Technical Paper 22

HISTORIC SCOTLAND
ALBA AOSMHOR

Scotstarvit Tower Cottage

A study of infrared electric heating installed in a refurbished 19th Century dwelling

Diane Hubbard

the National Trust for Scotland
a place for everyone

GreenFootsteps
Helping you to reduce your impact on the environment

This Technical Paper is available as web publication for free download from the Historic Scotland website:
www.historic-scotland.gov.uk/technicalpapers

This Technical Paper should be quoted as:
Historic Scotland Technical Paper 22

ISBN 978 1 84917 172 4

This paper was published by Historic Scotland, an executive agency of the Scottish Government.

You can contact us at:

Historic Scotland
Conservation Directorate
Longmore House
Salisbury Place
Edinburgh EH9 1SH

Phone 0131 668 8600
Email hs.conservationgroup@scotland.gsi.gov.uk
Web www.historic-scotland.gov.uk/conservation

Historic Scotland Technical Paper 22

Scotstarvit Tower Cottage

A study of infrared electric heating installed in a refurbished 19th Century dwelling

Foreword by Historic Scotland

Research Report by Diane Hubbard

Foreword

This Technical Paper forms part an on-going research programme focussed on improving the energy efficiency of traditional buildings and understanding how older buildings perform, both thermally and in terms of air and moisture transfer. Historic Scotland continues to look for new ways to reduce energy consumption without adversely affecting the building fabric and appearance of traditional buildings. However, It is also concerned with the knock-on effect that upgrading buildings can have on the people who live in them. Upgrades can be expensive, and do not always provide the hoped-for increase in comfort or financial paybacks. In addition, introducing new materials and increasing air tightness can potentially impact on occupants' health. Therefore, other ways of delivering thermal comfort with reduced energy use should also be considered.

This monitoring project was commissioned following the comprehensive refurbishment of Scotstarvit Tower Cottage to improve its thermal performance and install a new heating system. The account of the improvements to the building is published as Historic Scotland Refurbishment Case Study 7. Like many rural properties in Scotland, Scotstarvit Tower Cottage previously relied on oil for heating. Replacing oil heating with more efficient and cleaner types of fuel is one way in which rural properties can be improved and costs reduced. Conventional electric heating (such as night storage heaters) has in the past proved unsatisfactory, being expensive, unreliable and difficult for occupants to control. This study assessed whether thermal comfort could be delivered via a new electric radiant heating system while reducing actual energy use. The concept of reducing indoor air temperatures without affecting thermal comfort is discussed in more detail in Historic Scotland Technical Paper 14 *Keeping Warm in a Cooler House: creating thermal comfort with background heating and local supplementary warmth.* It suggests that a lower than standard interior air temperature can be comfortable if warmth is delivered by radiant heat rather than convection or warm air heating.

A great deal of time and resource is put into improving the building stock by installing insulation and increasing air tightness, but very little attention is generally paid to how this can affect indoor air quality. Historic Scotland Technical Paper 6 *Indoor air quality and energy efficiency in traditional buildings* identified the need to monitor indoor air quality in buildings which have been refurbished in order to gain a better understanding of the effects of increasing air tightness. The monitoring project at Scotstarvit Tower Cottage looked at whether levels of CO_2 and humidity were affected by a retrofit which increased air tightness almost to the standards of a new build. The study showed that for a single occupant, levels of contaminants remained at an acceptable level, suggesting that the building envelope was continuing to perform adequately in regulating moisture and air transfer.

This study raises some interesting questions about how we perceive thermal comfort, the 'human' element in evaluating energy needs and the resilience of a traditional building in continuing to perform passively following comprehensive energy efficiency upgrades. Historic Scotland will continue to research these matters, with further site projects, to improve our understanding of the best way to heat and ventilate traditional buildings while reducing overall energy consumption.

Historic Scotland

Scotstarvit Tower Cottage - Final Report

Contents

1. Introduction

Electric radiant heating panels were installed at Scotstarvit Tower Cottage following extensive refurbishment to improve the building's energy efficiency and replace the existing oil fired wet-heating system.[1] This report outlines the study that was carried out to assess the performance of the new heating system and considers the methods used, results obtained and the conclusions that can be drawn from the analysis. The property was occupied by a new tenant in Summer 2012, monitoring commenced in Autumn 2012 and ended in April 2013.

Radiant heating is widely recognised as an effective means of heating enclosed spaces that are subject to significant air flows in non-domestic buildings[2]. The role of radiant heating in older dwellings is outlined in Historic Scotland Technical Paper 14 *Keeping warm in a cooler house: Creating thermal comfort with background heating and local supplementary warmth*.

The key purpose of this study is to establish the effectiveness of electric radiant heating in the delivery of thermal comfort at a relatively low air temperature, within this particular dwelling, and its associated cost. A secondary objective is to examine the impact of reduced air flows in the dwelling on the indoor air quality. The air flow was reduced by increasing 'air tightness' during the refurbishment, and by providing manual control of the airflow through the chimney flue.

The focus of this report is on energy used (i.e. kWh) and the cost of that fuel rather than its carbon footprint. This is an intentional omission, but this study needs to be viewed primarily in the context of offering a means for reducing energy bills in older dwellings where energy use and the cost of that energy are foremost.

2. Background

There are three means by which we receive heat: radiation, conduction and convection. In a conventional wet central heating system, heat is provided to a room by 'radiators' which heat the room by a combination of radiation and convection. In convection, heat is transported through air movement, while conduction is heat transfer through direct contact. However, for radiation the amount of heat received depends on the relative temperature of the object that is radiating the heat in relation to our body, for example the warmth of the sun on a summer's day. The surface of every object above absolute zero (-273^{o}C) emits radiation and, generally, the hotter the surface the more it radiates, though the amount varies according to the properties of the surface.

---

[1] Jessica Snow, *Scotstarvit Tower Cottage, Cupar - Thermal upgrades & installation of radiant heating,* (Edinburgh: Historic Scotland, 2012).
[2] CIBSE, *Guide B: Heating, ventilating, air conditioning and refrigeration*, (London: CIBSE Publishing, 2005), 1-7.

Thermal comfort (or rather a lack of discomfort) is governed by a number of key factors:

- Air temperature
- Radiant temperatures of surrounding surfaces
- Humidity of the air
- Air motion
- Metabolic rate (depends on activity, age, sex, weight, health, etc.)
- Thermal resistance of clothing
- Lack of local discomfort (warm / cold) on any part of body

It is important to consider the relative weighting of these factors. It is generally perceived that air temperature is the most important. However, for an indoor environment, the air temperature and the radiant temperature of surrounding surfaces carry equal weight[3] and are the most important factors in how the occupant feels. The control of a wet central heating system is primarily based on air temperature using a conventional thermostat, which ignores radiant effects.

Radiant temperatures in a room are summarised as Mean Radiant Temperature (MRT). This has a complex exact definition, but broadly means the average, weighted by area, temperature of all the surfaces within a given space taking into consideration the and position of the occupant within the space. To illustrate:

- An open fire has a high radiant temperature and so elevates the MRT for the occupant of a room sitting in front of the fire, even though the hearth is relatively small.
- A single glazed window without curtains will have a low radiant temperature on a cold winter evening, reducing the MRT for the room occupant sitting close to the window and creating discomfort.

There are two other thermal comfort factors pertinent to this study – air movement and localised effects on the body. In a heated environment, air movement reduces the perceived air temperature and so if unwanted air movement, or draughts, can be reduced this will improve thermal comfort. Localised discomfort such as cold ankles or a warm head can occur when a space is subject to significant stratification, where the temperature increases with height in the room producing convective currents. It is usually the case that air at ceiling level will be the warmest as warm air is less dense, but the difference in temperature due to ceiling height depends on the type of heating and the thermal properties of the room. Ideally stratification should be kept to a minimum, for both comfort and energy use (since warm air at ceiling level is not available to heat the occupant of the room).

Unlike conventional central heating "radiators", which distribute a significant amount of heat through convection, radiant heaters emit a greater proportion of their energy through radiation (table 1). There are two modes by which a radiant emitter performs:

- Direct gains, e.g. the individual sitting in front of an open fire
- Indirect gains, where radiation is received by a surface and the heat is then transmitted by conduction and convection to the air, increasing the air temperature and then warming the occupant

[3] ibid., 1-5. Harvey, *L.D.D., A handbook on low energy buildings and district energy systems,* (London: Earthscan, 2006), 311.

The relative weighting of these two modes depends on the type of emitter, method of control and position of the subject being warmed, summarised in Table 1 below.

Emitter type	**Proportion**	
	Convection	**Radiation**
Forced warm air	1.0	0
Multi-column radiators	0.9	0.1
Single Column radiators	0.5	0.5
Vertical and ceiling panel heaters	0.33	0.67
High temperature radiant systems	0.1	0.9

Table 1 *Typical proportions of radiant and convective heat from heat emitters (CIBSE Guide A p5-11)*

In addition to assessment of the electric radiant heating, the project examined the impact of reduced air flows and infiltration on the indoor air quality of the building (IAQ). IAQ is the level of contaminants in the air. These contaminants could originate outside the building, such as traffic fumes, or be released inside the building, e.g. volatile organic compounds (VOCs) from air fresheners and paints, water vapour from cooking or CO_2 from human respiration. Some contaminants may be harmless, but others could have serious or even fatal effects on occupants. Since it would be costly to monitor for a range of pollutants, relative humidity and CO_2 are being monitored at Scotstarvit Tower Cottage as CO_2 is recognised as an indicator, or proxy, for higher levels of other contaminants[4].

3. Project outline

The dwelling studied is Scotstarvit Tower Cottage, which has been refurbished as detailed in Historic Scotland Refurbishment Case Study 7. The tenant (a single person) of the newly refurbished, single storey, 79 m^2 property moved in just prior to the start of the project and normally resides in the property 24 hours a day. Scotstarvit Tower Cottage has three bedrooms, although Bedroom 1 is currently a reception room which is only occasionally used. This room is therefore referred to as the Sitting Room throughout this report. The property has one remaining fireplace with an open flue, in the Living Room, and a capped flue in the Sitting Room which has a register plate fitted.

[4] CIBSE, *Guide A: Environmental design*, (London: CIBSE Publishing, 2006).

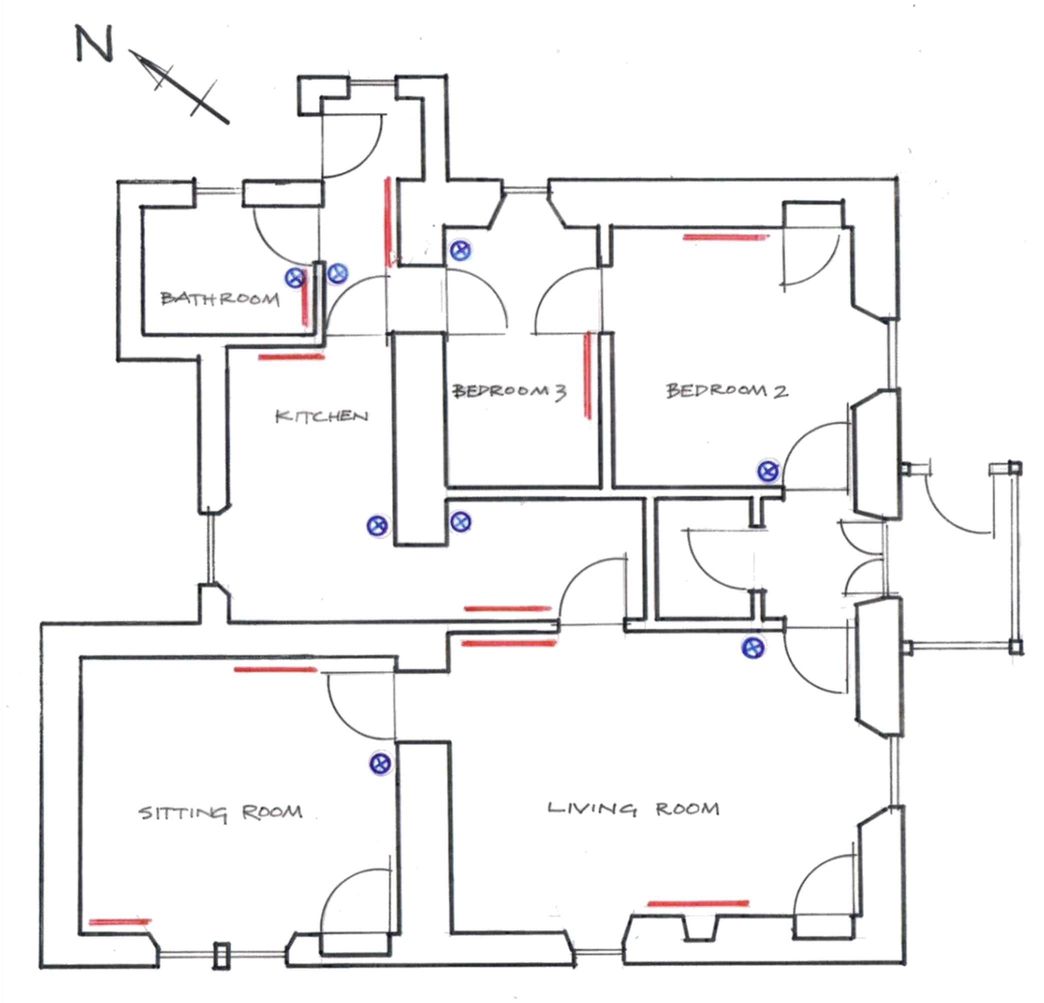


__Fig. 1__ Floor plan of Scotstarvit Tower Cottage showing indicative locations for radiant heaters (shown in red) and room thermostats (in blue).

Radiant heating panels were installed mounted flat onto walls in the property (Fig. 1) at a variety of heights. These are detailed in Table 2. Initially a mirrored heater had been installed in the bathroom above the basin, but this proved unsatisfactory to the occupant and was replaced with a heater on the adjacent wall (as specified in the table). There was no heater fitted in the kitchen in the original installation, but subsequently a heater was installed on 4 March 2013. Radiant heating panels were either mirror or white finish (Fig. 2 and 3).

