


22.5 °C
17.5


Your toilet has been sanitised

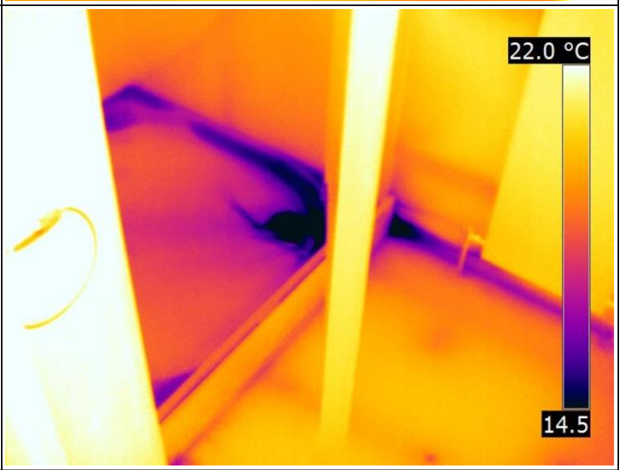

20.0 °C
15.0



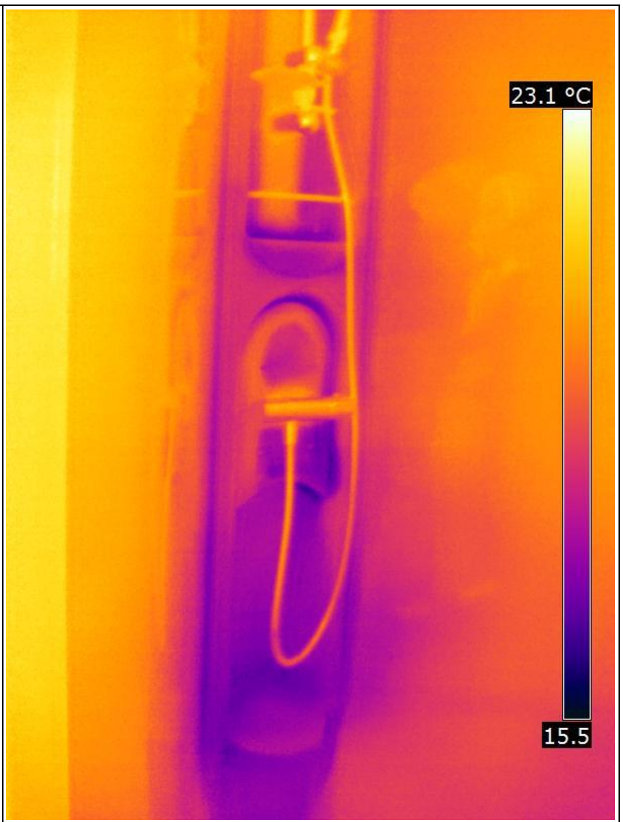

22.5 °C
15.0

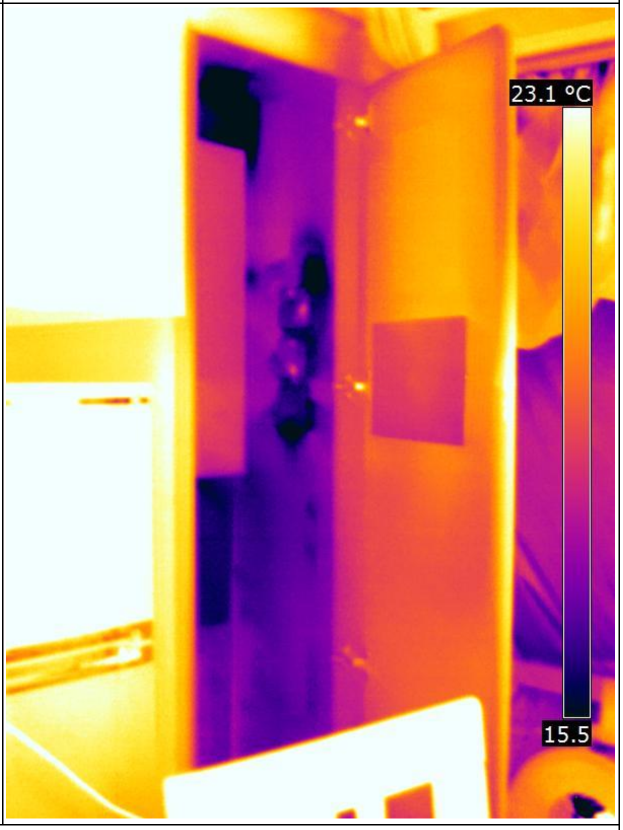

22.5 °C
17.5


21.5 °C
14.0


22.0 °C
14.5


22.0 °C
14.5





C05 Door and mullion window replacement


RUBY
ATLAS