	Volume (m^3) calculated by supplier	Wattage for room calculated by supplier	Number of heaters in room	Size of heater installed	Wattage of each heater	Finish of panel	Installed wattage in room
Living Room	61	1500	2	1200 x 600 1200 x 600	700 700	Mirror White	1400
Sitting Room	42	1100	2	1100 x 600 1100 x 600	600 600	White	1200
Bedroom 2	27	750	1	1200 x 600	700		700
Bedroom 3	18	480	1	900 x 600	500		500
Bathroom	9	320	1	700 x 600	400		400
North Hall			1	600 x 400	200		200
Passage	14	480	1	900 x 600	500		500
Kitchen	22	580	1	1100 x 600	600		600

Table 2 *Radiant heater details (heater sizes and wattages advised by supplier).*

Fig. 2 *Radiant heaters installed in the living room (mirror finish)*

Fig. 3 *Radiant heaters installed in bedroom 2 (white finish)*

The heaters are controlled on a room by room basis by a battery operated wireless thermostat controller with the radiant heating panel(s) wired into a wireless receiver (installation and operating instructions in Appendix 1). The thermostat controller has 4 separate settings per 24 hour period, with the opportunity to set different heating patterns

Monday - Friday, Saturday and Sunday. The current room temperature is clearly displayed continuously, together with the thermostat set temperature. There is a tolerance of 1°C on when the thermostats trigger the heater. It was noted that this was inconsistent between the different units, some triggering at ±0.5°C, others at -0°C+1°C. The operational instructions for the controller (Appendix 1) state the equipment has an "accuracy" of 0.5°C, but this is actually the resolution of the equipment so the accuracy would be expected to be greater.

Throughout the project, the occupant co-operated with a variety of heating regimes and reported informally on their thermal comfort. Though the heating patterns were agreed, the occupant was free to boost or lower the heating if they felt discomfort.

Infiltration is the unwanted ingress/egress of air from buildings through the building fabric, such as through leaks in floors, walls and windows. The rate of infiltration is often referred to as the 'air tightness' of a building. As outlined in Refurbishment Case Study 7, the property had been tested for air tightness before and after refurbishment and achieved an air permeability of 10.7 $m^2h^{-1}m^{-2}$ @50Pa post refurbishment (prior to the draught proofing of the south door). The building showed a significant improvement from the pre-refurbishment test (16.9 $m^2h^{-1}m^{-2}$ @50Pa) and is just above the threshold required for new dwellings (10 $m^2h^{-1}m^{-2}$ @50Pa).

Fig. 4 *Blower door fitted to test for air-tightness*

Air permeability testing is a way of quantifying infiltration (or air tightness) and is established using a blower door (Fig. 4) which maintains a set pressure difference between inside the building and ambient pressure. Though air permeability testing does not fully represent the infiltration situation, it is the most favoured indicator for measuring it – reflected in the fact that there is a requirement for new buildings to be tested using this method. A further test has been carried out as part of this study in order to establish the final air tightness after final draught proofing. Thermal imaging has been used in conjunction with this technique and the following should be noted regarding the thermal imaging included in this report:

- In all images, the temperatures represented by a particular colour depend on the temperature range in the field of view (refer to the scale for confirmation).
- The emissivity (the ability of a surface to radiate) will affect the temperature the camera perceives. The images used have not been corrected for variations in emissivity and are indicative only.

In terms of deliberate ventilation, as part of the refurbishment an extractor fan was fitted in the bathroom, which is humidity triggered at 70% RH (Relative Humidity). In the kitchen a manually operated extractor hood is fitted over the location for the cooker.

In order to assess the performance of the radiant heating and indoor air quality, a range of monitoring equipment was supplied and installed:

- Power meter – taking its signal from the two separate circuits on which the radiant heaters are installed (Fig. 5)

- External CO_2, temperature and RH sensor, powered by PV panel feeding into battery (Fig. 6 and 7)
- Internal CO_2, temperature and RH sensors for three rooms – living room, kitchen and bathroom (originally planned to have equipment in the main bedroom as well)
- Web logger to collect data and transmit intermittently using the existing broadband connection, for remote access to the collected data (Fig. 5).

Fig. 5 *Monitoring equipment installed at Scotstarvit Tower Cottage. Web logger (with green light) and power meter above.*

Fig. 6 *Monitoring equipment installed at Scotstarvit Tower Cottage. External CO_2, temperature and RH sensors (shown with the screen open).*

Fig. 7 *Monitoring equipment installed at Scotstarvit Tower Cottage. Internal CO2, temperature and RH sensors in living room. Note: red heat flux plate at base of this picture is not associated with this study.*

The sensors in the living room and kitchen were mounted at the recommended height for CO_2 monitoring, 1.4-1.6 m above floor level and broadly coinciding with the thermostat heights. In the bathroom there was only one option for location, above the entrance door just below ceiling level, due to the requirement for a power supply (Fig. 8). After an initial monitoring period, all data was recorded at 15 minute intervals.

Fig. 8 *Location of sensor above door in the bathroom*

4. Project landmarks

The landmarks in the project are outlined in Table 3 and are used as reference points throughout the report.

Though the formal data reference period has ended, the data logging equipment and sensors currently remained in the property and continued to log information.

Date	Details	Comments
18 Oct 2012	Installation of power meter and trial sensor. Heating pattern set at Regime 1.	
23 Nov 2010	Installation of sensors (3 internal plus 1 external). Additional mobile radiant heater introduced (not wired in – so energy use not being recorded).	Sensor in bathroom at higher level than other locations. Following calibration off site, all 4 sensors set to the same CO_2 level, based on external reading.
Between 24 Nov and 3 Dec 2012	Door fitted between kitchen and passage. South external door draught proofed.	Infiltration still noticeable around door.
4/5 Dec 2012	Heater supplier visit to repair thermostat and re-set all of temperature settings (occurred prior to 1130am on 5 Dec 2012). Heating pattern changed to Regime 2 by supplier.	Battery failed in hall thermostat
5-10 Dec 2012	Issues with voltage from battery for external sensors.	Additional battery fitted temporarily by sensor supplier.
20 Dec 2012	Living and kitchen sensors cross checked with external sensor Board installed on fireplace (air flow stopped)	Drift seen with CO_2 readings i.e. they do not read the same when put in the same conditions. Bathroom sensor not cross checked.
31 Jan 2013	Air tightness testing Bathroom and living room sensors swapped Heating pattern changed to Regime 3 - 18^{o}C, 24 hours a day (supplier /manufacturer recommendation).	
27 Feb 2013	Discussion (owner / supplier) on location for kitchen heater. Heating pattern changed to Regime 4 (18^{o}C daytime, 16^{o}C overnight).	Prior to site visit, occupant re-arranged living room to achieve more direct gain from low level of heater.
4 March 2013	Heater in kitchen fitted and thermostat settings adjusted by supplier to be consistently ±0.5^{o}C (some were -0+1^{o}C)	
w/c 11 March 2013	Thermostat in hall failed – batteries had to be replaced again	
10 April 2013	Ceased formal data reference period. Ceased data formal heating pattern and occupant can now set desired heating pattern	
22 May 2013	Reset thermostats pattern to minimise energy use over summer	Occupant had not changed heating pattern since the end of the formal data reference period.

Table 3 *Project landmarks*

5. Heating regimes

There were 4 different heating patterns applied at Scotstarvit Tower Cottage over the monitoring period and they were as follows:

Regime 1 – applied 18 October 2012					
Room	**Day**	**Time**		**Temperature setting °C**	**Comments**
		Start	**Finish**		
Living Room	Mon-Sun	1000	1800	16.0	
		1800	2345	21.0	
		2345	1000	10.0	
Passage	Mon-Sun	1000	2345	16.0	
		2345	1000	10.0	
Sitting Room	Mon-Sun	1000	2345	10.0	i.e. 24 hours. Room only used occasionally
		2345	1000	10.0	
Bedroom 2	Mon-Sun	1000	2345	16.0	
		2345	1000	10.0	
Bedroom 3	Mon-Sun	1000	2345	16.0	
		2345	1000	10.0	
Bathroom	Mon-Sun	1000	2345	16.0	
		2345	1000	10.0	
North Hall	Mon-Sun	1000	2345	16.0	
		2345	1000	10.0	

Regime 2 – applied 4/5 Dec 2012					
Room	**Day**	**Time**		**Temperature setting °C**	**Comments**
		Start	**Finish**		
Living Room	Mon-Sat	0600	2300	21.0	
		2300	0600	16.0	
	Sun	0600	2300	21.0	
		2300	0600	16.5	
Passage	Mon-Sun	1000	2345	16.0	
		2345	1000	10.0	
Sitting Room	Mon-Sun	1000	2345	10.0	Changed to 16.0 on 20 Dec
		2345	1000	10.0	
Bedroom 2	Mon-Sun	1000	2345	16.0	
		2345	1000	10.0	
Bedroom 3	Mon-Sun	1000	2345	16.0	
		2345	1000	10.0	
Bathroom	Mon-Sun	0600	2300	21.0	
		2300	0600	16.0	
North Hall	Mon-Fri	0600	2300	21.0	Set to wrong day (adjusted on 20 Dec)
		2300	0600	16.0	
	Sat	0600	2300	21.0	
		2300	0600	16.5	
	Sun	0600	2300	21.0	i.e. 24 hours
		2300	0600	21.0	

Regime 3 – applied 31 January 2013					
Room	**Day**	**Time**		**Temperature setting °C**	**Comments**
		Start	**Finish**		
Living, Passage, Sitting Room, Bedroom 2, Bedroom 3, Bathroom, North Hall	M-Su	0000	2400	18.0	

Regime 4 – applied 27 February 2013					
Room	**Day**	**Time**		**Temperature setting °C**	**Comments**
		Start	**Finish**		
Living, Passage, Sitting Room, Bedroom 2, Bedroom 3, Bathroom, North Hall. Applied to Kitchen heater after installation.	M-Su	0745	2345	18.0	
		2345	0745	16.0	

The time settings for Regime 1 were agreed with the dwelling occupant based on their living pattern. However, when the supplier changed the heating pattern to Regime 2 on 4 / 5 December, they did not take this living pattern into account or seek approval from the project team to change the thermostats. This pattern resulted in higher internal temperatures and a heating schedule inappropriate for this particular occupant.

Following discussions with the supplier, the heating regime was changed to Regime 3 on 31 January. This was 18°C throughout the property, 24 hours per day. This was based on advice from the supplier that the heating system would be at its most energy efficient when a constant room temperature was maintained and every room in the building heated.

Further discussions on minimum energy use with the supplier concluded in their revised recommendation that for minimum energy use, a set-back of no more than 2°C should be used overnight, but uniform heating should be applied throughout the property. This was applied as Regime 4 from 27 February. An initial daytime temp was set at 18°C (set back to 16°C overnight), with a view to potentially reducing the temperature further if acceptable. Regime 4 also acknowledged the earlier waking time of the occupant, where the previous regimes had not.

On each visit to the property, the heating pattern set on each thermostat was checked. The thermostats remained unchanged, apart from the situations outlined above. The only major exception to this was the hall thermostat, checked on 10 April, which was 12 hours out and had presumably been set to that following the replacement of batteries during w/c 11 March by the supplier.

Following the end of the data analysis period on 10 April, the occupant was free to change the heating pattern to whatever they wished. However they made no change. The heating was revised to the following on 22 May:

22 May 2012 (after end of data monitoring period)					
Room	**Day**	**Time**		**Temperature setting °C**	**Comments**
		Start	**Finish**		
Living, Passage, Kitchen	Mon-Sun	0900	1100	18.0	
		1100	1900	16.0	
		1900	2300	18.0	
		2300	0900	10.0	
Bedroom 1 (Blue Room), Bedroom 2 (used as bedroom), Bedroom 3 (Yellow Room), Bathroom, North hall	Mon-Sun	0900	2300	14.0	
		2300	0900	10.0	

6. Results

The thermostat triggers the radiant heater to be either on or off (no intermediate settings) and a variation in the operating temperatures of the white finished panels was noted. An emissivity of 0.95 was applied for the general survey (Fig. 9 and Fig. 10). Emissivity expresses the ability of an object to radiate. Convention would indicate the emissivity of the glossy white heating panels are expected to be significantly less than this figure, affecting the absolute temperature reading but the comment of there being a temperature variation remains valid. Unfortunately information on the actual emissivity of the different panel finishes has not been forthcoming from the equipment suppliers.

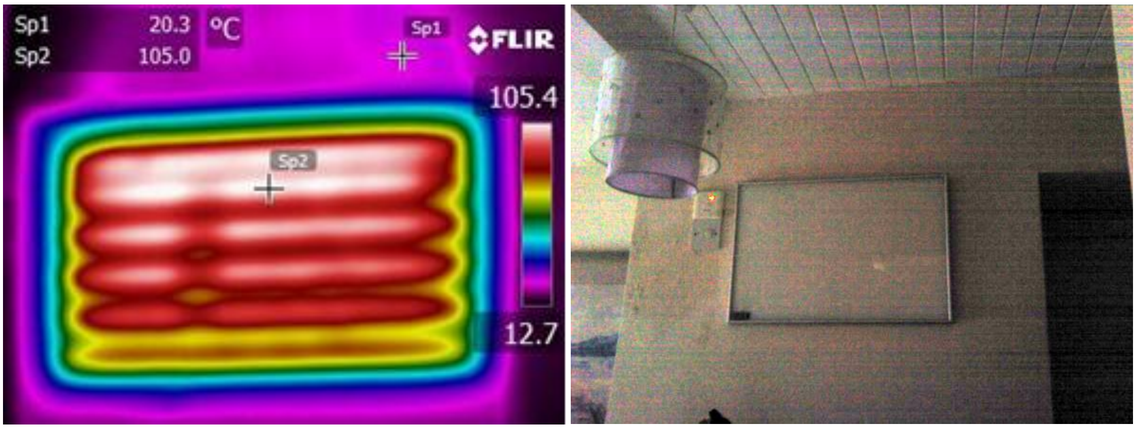


Fig. 9 *Images of the heater in the north hall*

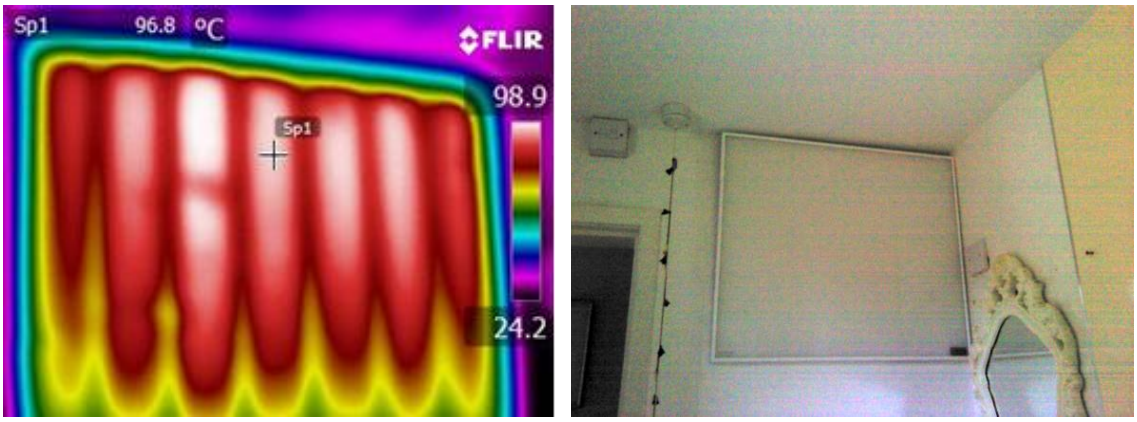


Fig. 10 *Images of the heater in the bathroom*

There is also evidence of the convective effect above the heater (Fig. 9). A conductive effect from the rear of the bathroom heater into the adjacent hall through the partition wall was also noted (Fig. 11).

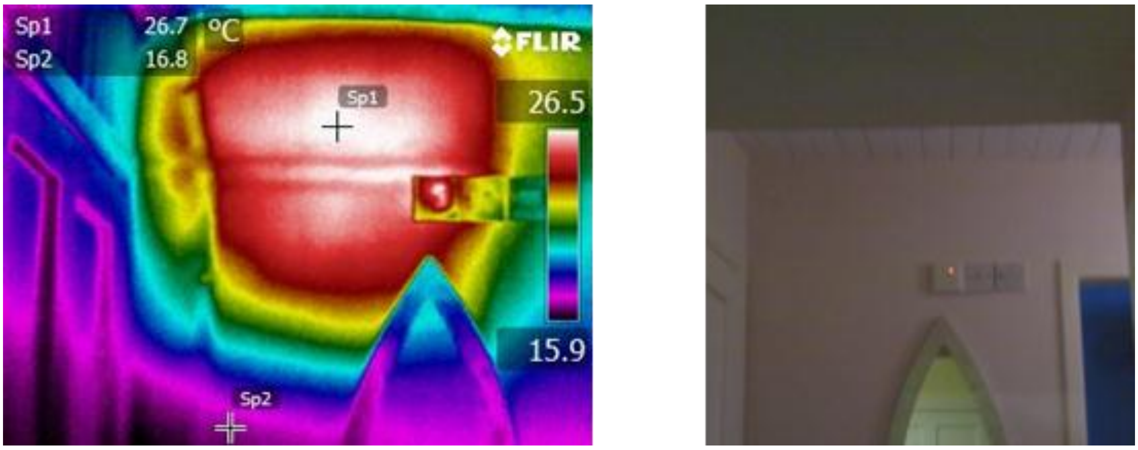


Fig.11 *Conductive effect of bathroom heater on north hall wall*

6.1 Thermal comfort

The trial at Scotstarvit Tower Cottage has confirmed the 5kW of radiant heaters installed are able to deliver an acceptable to good level of thermal comfort, depending on the heating pattern applied.

Initially there was a desire to get formal feedback from the occupant on their level of comfort, but this proved impractical, with the study being pursued through informal feedback from telephone conversations and meetings at the property (with its inherent inaccuracies and resulting generalisations). From the early stages of the project, it became evident the temperature displayed on the thermostat was being focused on by the occupant, rather than their actual perception of comfort.

There was clearly a period (which may not yet have ended), of adjustment to this different type of heating. The occupant has lived in properties with different types of heating and likes a direct radiant gain, such as a wood burning stove or range. This has been expressed on a number of occasions and the occupant has even purchased a “living flame” DVD for the television, to provide the psychological effect of a real fire. The occupant has expressed satisfaction especially when receiving direct radiant gains from the heaters and has been much happier with the seating arrangements in the living room since furniture was re-arranged to receive direct radiant gains. When the seating was in front of the (unused) fireplace, significant direct radiant gains were not received due to the height of the heater above the fireplace mantle and its fitting flush to the wall, rather than oriented downwards.

Feedback on thermal comfort for Regime 1 was mixed. It should be noted the occupant did suffer a couple of bouts of cold / flu under this regime, which may have affected their perception. Again, it became evident that judgement of comfort was based on the temperature seen on the display of the thermostat, rather than how comfortable they actually felt. An additional mobile radiant heater was taken to the property on 23 November, but the occupant reported that it was only used occasionally and was not used during any of the subsequent heating regimes. The heater was plugged into a normal socket, with an electricity monitor attached from 20 Dec onwards, but no energy use was recorded.

Based on feedback, Regime 2 gave the occupant the highest level of thermal comfort, primarily based on a thermostat temperature of 21^{o}C. The occupant expressed satisfaction with this pattern of heating.

The occupant reported that during Regime 3, there were occasions when the temperature needed further boosting, primarily for visitors. The occupant expressed discomfort at the high overnight temperature in the bedroom. They were also concerned that a room which was only used occasionally (Sitting Room) was being heated to the same temperature as the rest of the house. At some point between 31 January and 27 February, furniture in the living room was re-arranged so that the main seating area received direct radiant gain from the lower heater in this room. The occupant confirmed they preferred this arrangement from a heating point of view.

Feedback at the end of the Regime 4 heating period indicated that it had generally delivered a satisfactory level of thermal comfort, with odd occasions where the heating had needed boosting. They expressed great satisfaction with the heater in the kitchen, which had increased comfort levels. The occupant was not prepared to consider a reduction in daytime temperatures below the thermostat setting of 18^{o}C.

It should be highlighted that under normal circumstances there is a balance between thermal comfort, expectations from a heating system and affordability of energy bills. For most of the monitoring period, the occupant had a low level of awareness of energy use and its associated costs. In the early stages of the project, advice was provided on energy efficiency and competitive tariffs, but this was not acted on by the householder. However towards the end of the project, they became more aware of energy use for heating in particular and took a more active role in the heating regimes.

6.2 Energy use

For the heating regime recommended by the manufacturer and supplier for minimum energy use (Regime 4), the energy use was an average of 64kWh per day, which equates to £8.80 per day and 0.8 kWh per m^2 of floor area per day. The period this heating pattern was used was through March and into April, which was a relatively cool period in 2013. It is important the energy use figures take into account weather conditions and so a comparison has been made to calculated degree days. Degree days for heating are calculated from the difference between the recorded external temperature and 15.5^{o}C, with any readings in excess of 15.5^{o}C ignored. The information is recorded on an hourly basis and then converted to degree days e.g. If the outside temperature was consistently 2^{o}C for a 24 hour period, this equates to 13.5 degree days.

Inclusive dates				No of days of heating	Mean kWh per day
Start	End		Heating pattern		
24/11/2012	03/12/2012	Without kitchen heater	Regime 1 - DH original heating pattern	10	41.7
06/12/2012	30/01/2013		Regime 2 Supplier's heating pattern	56	55.5
01/02/2013	26/02/2013		Regime 3 - Uniform 18^{o}C throughout property	26	64.5
28/02/2013	02/03/2013		Regime 4 - Uniform 18^{o}C daytime, 16^{o}C set back overnight	3	44.3
04/03/2013	10/04/2013	Includes kitchen heater	Regime 4 - Uniform 18^{o}C daytime, 16^{o}C set back	38	64.2

Table 4 *Comparison of the energy use of the heating regimes applied at Scotstarvit Tower Cottage during winter 2012-13*

The mean energy use per day over the test period as a whole is 58.5 kWh (0.7 kWh per m^2 of floor area per day). The building occupant was paying 13.75p per kWh, so this equates to £8.04 per day (£1070 over the 133 days of data taken into account). Table 4 shows the amount of energy used varies between each regime, with a pattern typically applied to a conventional heating system (Regime 1), with the highest use for the building being heated a uniform temperature 24 hours a day (Regime 3).

The total energy used for space and water heating and all other equipment from mid- July 2012 to 10 April 2013 was 12,500 kWh, compared to estimated total annual energy consumption per Scottish household of 19,900 kWh[5]. In terms of energy use per square metre of floor area, comparison from this study can be drawn to Hong[6]. The energy use during Regime 4 was 0.8 kWh per m^2 per day, compared with the average over the project of 0.7 kWh per m^2 per day. Hong recorded data for 750 dwellings for 3-4 week heating periods during the winters of 2001/2002 and 2002/2003. The study was of low income households (variety of household types, 97% of dwellings in the overall study were of brick construction of which about a third were solid wall brick) and the properties had draught proofing, insulation and conventional central heating measures installed under the *Warm Front* programme. The mean gas and electricity use was 0.77 kWh per m^2 per day after refurbishment.

The amount of energy used will vary from day to day according to the external conditions and whether the occupant choses to override the settings if they feel discomfort. With the above figures being viewed in isolation, no conclusions can be drawn. The level of energy use has therefore been related to the degree days measured at the property. The measured

[5] Walker, S., *Energy use in the home : Measuring and analysing domestic energy use and energy efficiency in Scotland,* (Edinburgh: Scottish Government, 2012),15.
[6] Hong, S., *Changes in space heating energy consumption following energy efficient refurbishment in low-income dwellings in England,* (London: Bartlett School of Graduate Studies, UCL, 2011),150.

degree days over the study period in table 5 were 1226 (24 November – 10 April, excluding days when the regime was changed and 5 days in December when there was a battery failure for the external sensors). This can be compared to a degree day figure for the nearest weather station at Leuchars of 1455 for the period 1 December – 31 March. The difference between the measured on-site degree days and the weather station at Leuchars may be due to differences in climate between the two locations or, more likely, inconsistencies in measurement at Scotstarvit compared to the official weather station at Leuchars. Using the site measured degree day data, the energy use does not appear to be directly proportional to the on-site degree day measurement. One suggestion to explain this may be that the screen shielding the external sensor may not be completely effective for shading, resulting in elevated recorded external air temperatures. This has the effect of under-estimating the number of degree days, as generally through the recording period there are higher figures for kWh/degree day when there are fewer degree days (i.e. warmer weather).

The energy use has been analysed taking into account the on-site degree days and is shown in Table 5. The results show a difference of more than 60% in energy use between the most efficient (Regime 1) and least efficient (Regime 3). Regime 4, prior to the installation of the heater panel in the kitchen has been discounted, as it applied to such a short period of mild weather (bearing in mind the above comments). Though a mobile infrared panel heater was delivered to the dwelling on 23 November, the tenant reported they only used it very occasionally during Regime 1. The energy use of this equipment is not included in these figures since the mobile heater plugs into a power socket.

The first heating pattern (Regime 1) was only applied for 10 days, due to the supplier amending the pattern without agreement and it has to be questioned whether the low energy use per degree day in this period is representative. However, the on-site degree days appear to be comparable to other regimes and the heating had been running for a number of weeks prior to the start of the monitoring period, so it should therefore be considered relevant.

The installation of the heater in the kitchen takes place within a few days of the change from Regime 2 (uniform 18^{o}C throughout the property) to Regime 3 (uniform 18^{o}C daytime temperature with reduction to 16^{o}C overnight). A reduction in the average kWh/ degree day results between the two regimes can be seen (from 6.9 to 6.1 kWh/degree day). It is unknown what the relative effects of the additional heating panel and the introduction of the setback temperature are. Two comparable days, 8 February and 28 March, were compared. The first day, 8 February, had the heating set to run at 18^{o}C for the full 24 hour period and second day, 28 March, had an overnight setback temperature of 16^{o}C (Fig. 12). They have an energy use of 64.02kWh and 64.76kWh respectively (around the mean for each group) and comparable figures for degree days bearing in mind the difference in the kwh/degree day ratio. The additional energy use in the early part of the day on 8 February under the 24 hour heating regime is shown in upper graph of Fig. 12, when the two days have very comparable degree hour figures, potentially indicating an energy saving would have been attained if the setback temperature had been applied on 8 February. This is particularly relevant since the occupant is asleep at this time and there is no particular requirement to heat the accommodation to relatively high temperatures for their thermal comfort.

It was noted by the householder that under all of the regimes both the bathroom and north hall heaters were running for significantly longer periods than heaters elsewhere in the building, indicating they may have been underspecified.

Inclusive dates									Min energy use in 24 hour period			Max energy use in 24 hour period			
Start	End		Heating Pattern	Number of days of heating	Total kWh	Total degree days	Mean degree days per day	Mean kWh per degree day	kWh	Degree days	kWh/ degree day	kWh	Degree days	kWh/ degree day	Comments
24/11/2012	03/12/2012	Without Kitchen heater	Regime 1 DH original heating pattern	10	416.6	97.3	9.7	**4.3**	30.5	9.2	3.3	47.0	11.6	4.1	
11/12/2012	30/01/2013		Regime 2 supplier heating pattern	51	2812.2	468.7	9.2	**6.0**	34.1	4.4	7.7	77.1	12.0	6.4	Excludes days without external readings (battery failure) 6-10 Dec. inclusive
01/02/2013	26/02/2013		Regime 3 Uniform 18°C through out property	26	1676.9	243.3	9.4	**6.9**	48.8	7.4	6.6	85.1	12.8	6.7	
28/02/2013	02/03/2013		Regime 4 Uniform 18°C daytime, 16°C set back	3	132.8	17.9	6.0	**7.4**	40.6	6.4	6.4	51.4	6.3	8.2	Only 3 days with relatively low degree days – therefore discount this period?
04/03/2013	10/04/2013	With Kitchen heater	Regime 4 Uniform 18°C daytime, 16 °C set back	38	2438.2	398.2	10.5	**6.1**	47.6	7.2	6.7	84.5	13.5	6.3	

***Table 5** Scotstarvit Tower Cottage – Heating energy use with reference to degree days measured on site.*

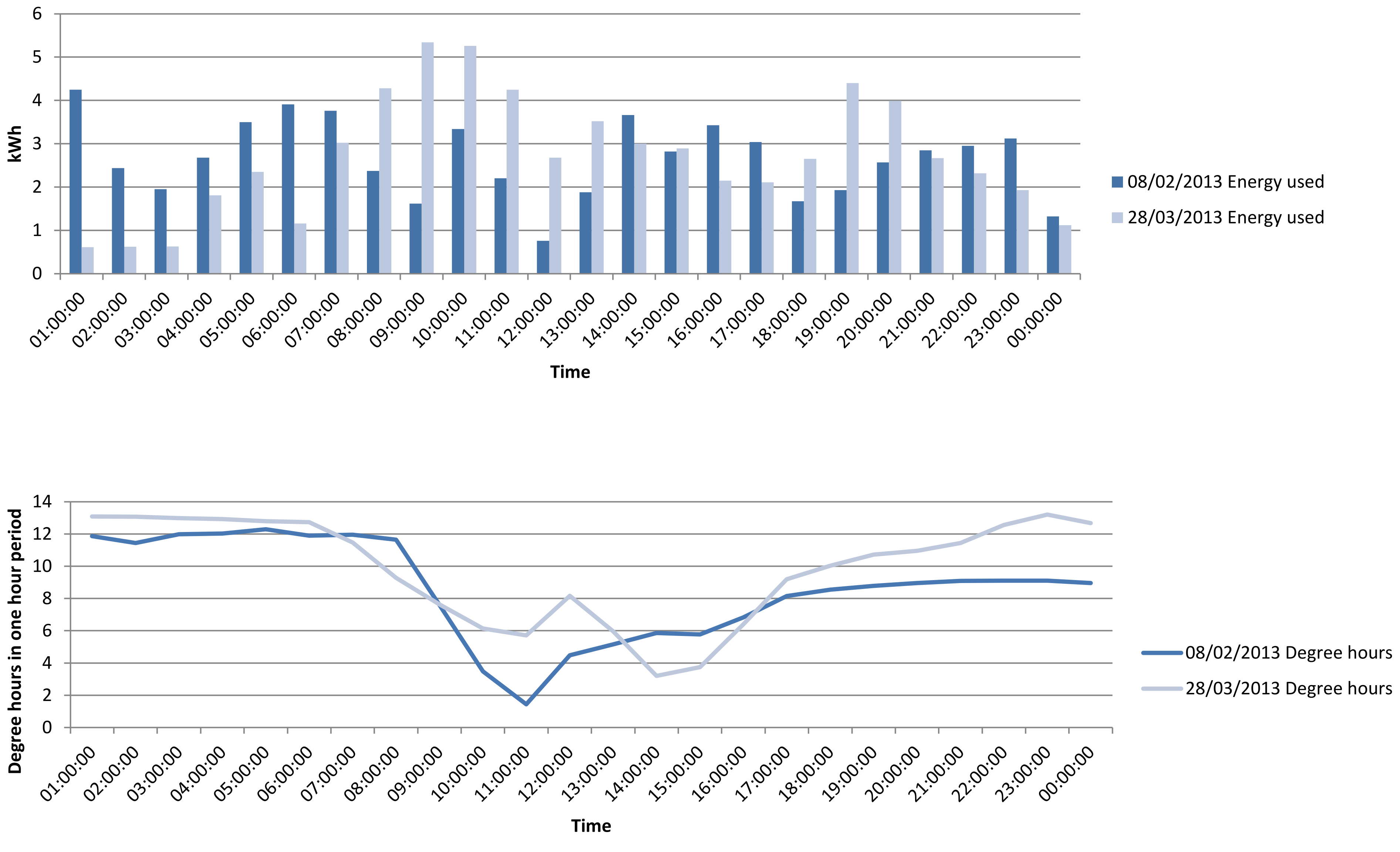


Fig. 12 *Comparison of energy use and degree day pattern between 8 February 2013 and 28 March 2013.*

6.3 Air temperature, relative humidity and CO_2

The sensor used in both the external and internal locations is the Cozir Ultra Low Power Carbon Dioxide Sensor and the data sheet for the equipment is provided in Appendix 2, with the accuracy stated as follows: CO_2 ±50ppm / ±3% of reading, temperature ±1°C (0-55°C), relative humidity ±3%. The response time is given as 30 seconds to 3 minutes. The sensors were all calibrated by the suppliers prior to the installation. The equipment establishes the level of CO_2 by "non-dispersive infrared absorption" – CO_2 absorbs infrared and, through the use of mirrors, the sensor measures the level of absorption.

Care was taken over the choice of location for the sensors, with the living room and kitchen equipment being located within the height band recommended for the detection of CO_2 (around 1.5m above floor level). In the case of the bathroom, there was no choice of location. The only possibility was above the door due to the availability of power (Fig.7). This clearly has implications both in terms of the temperatures and CO_2 levels recorded, discussed below. The equipment outside the property was mounted on a free standing tripod (Fig. 5) and received its power supply from a combination of a battery and photovoltaic panel. It was therefore located on the south side of the property with the equipment protected by a screen.

The level of CO_2 recorded in the external environment varies considerably (Fig. 13). Examining a 48 hour period, the variation appears to represent the level of respiration of the vegetation. The temperature graph also illustrates the issue of the screen not being wholly effective over shading the equipment from solar gain.

By 20 December, it became evident there were issues over the CO_2 levels recorded, particularly in the living room where gradually levels were creeping upwards. The living room and kitchen sensors were taken outside for comparison to the external conditions recorded, outlined in table 6. It subsequently transpired that the calibration process carried out by the suppliers was for tolerance rather than accuracy, and there was an adjustment of the values being recorded, which was applied retrospectively, allowing the data to still be valid. For example, the external CO_2 levels being recorded were too low and they vary considerably over a day (Fig. 13). A base level of 400 ppm CO_2 was agreed taking into account the property's rural location. It should also be noted from the table that the actual speed of response of the sensors is much slower than indicated by the data sheet and the suppliers.

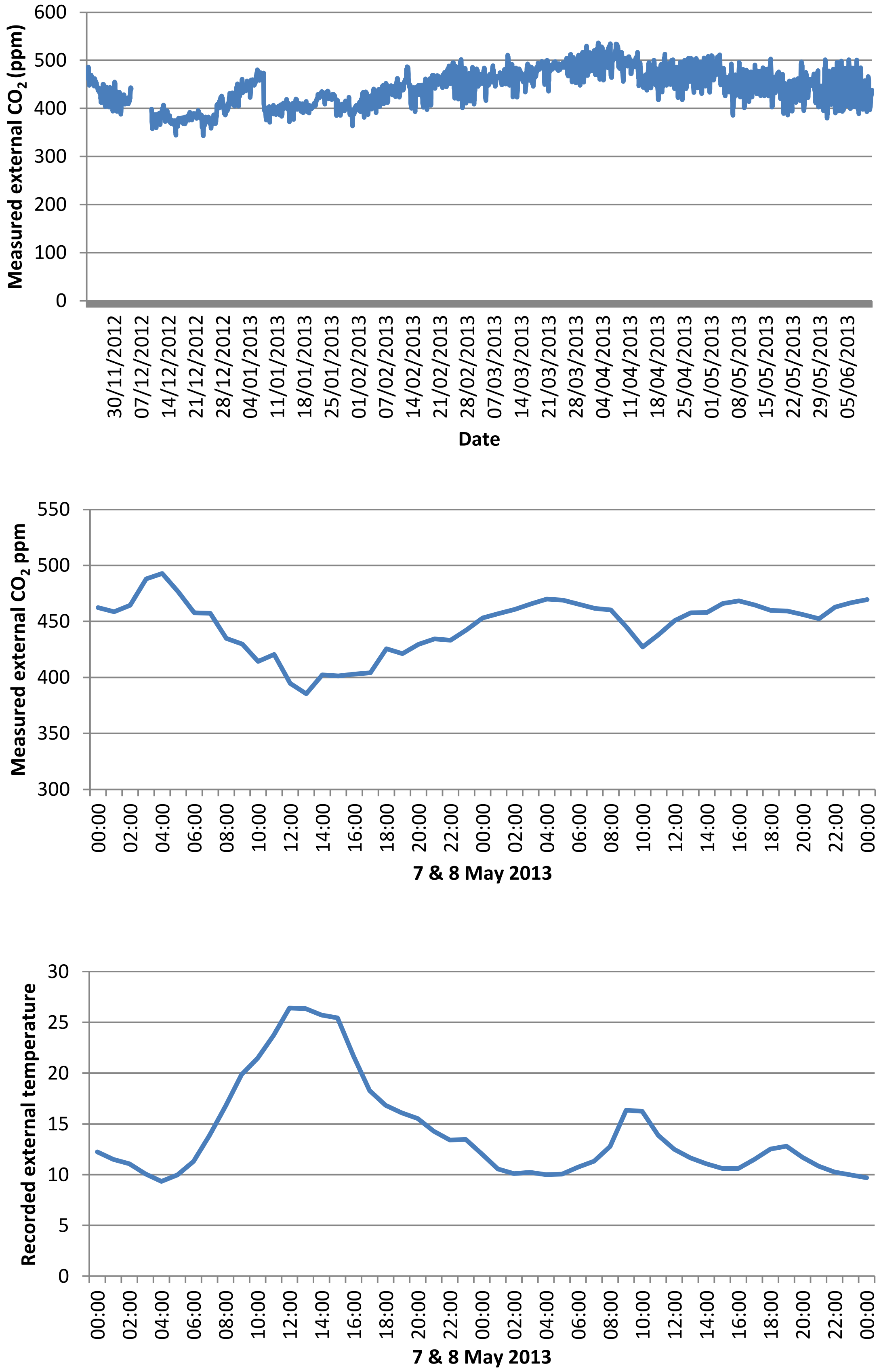


Fig. 13 *Measured external CO2 levels over duration of project (top) and detailed variation over a 48 hour period compared to temperature (bottom)*

Time		CO2 ppm			Air temperature °C			% RH		
		Living Room	Kitchen	External	Living Room	Kitchen	External	Living Room	Kitchen	External
15:45		678.9	651.9	303.0	21.1	18.6	6.2	37.6	44.6	83.1
16:00	Sensors taken outside @ 1603h	664.2	631.0	303.5	21.1	18.6	6.1	37.5	44.5	83.3
16:15		628.6	595.3	299.5	15.5	13.4	6.0	41.6	48.8	83.7
16:30		609.9	590.5	298.5	6.6	6.5	6.0	60.3	66.3	83.6
16:45		648.3	607.4	300.5	5.4	5.5	6.0	69.0	74.7	83.8
17:00	Sensors returned indoors just after 1700h	662.0	612.0	308.5	5.3	5.4	6.1	73.1	78.3	83.9
17:15		910.7	798.9	302.0	7.6	7.8	6.1	81.6	84.3	84.3
17:30		1050.1	933.6	306.5	14.6	11.3	6.0	74.6	84.2	84.6
17:45		1108.8	1240.7	307.0	18.8	16.1	6.0	58.5	65.9	84.9
18:00		1137.2	1552.6	305.0	20.4	17.4	6.0	52.6	61.9	84.9

Table 6 *Comparison of sensors from the living room and kitchen with the external equipment on 20 December 2012*

However, a problem with the gradually increasing CO_2 levels recorded in the living room remained. It was identified by the sensor suppliers that a build-up of particulate matter on the mirrors within the sensor might be the reason, since the dwelling occupant is a smoker. The bathroom and living room sensors were swopped, since the bathroom sensor had not shown signs of drifting. It was subsequently noted that this replacement sensor also started to creep, corroborating the supplier’s view. A question should therefore be raised over the suitability of these sensors for this purpose.

Before considering the air quality data recorded, consideration should be given to the thresholds used for comparison. There are no air quality standards for dwellings in the UK[7], so an indicator for offices of 1000 ppm CO_2 is being used as a threshold to be applied over a period of time. With respect to relative humidity, an RH in excess of 70% for prolonged periods should be avoided[8]. With the upgrades carried out at Scotstarvit, the air-tightness is broadly comparable to that of a new dwelling and so maintaining these acceptable levels could be an issue, especially when air flow via the chimney flue was restricted with the original adjustable baffle. However, the property is occupied by a single person who cooks infrequently and so these problems have not transpired. It should also be highlighted again there is a humidistat triggered fan in the bathroom and, although there is a manually switched extractor cooker hood, this was not used during the period of the study.

[7] CIBSE Guide A, 8-5.
[8] Halliday, S., *Technical Paper 6 : Indoor air quality and energy efficiency in traditional buildings,* (Edinburgh: Historic Scotland, 2009).

With respect to carbon dioxide, an example period is charted in Fig. 11, which demonstrates that though the CO_2 level does vary, it oscillates around an acceptable mean for all of the living spaces monitored (Fig. 14).

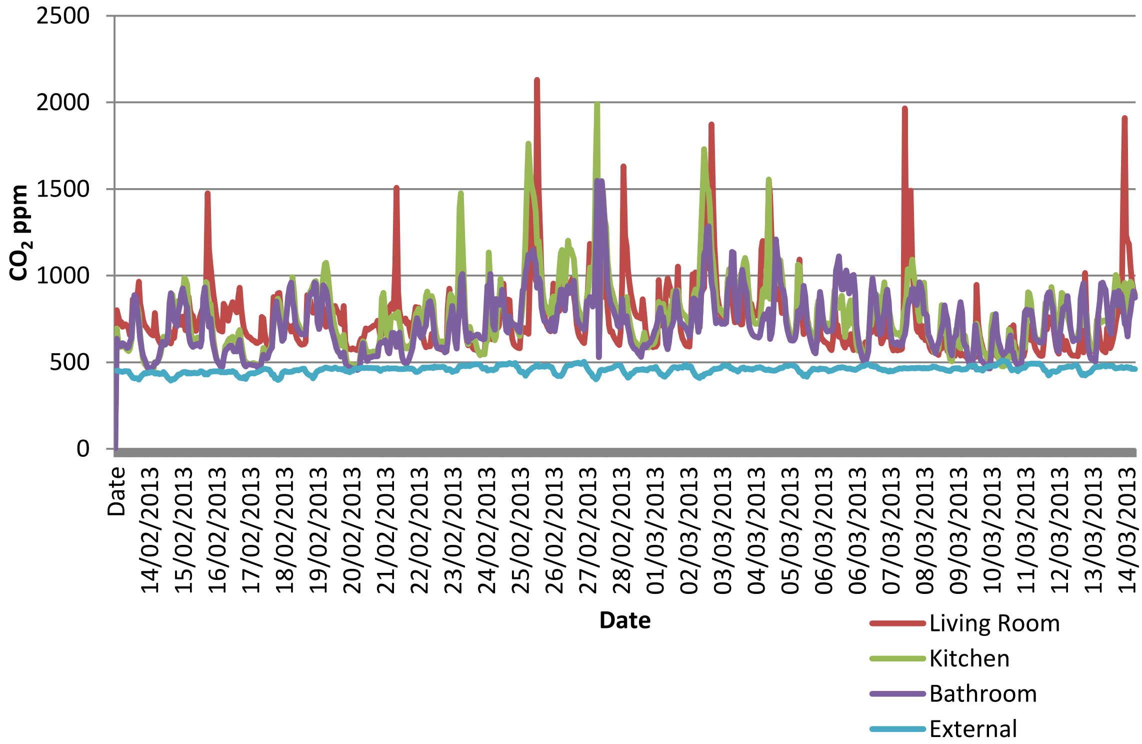


Fig. 14 Carbon dioxide levels from 14 February to 14 March 2013 inclusive

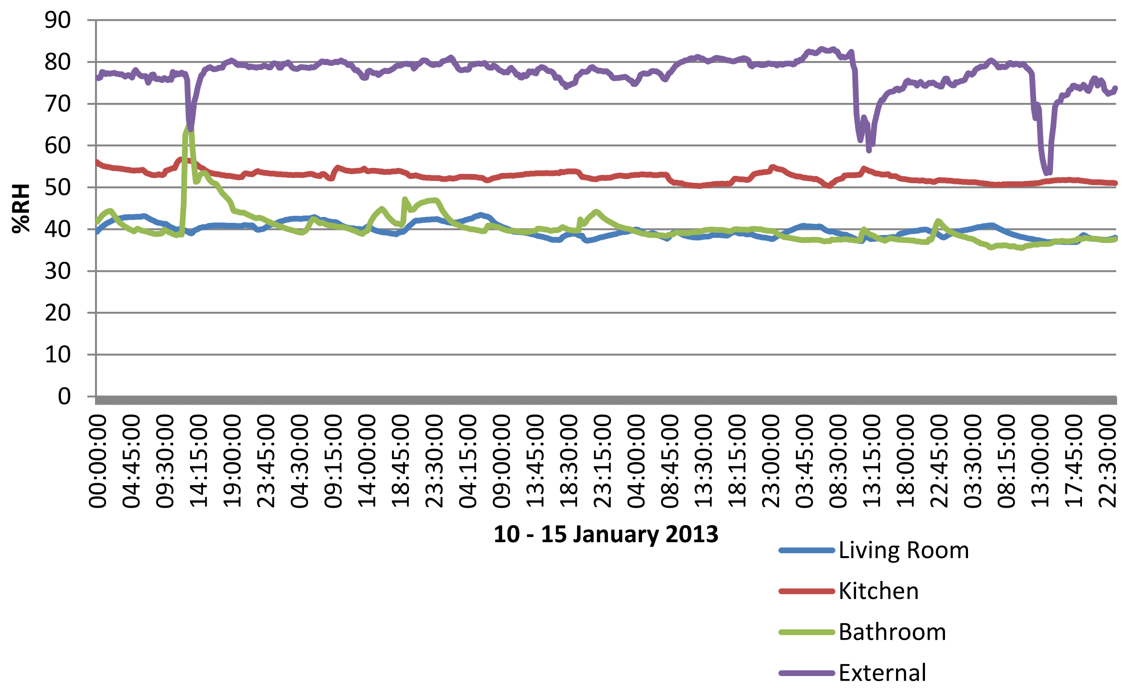


Fig. 15 Comparison of relative humidity levels

Fig. 15 shows a short period under heating regime 2 which demonstrates the stability of the humidity levels within the property due to the low occupancy density. The consistently higher relative humidity in the kitchen is due to a lower room temperature (the kitchen radiant panel was installed in this room on 4 March).

In order to explore the effect of an increased level of activity in the property, one of the project visit days at the property has been examined. On 27 February visit, there were 4 additional people present for part of the afternoon. Fig. 16 shows the effect of the additional occupants on the CO_2 level, whilst an impact on RH is not seen (Fig. 17). The gap in the data in both graphs represents the period when the room sensors were taken outside for cross checking.

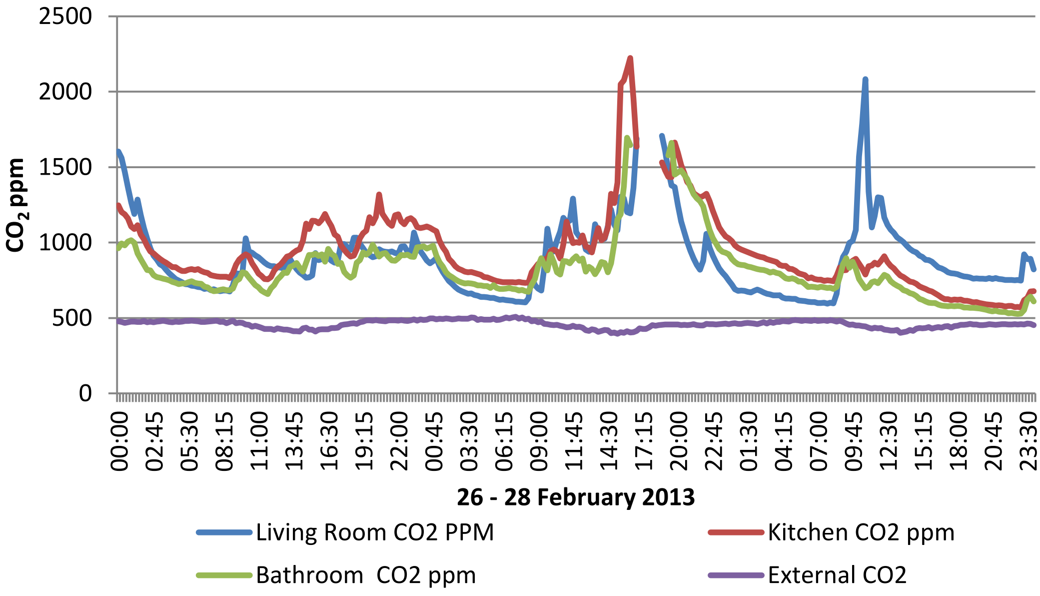


Fig. 16 *CO_2 levels during 26-28 February 2013*

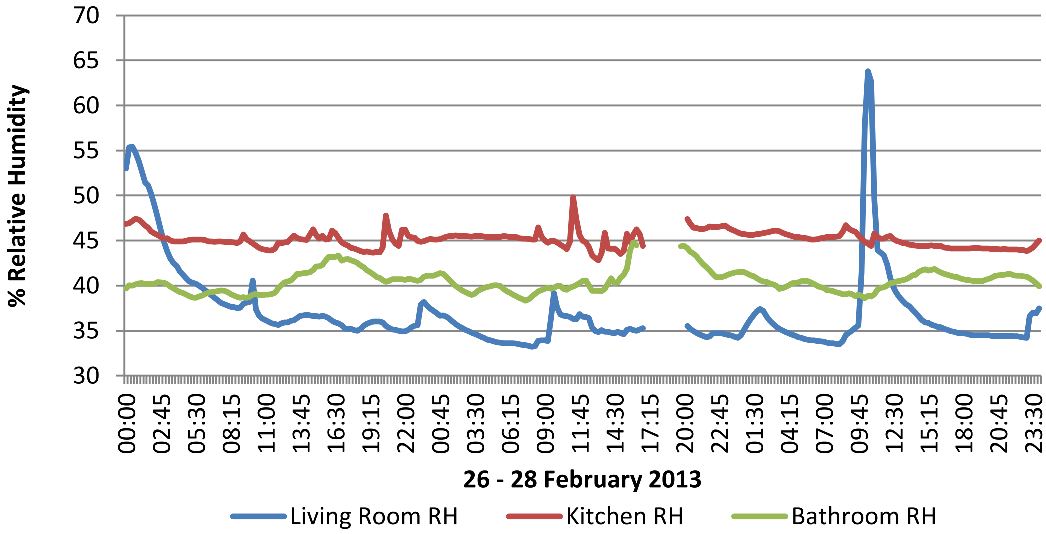


Fig. 17 *RH levels during 26-28 February 2013*

As identified earlier, the location of the bathroom sensor is problematic and affected the accuracy of each element of the data collected: The CO_2 reading will be lower, as the CO_2 is slightly heavier than air; the temperature recorded will be higher; RH will be lower because of the elevated temperature.

This situation is clearly not satisfactory, but it was unfortunately unavoidable.

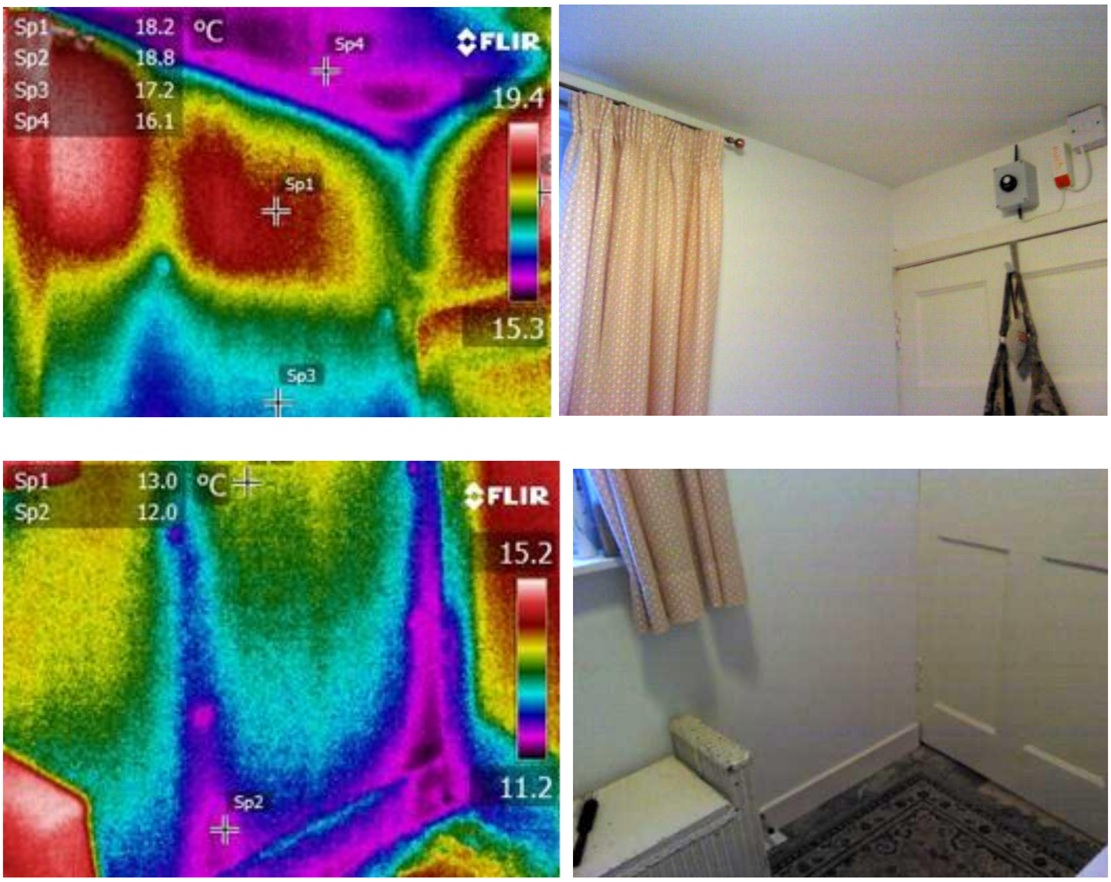


Fig. 18 External wall temperatures in bathroom. Images taken using a thermal imaging camera on 20 December 2012 at 13:46

A thermal imaging camera was used to try to establish the stratification (vertical temperature difference) in the bathroom. Due to the size of the room, it was not possible to view all surfaces at 90^o for better accuracy, but the images indicate there is about a 6-7^{o}C temperature difference between the top and the base of the external wall (Fig. 18). This may also be reflected in the air temperature but it cannot be confirmed.

During Heating Regime 4, the temperature was uniformly set to 18^{o}C from 0745 until 2345 and set back to 16^{o}C overnight. Fig. 19 shows the data recorded under this regime between 21 and 31 March, compared to the recorded external temperature. The pattern of the bathroom heater switching on and off in response to the thermostat is shown in Fig. 19. Due to the height of the sensor in the bathroom, the temperature recorded is expected to reach temperatures in excess of that set on the thermostat. However, this is not the case for the equipment in the living room or kitchen. The kitchen heater was installed before this period and unfortunately the sensor is in direct line of sight of the heater and will be receiving direct radiant gains, elevating the recorded temperature. With respect to the living room, the building occupant may have boosted the heating further, but this cannot be confirmed. In order to investigate further, a direct comparison was made and this is shown in Table 7.

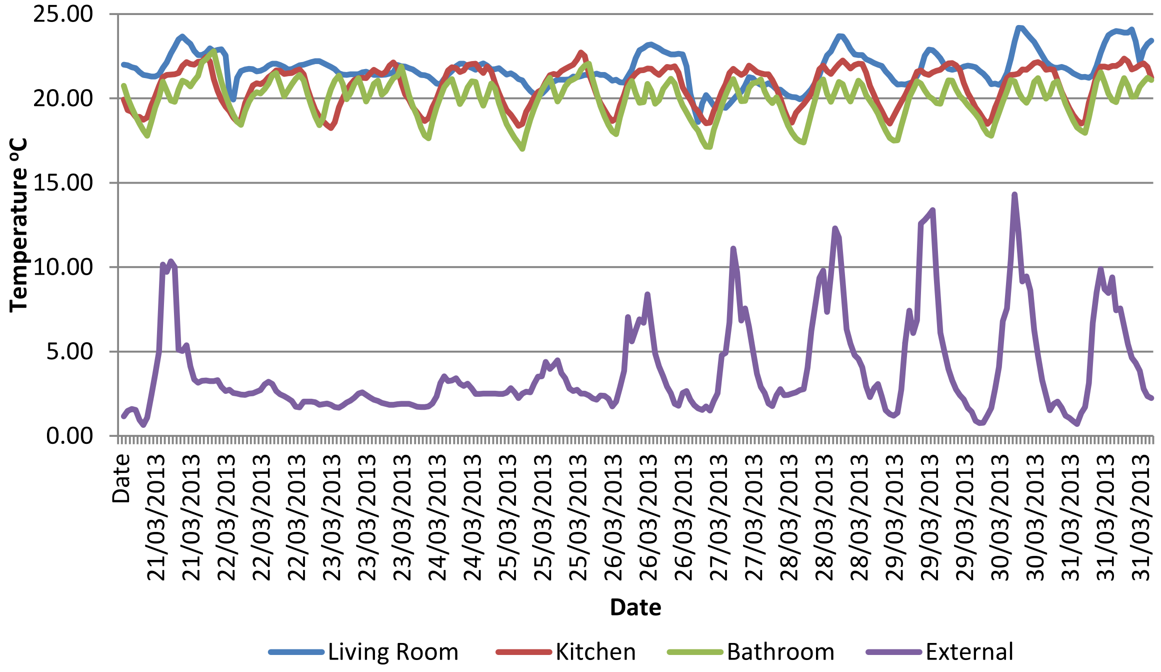


Fig. 19 *Logged temperatures 21-31 March 2013 inclusive*

Room	**Thermostat in direct line of sight of heater?**	**Date**	**Thermostat**		**Logged air temperature**	
			Time	**Temp °C**	**Time**	**Temp °C**
Living	Y	20 Dec	1340	18.0	1345	20.9
			1415	18.0	1415	21.1
			1605	18.0	1600	21.1
		31 Jan	1245	18.0	1245	20.7
Bathroom	N	20 Dec	1300	17.0	1300	22.3
			1605	16.5	1600	22.4
		31 Jan	1220	17.0	1215	22.4

Table 7 *Observed temperatures on manufacturers thermostats vs. logged air temperature*

There is a clear discrepancy between the temperatures appearing on the thermostat controllers and the logged information. Considering the bathroom, a thermal image of the sensor taken on 31 January (Fig. 20) indicates the casing behind the sensor may be receiving more radiant gain (although the emissivity of the casing could also be a factor) and this coupled with the stratification may account for the difference. At this stage it is impossible to confirm which equipment is correct and the supplier will verify the situation on the removal of the equipment from the dwelling. Fig. 21 shows thermal imaging in the living room.

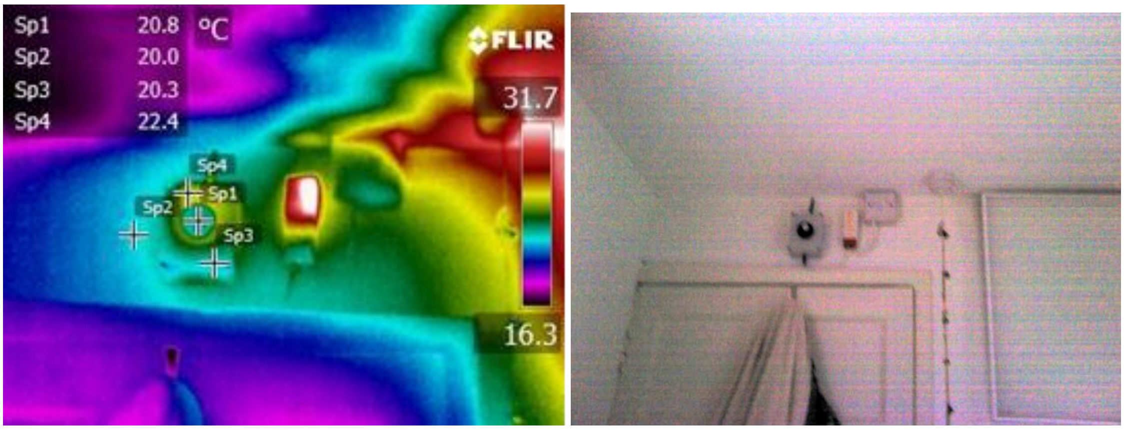


Fig. 20 *Bathroom sensor. Thermal image taken at 13:18 on 31 January 2013*

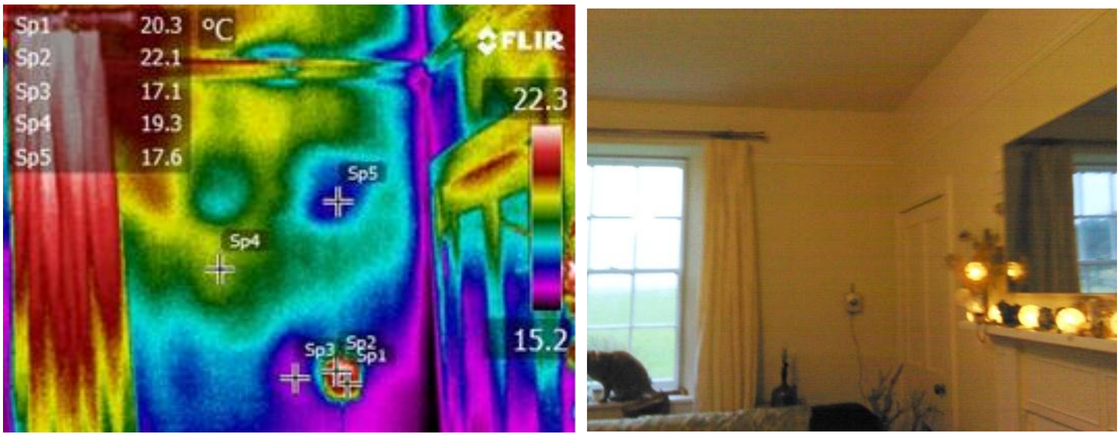


Fig. 21 *Living Room sensor. Image taken at 14:39 on 20 December 2012*

6.4 Air permeability test

Air permeability tests were carried out at Scotstarvit Tower Cottage before and after the refurbishment process and these results appear in Historic Scotland Refurbishment Case Study 7. However, the south door exterior door into the porch had not been draught stripped at the time of the post –refurbishment test in June 2012 so a further test after draught stripping was carried out in January 2013 and the results are shown in Table 8. The 2013 result of 9.75 $m^3h^{-1}m^2$ @50Pa is below the maximum leakage rate of 10 $m^3h^{-1}m^2$ @50Pa specified for new dwellings in the Scottish Building Standards Technical Handbook Domestic (section 6.2.4).

The testing was carried out using an in accordance with ATTMA Technical Standard L1 (2010) and excludes permanent points of ventilation such as boiler flues, chimney flues, extractor fans, mechanical ventilation points and trickle vents.

	Units	**After south door draught stripped 31 January 2013**	**Post-refurbishment results 26 June 2012**	**Pre-refurbishment results 29 July 2011**	**Comments**
Internal floor area	m^2	79			
Habitable building volume	m^3	225			
Dwelling envelope area i.e. surface area of living space	m^2	286			
Measured air flow @ 50 Pa	m^3h^{-1} @50 Pa	2787	3057	4847	All tests were carried out with the front door and loft hatch un-taped and the outer porch door open. For the post-refurbishment and post door draught stripping tests, the secondary glazing was installed. Pre-refurbishment test was pressurisation only.
Air permeability test result at 50Pa	$m^3h^{-1}m^{-2}$ @50 Pa	9.75	10.7	16.9	m^3 of air per hour per m^2 of surface area of the living space at the test pressure.
Air changes per hour at 50Pa	ach@50 Pa	12.37	13.6	21.5	The number of times the complete volume of air in the property is changed per hour at the test pressure.

Table 8 *Scotstarvit Tower Cottage: Comparison of air permeability results*

Thermal imaging had not been used on the property during the previous tests, as they were undertaken during the summer, when external temperatures are generally too high to achieve meaningful results. Figures 22 – 24 show the locations of air ingress noted during the 2013 test whilst building was depressurised (using a thermal imaging camera). An area on the south wall of the living room was also noted on 20 December, when the building was under normal conditions and this is shown in Fig. 25.

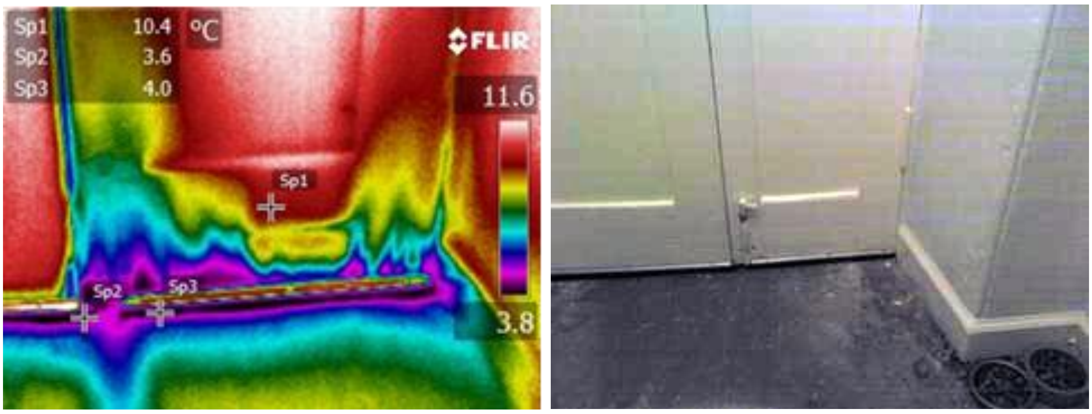


Fig. 22 *Air leakage around the south door into the porch*

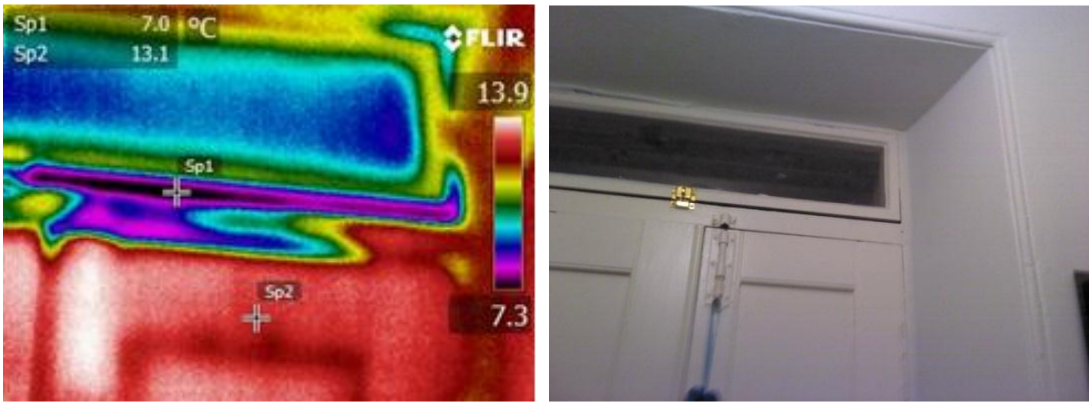


Fig. 23 *Window above door south door*

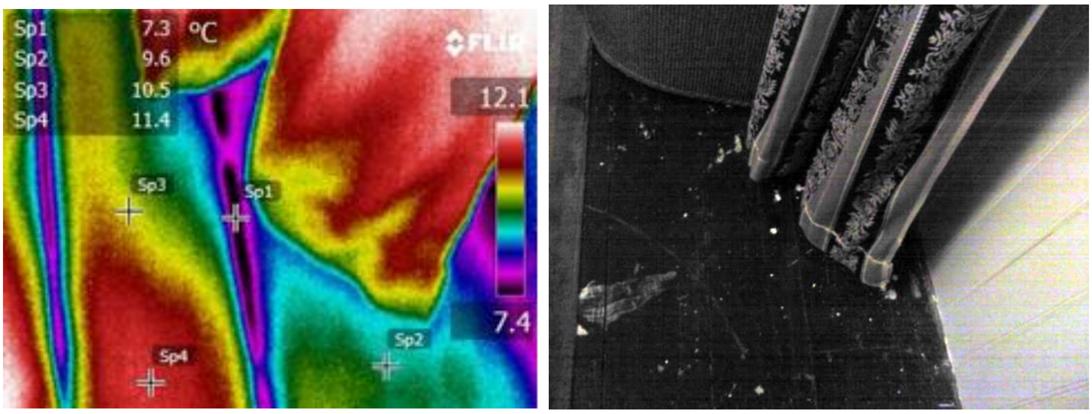


Fig. 24 *Sitting room south wall*

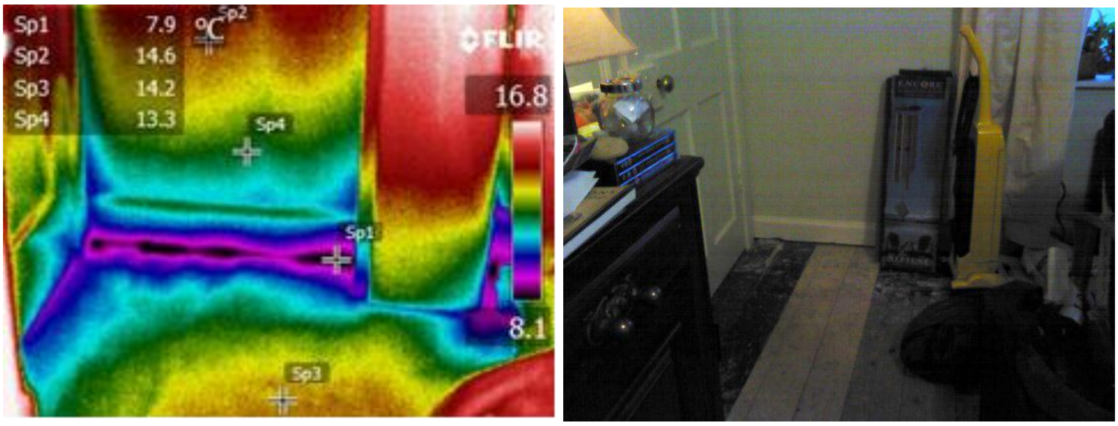


Fig. 25 South wall of living room

6.5 Effect of the chimney on ventilation

The ventilation effect of the chimney flue in the living room on IAQ was assessed as part of the study. The flue and chimney stack appear to date from the mid-19th century and are likely to be original. The hearth and chimney piece appear to be later, probably from the late 19th or early 20th Century and feature a cast iron insert and grate. The inset features a built in hood that can be pushed back flush with the inset, largely closing off the chimney flue from the room (Fig. 26). Under standard air test conditions, the air flow relating to flues is excluded from the air permeability test. However, the air flow relating to the flue was evaluated under pressurised blower door test conditions. This will not directly relate to the actual air flow experienced but offers a means of comparison. Whilst the integral baffle appeared to work satisfactorily, to allow extra quantification of the opening a board perforated by a series of holes was fixed to the fireplace with the baffle closed and its outer edge sealed (Fig. 27). The intention was to vary the air flow in the flue and to measure the effect of the reduced air flow on indoor air quality. The board was put into place on 20 December and as a first step all holes covered over to see the effect of closing the flue off completely. As discussed in Section 6.3 above, this action did not result in significant air quality issues and the fireplace and flue remained sealed for most of the monitoring period (apart from during part of the air permeability test process on 31 January). A further reason for not uncovering the flue was to avoid introducing another variable into the changing heating regime.

Fig. 26 Living room fireplace shown with damper closed (top left), open and suitable for use (top right and bottom).

Fig. 27 Living room fireplace showing temporary board fixed into place.

Measurements were taken with the flue open and the baffle closed in the 2012 and 2013 tests and these are shown in table 9. It must be highlighted that these figures may not reflect the actual air flow in the flue as this will be governed by a range of effects including the interior to exterior temperature difference and wind speed. It does however offer a means of comparing air flow under a standard set of conditions. The test results reflect the change in chimney pot shown in Fig. 28.

	Additional air flow above baseline (m^3h^{-1} @ 50Pa)	
	2013 Test	**2012 Test**
Fireplace damper closed	**168**	**112**
Fireplace damper open	**642**	**134**

Table 9 *Additional air flow above baseline under pressure test conditions (2012 baseline was a taped over fireplace, 2013 baseline was with fireplace board fitted and the holes in the board sealed)*

Though the air flow measured when the flue was uncovered will not represent actual air flow in the flue (as this depends on a number of factors), it should be noted that for the 2013 test, the flue with baffle open adds an additional air flow of 23% to the property as a whole under the test conditions. This compares to only 6% with the baffle closed.

Fig. 28 *Change in chimney pot. Left to right: 2011, 2012 capped with an "elephant's foot", 2013 – replaced with a cowl so the hearth or flue can still be used.*

7. Discussion of results

Direct or indirect radiant heat gain

It has been observed from the study that the heating arrangement at Scotstarvit Tower Cottage is not ideally suited to the stated objective of delivering thermal comfort by radiant heat using localised heating with a lower air temperature. The current system of the radiant heating panels being triggered by thermostatic controls measuring air temperature means the system is relying on indirect gains to occupants rather than direct. In order to explore the research objective better, panels offering direct heat gains and under the direct control of the occupants would have offered a more effective trial.

Following contact with a number of installers and suppliers of radiant heating equipment, it is evident a better understanding of how this type of heating can be used is required. The project has confirmed the equipment offers a good level of thermal comfort and has the potential for efficient energy use under appropriate circumstances (subject to further trials). If the heating is to be used primarily for direct gain, then the location of the panels becomes more critical and this needs to be taken into account when installations are specified.

Thermal comfort

The feedback from the building occupant clearly shows the infrared panels are able to deliver good levels of thermal comfort, with Heating Regime 2 being the most satisfactory, though it did not have the greatest energy use. The expectations from a heating system depend not only on the thermal comfort delivered, but also our expectations from the heating system and the affordability of energy bills. The dwelling occupant now has a greater awareness of energy use for heating and, if the trial were repeated, this understanding could influence the feedback given.

Energy use

The mean energy use for the heaters over the period of the study was 0.7 kWh per m^2 per day, with the lowest energy use during Heating Regime 1 (4.3 kWh per degree day for the property) and the greatest from Regime 4 (6.1 kWh per degree day). The latter is the pattern recommended by the equipment suppliers for minimum energy use and consumed more than 40% more energy per degree day than Regime 1.

Ideally, a comparison should be made to an alternative type of heating, but this is unavailable at Scotstarvit Tower Cottage. Contact was therefore made with two other trials being carried out – one at the University of St. Andrews and the other by a St. Andrews based community group, StAndEn, both of which are outlined in Appendix 3. These projects are still in progress, but the following can be noted:

- In both cases the complexity of using the thermostat controllers was highlighted. This is reflected and supported by the findings of this project.
- It was appreciated that the heating timings and zoning would impact on energy use. In neither case have a range of different heating patterns been tested.
- For the StAndEn property, the use of off-peak electricity has an impact on the final heating bill and the use of different tariffs is being explored.

The supplier of the electric radiant panels also commissioned a report on the energy use of this form of heating based on modelling[9] and the study at Scotstarvit Tower Cottage does not seek to validate that report. It should also be noted the heating pattern used for the modelling of the infrared heaters in that report assumes an intermittent heating pattern similar to that usually applied to a conventional wet central heating system, rather than the actual heating pattern recommended by the supplier and implemented under the heating regimes at Scotstarvit Tower Cottage.

Effect of flue

At Scotstarvit Tower Cottage, there will be an impact on energy use from the open flue, as when the flue is open it increases the air flow through the property by more than 20% under the air permeability test conditions (this figure does not allow for the wind and stack effects which make a flue draw). The fireplace was closed off after 20 December with a perforated board and this should be borne in mind when viewing the energy use results.

Thermostat controller

Considering the capital investment involved in radiant panels, the thermostats used seem to be a budget option, with potential inaccuracy. The individual room thermostats also make the system more difficult to adjust. It was also very noticeable that to the occupant, the temperature displayed on the thermostat controller often took precedence over an assessment of whether they felt comfortable. It is understood that the supplier is currently developing a more intuitive controller which does not display the room temperature and can be applied on a zonal basis.

Indoor air quality

From the measurement of relative humidity and CO_2 as proxy for other pollutants, no air quality problem has been identified at Scotstarvit Tower Cottage following the refurbishment. Despite the air permeability level being within the threshold applied to new dwellings under the Scottish Building Standards Technical Handbook (section 6.2.4) and the temporary sealing of the chimney flue during the early stages of the project, the CO_2 levels remained within acceptable limits. This may be due to the low level of occupation and moisture generation for a dwelling of this size.

Some limitations of the air quality monitoring need to be recognised:

- The importance of ensuring the sensor locations are consistent between rooms and at the same height at the controller thermostats
- The problem with the variation in the temperature being recorded between the data logging equipment and the thermostats. In retrospect an on-site temperature calibration of all equipment should have taken place at the outset of the project.
- The need for cross referencing and recalibration of the CO_2 monitor on a regular basis according to the indoor environmental conditions experienced.

[9] Verco, Silver, S., *A comparative study of Infranomic far-infrared heating panels with existing heating systems.* Commissioned by Direct Savings Ltd.

8. Conclusions

The objectives of this study were as follows:

- To establish whether the radiant heating system can deliver thermal comfort at an air temperature lower than the standard (18-21^{o}C)
- To establish the energy efficiency of this mode of heating
- To examine the impact of reduced air flows / infiltration levels on indoor air quality

It has not been possible to adequately investigate the delivery of thermal comfort at a lower air temperature because of the manner in which the heating system is controlled, using thermostats based on air temperature. This means the installed system relies on indirect gains from the heaters rather than direct radiant gains to the building occupants which are required when the air temperature is lower.

The monitoring project at Scotstarvit Tower Cottage has confirmed electric radiant heating panels can deliver good levels of thermal comfort. However, the cost of providing this comfort is important and there was a wide variation in the energy use between the different heating patterns monitored. The pattern recommended by the equipment installers as “for the minimum energy use” yielded the poorest results. This illustrates the need for suppliers to understand how the heating system functions, how the building performs and what the needs of occupants are. It also needs to be appreciated that zoning as well as variable timing patterns, ease of use of controls by the dwelling occupant and the energy tariffs all influence energy use.

The mean electricity use for heating over the monitoring period was 0.7 kWh per m^2 per day for the 79m^2 3-bedroom dwelling over the heating period. Bearing in mind the comments above, this amount is probably overstated and the energy use with the current heating system arrangement could be reduced whilst maintaining reasonable levels of thermal comfort.

With respect to indoor air quality, the low occupant density meant there were no significant air quality issues, even with the closed chimney flue.

9. Further research

- No comparison has been drawn in this study to the cost of heating the dwelling by other heating systems or fuels. This could be investigated through modelling.
- Scotstarvit Tower Cottage is not typical for its age – the refurbishment process has reduced the effective thermal mass of the building and it has a level of air tightness comparable to new dwellings. Modelling could also be used to explore the impact of these factors on energy use.
- In the light of the findings of this report, there is merit in considering monitoring the energy use in the property for a further heating season, noting the lessons learnt from this trial.

10. References

CIBSE, *Guide A: Environmental design*. London: CIBSE Publishing, 2006.

CIBSE, *Guide B: Heating, ventilating, air conditioning and refrigeration*. London: CIBSE Publishing, 2005.

CIBSE, *Degree days: theory and application TM41:2006.* London: CIBSE Publishing, 2006.

Halliday, S., *Technical Paper 6 - Indoor air quality and energy efficiency in traditional buildings.* Edinburgh: Historic Scotland, 2009.

Harvey, L.D.D., *A handbook on low energy buildings and district energy systems.* London: Earthscan, 2006.

Hong, S., 2011. *Changes in space heating energy consumption following energy efficient refurbishment in low-income dwellings in England.* PhD thesis, The Bartlett School of Graduate Studies, University College London.

Humphreys, M., Nicol F., and Roaf, S., *Technical Paper 14 - Keeping warm in a cooler house, Creating thermal comfort with background heating and local supplementary warmth.* Edinburgh: Historic Scotland, 2011.

Nicol, F., Humphreys, M. and Roaf, S., 2012. *Adaptive thermal comfort: Principles and practice.* Abingdon: Routledge

Snow, Jessica, *Scotstarvit Tower Cottage, Cupar - Thermal upgrades & installation of radiant heating.* Edinburgh: Historic Scotland, 2012.

Verco (author: Silver, S.), June 2013. *A comparative study of Infranomic far-infrared heating panels with existing heating systems.* Commissioned by Direct Savings Ltd.

Walker, S., August 2012. *Energy use in the home: Measuring and analysing domestic energy use and energy efficiency in Scotland.* Scottish Government (Scottish House Condition Survey and Research Team**.**

Appendix 1 – Products and Suppliers

Radiant heating panels	Infranomic installed by Direct Savings
Battery operated wireless thermostat controller	TPS Thermal Controls TPS908WHB-3-RF
Extractor Fan	Airflow QT100HT
Extractor Hood	Lamona HJA2180
Screen over CO_2 and RH sensors	Stephenson Screen
CO2 and RH sensors, power meter, web logger	Supplied and installed by Air Monitors
Thermal imaging camera	FLIR E60
Blower Door	Energy Conservatory Minneapolis Model 3

Appendix 2 – TPS Thermal Controls TPS908WHB-3-RF Installation and operating instructions

tpsthermalcontrols

TPS908WHB-3-RF WIRELESS THERMOSTAT

Installation and operation instructions

TPS908WHB-3-RF can replace most common residential thermostat and is designed to be used with electric, gas or oil heating control system.

Unlike ordinary single unit design thermostat, this unit is a new type of thermostat separating the thermostat function into two units. Receiver TPS2000WHB-Re and Control Centre TPS908WHB-3-Tr. The Receiver serves for wiring connections and heat on/off control. The Control Centre serves as user interface and temperature sensing/control. User can put the control Centre nearby and can read/control the temperature of really the living area while put the Receiver besides the heating. The two units are linked by RF.

SPECIFICATION:

Power source............................ Control Centre 2 AA batteries
Receiver 220VAC±10% 50/60HZ
Frequency band.......................... 433 MHZ
Relay contact (Receiver)................ 250VAC 16A
Room temperature setting range........ 5℃ to 35℃ (41℉ to 95℉)
Accuracy................................ ±1℉ or ±0.5℃
Dimensions.............................. Control Centre 115mm×90mm×28mm
Receiver 88mm×88mm×16mm

NOTE:

1) When testing, the distance between Transmitter and Receiver should above 150CM.
2) If install two or more Receivers, the distance of any two units should above 40CM. To avoid interfered.

FEATURE:

- Can be placed anywhere in the home to detect and control the temperature of an area of the user's choice. Not limited by power control wiring locations
- Link with the Receiver via RF. Control distance 100M open site
- Large LCD display
- The screen displays the set temperature and the room temperature also time simultaneously
- Permanent user setting and program setting retention during power loss
- Optional temperature display of Celsius or Fahrenheit scale
- Both Vacation mode and hold duration mode available for comfort and energy saving
- Separate 5-day (weekday) and 1-day/1-day (Saturday/Sunday) programming with four separate time/temperature periods per day
- Display temperature recalibrates
- Low battery indication
- Anti-freezing protection
- Pump protection available

IMPORTANT SAFETY INFORMATION:

- Always turn off power at the main power source by unscrewing fuse or switching circuit breaker to the off position before installing, removing, cleaning, or servicing this thermostat.
- Read all of the information in this manual before installing this thermostat.
- Only a professional contractor should install this thermostat.
- All wiring must conform to local and national building and electrical codes and ordinances.
- This thermostat has a removable fuse to protect the system from damage. If system is not operating properly, check wiring and replace fuse if necessary.
- Use this thermostat only as described in this manual.

RF ADDRESS CODE SETTING

If there is another user nearby, e.g. in the next house, your receiver may be fault triggered by their transmitter. You may select a different RF address code to prevent this. Receiver can only response to RF coding with the same address code setting as its own address code. **If you want to change the RF address to avoid mis-triggered by other user, you should adjust address code of both Receiver and the Control Centre.**

1. To adjust address code of Receiver, simply push up one or more of the 8 dip switch levers.
2. To adjust address code of Control Centre, open the housing of the Control Center. See install the Control Centre, According to the modified address code of Receiver, adjust the address code of Control Centre to the same address of Receiver by pushing up the 8 dip switch levers.

Caution:

1. ***Address code of Control Centre must be the same as address code of Receiver.***
2. ***Disconnect AC power and remove batteries prior to adjusting address code.***

Address code of Control Centre

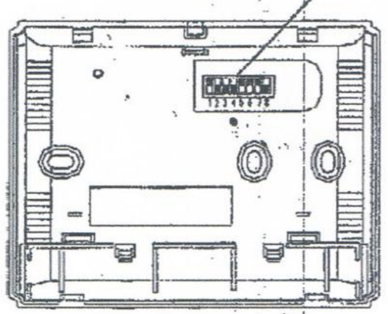


Figure 1

Address code of Receiver

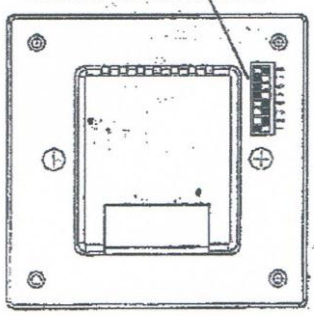


Figure 2

MOUNTING THE RECEIVER

Mounting the Receiver onto the optional wall box (See Figure 3)

1. Remove the front cover of the Receiver.
2. Mark the holes position for the wall box.
3. Drill two holes and insert the plastic anchors carefully into the holes until they are flush with the wall.
4. Push the wires into the wall box and fasten the wall box onto the wall.

5. Connect the wires-See wiring diagram.
6. Push on the wires in the wall box.
7. Securely fasten the Receiver to the wall box with the two screws.
8. Replace the front cover and installation is completed.

Pls note: The distance of two units should above 40CM. To avoid interfered.

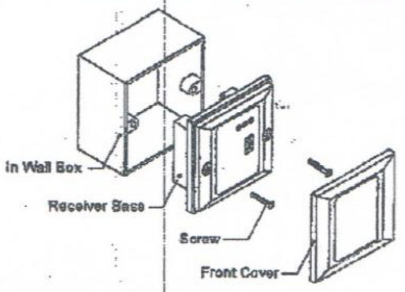


Figure 3

WIRING DIAGRAM

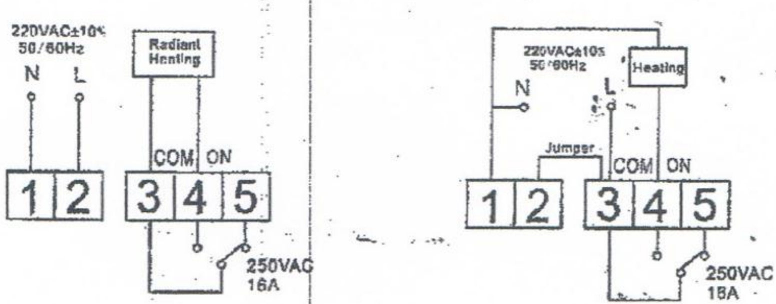


Figure 4

Figure 5

For Water Radiant Heating System, the Unit requires 220VAC application. (As **Fig.4**)
NOTE: Please remove jumper.
Don't connect terminal 2 & 3 . It will cause short circuit.

For other Heating System, the Unit requires 220VAC application. (As **Fig.5**)

INSTALL THE CONTROL CENTRE

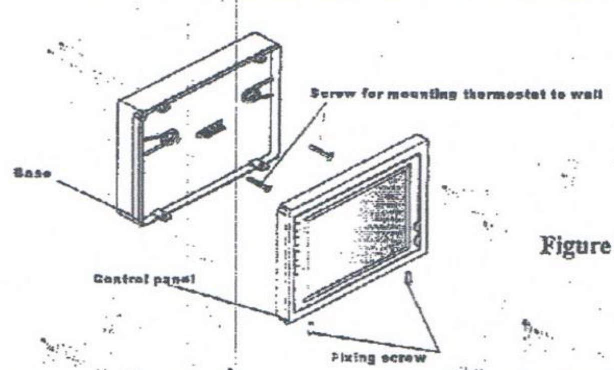


Figure 6

3

1. Remove 2 screws from the bottom of thermostat. (See Figure 6) Gently pull the control panel straight off the base. Forcing or prying on the thermostat will cause damage to the unit.
2. Push power base into wall.
3. Using two mounting screws mount the power base to the wall. Place a level against bottom of base, adjust until level, and then tighten screws. (Leveling is for appearance only and will not affect thermostat operation.)
4. Replace control panel on the power base and fix power base and control panel by removed two screws in item 1.

KEYBOARD, DISPLAY AND SWITCH DESCRIOPTION OF CONTROL CENTRE

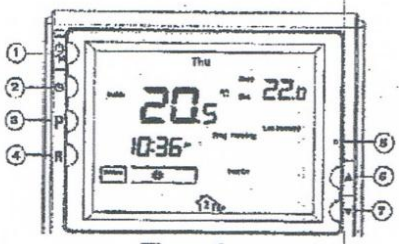


Figure 6

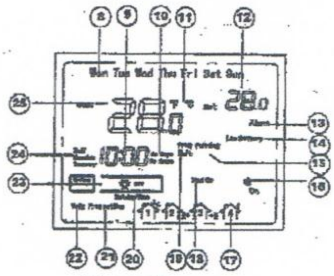


Figure 7

① Power on/ anti-freezing /off button
② Time setting button
③ Program setting button
④ Program run confirmation button
⑤ Reset button
⑥ Raise Temperature setting button
⑦ Lower Temperature setting button
⑧ Shows current day or days being programmed.
⑨ Shows current time or times being programmed
⑩ Am:: Morning , Pm:: Afternoon Days: Nr of days, Hours: Nr of hours
⑪ Shows temperature display in ℃ or ℉
⑫ Setting temperature
⑬ Indicates a malfunction with the system.
⑭ Low battery indicator
⑮ Shows when thermostat is in the programming mode.
⑯ Shows when thermostat is in the pump protection mode
⑰ 1 time to get up 2 time to go out 3 time to come back home 4 time to go to bed
⑱ Shows the thermostat is calling for heat
⑲ Wait icon
⑳ Set day/time: Shows current day and time being displayed
㉑ Prog setting: Shows when the thermostat is in program setting mode.
㉒ Cofg: Shows when the thermostat is in the configuration mode
㉓ Shows current system mode
㉔ Hold: Shows when thermostat is in the holding temperature mode
• Vacation: Shows when thermostat is in the vacation mode.
㉕ Shows current room temperature.

SWITCH AND LED DESCRIPTION OF RECEIVER

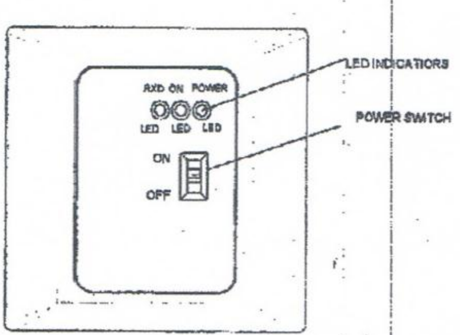


Figure 8

POWER SWITCH: When there is no demand to turn on the heating device, it is recommended to turn the power switch to the off position.

LED INDICATOR:

1. Red LED turns on as long as there is power to the unit
2. Green LED turns on as long as the heating device is energized.
3. Yellow LED flashes as long as there are any signals received from the Control Centre.

CHECK THERMOSTAT OPERATION

The unit will be controlled via air sensor in the Control Centre and the Control Centre will determine to activate/deactivate heating system by comparing set temperature with room temperature. Press ▲ to adjust Control Centre setting above room temperature 1℃ in fast heating mode or 3℃ in slow heating mode, See configuration menu item 5. The Control Centre will emit signals to the Receiver asking to turn on the heating device. Yellow LED on the Receiver flashes means Receiver has received the signals. Green LED turns on means heating device is energized. Press ▼ to adjust Control Centre setting below room temperature. The Control Centre will emit signals to the Receiver asking to turn off the heating device. Yellow LED on the Receiver flashes means Receiver has received the signals. Green LED turns off means heating device is deactivated.

OPERATION

1. Configuration Menu

The configuration menu allows you to set certain thermostat operating characteristics to your system or personal requirements. Shortly press button ① to make sure the thermostat is in anti-freeze mode. Hold button ③ for 3 seconds to enter the configuration menu. The display will show the first item in the configuration menu. Press button ③ to shift to the next menu item. Use ▲or▼ to select. To exit the menu , press button ① revert to the anti-freeze mode . Press button ④ revert to the program operation. If no buttons are pressed within 20 second the thermostat will exit the menu. To revert to factory default setting , push ▲&▼ button in a same time for 3 seconds. Display will show "DEF" blinking 3 times and return to Menu item 1 indicates all the configuration setting has reverted to factory default setting.

Step	Press buttons	Displayed (factory default)	Press ▲or▼ to select	Descriptions
1	③	01 (0)	-3 --- +3	Select temperature display adjustment higher or lower.
2	③	02 (35℃)	18℃(64℉)—35℃(95℉)	Select maximum setting temperature limitation.
3	③	03 (5℃)	5℃(41℉)—20℃(68℉)	Select minimum setting temperature limitation.
4	③	04 (℃)	℃/℉	Select temperature display to ℃ or ℉.
5	③	05 (FA)	FA/SL	Select fast heating or slow heating.
6	③	06 (OO)	PP/OO	Select pump protection PP,Cancel pump protection OO.
Press button ④ revert to the program operation				

1) **Select temperature recalibrates Adjustment 3 LO to 3 HI –**

You can adjust the room temperature display up to 3 higher or lower. Your thermostat was accurately calibrated at the factory but you have the option to change the display temperature to match your previous thermostat. The current or adjusted room temperature will be displayed on the right side of the display.

2) **Select maximum temperature set point**

This feature provides a maximum set point temperature. The default setting is 35℃ (95℉), It can be changed between 18℃ (64℉) to 35℃ (95℉).

3) **Select minimum temperature set point.**

This feature provides a minimum set point temperature. The default setting is 5℃ (41℉), It can be changed between 5℃ (41℉) to 20℃ (68℉).

4) **Select ℉ or ℃ readout.**

Changes the display readout to Centigrade or Fahrenheit as required. The default setting is ℃.

5) **Select fast heating or slow heating**

Select FA to start heating immediately when the set point is 1℃ above the room temperature. Select SL to start heating only when the set point is 3℃ above the room temperature. The default is FA.

6) **Select pump protection mode**

For hot water installations, it is recommended to activate the pump at least 15 second every 24 hours in order to avoid any seizing. Select PP will activate pump protection mode. Select OO will cancel the function. When thermostat activating the pump, ⑮ in the display will blink. The default is OO.

2. Manual Operation

1) On/Anti-freezing mode

You can press power button ① to activate the anti-freezing mode. The unit only displays Clock time, Weekday and Room temperature. The default set temperature for anti-freezing mode is 5℃. During anti-freezing mode, if room temperature is below 5℃, the unit will activate the heating system till room temperature reach to 9℃. For hot water installations, if PP had been selected (See Configuration menu item 6), the unit will activate the pump at least 15 seconds every 24 hours in order to avoid any seizing. Press power button ① again will terminate the anti-freezing mode and return to normal operation mode.

2) Program operation and Hold temperature operation

Momentarily press button ④, the thermostat will control the heating system by preset program and if press ④ over 3 seconds the thermostat will enter into hold temperature operation. **Prog running** shows when thermostat is in program operation. Thermostat controls the heating system by presetting program. See **Planning your program** section. **Hold** shows when thermostat is in hold temperature operation. The thermostat will hold the room temperature at the selected setting

3) Temperature override

During program operation. Press ▲or▼ until the temperature you want is displayed. The thermostat will override the current programming and keep the room temperature at the selected temperature until the next program period begins. Then the thermostat will automatically revert to the program.

4) Vacation Temperature hold

Continue pressing button ③ over 3 seconds until display will show Vacation indicates you have now entered into vacation hold.Use time key ②to select the number of the days (from 1 to 99 days) during your vacation,you can use ▲or▼ to adjust the temperature during your holiday. Push button ④ to revert to program operation.

5) Reset operation

If the display is abnormal, press the Reset button by using a fine probe such as a straightened paper clip to gently push the Rest button. This will reset the thermostat.

3. Set current day and time

1) Press ② button. The display will show the hour flashing;
2) Press and hold either ▲or▼ until you reach the correct hour and AM/PM designation; (AM begins at night, PM begins at noon)
3) Press ② button once again. The display will only show minutes flashing;
4) Press and hold either ▲or▼ until you reach the correct minutes;
5) Press ② button once again. The display will show the day of the week flashing;
6) Press ▲or▼ until you reach the correct day of the week.

Press button ④ once. The display will show the correct day of the week and the time. If no keys are pressed within 20 seconds, the thermostat will revert to program operation.

4. Planning your program

Look at the factory preprogrammed times and temperatures shown in the sample schedule. If this program will suit your needs, simply press the ④ button to begin running the factory preset program.
If you want to change the preprogrammed time and temperature, follow these steps.

Determine the times period and temperature for your program. You must program four periods for each day. You can choose heating temperature and start time independently. (for example, you may select 5:00 AM and 21°C as the weekday 1st period heating start time and temperature and also choose 7:00 AM and 26°C and the weekday 1st period cooling start time and temperature)

. Use the table to plan your program time periods and the temperatures you want during each period. Fill in the complete table to have a record of your program

Heating Schedule Plan (Factory default program setting)

Period		Weekdays (5 day)		Saturday		Sunday	
		Start time	Temperature	Start time	Temperature	Start time	Temperature
Heat	1	6:00 AM	21°C	6:00 AM	21°C	6:00 AM	21°C
	2	8:00 AM	16.5°C	8:00 AM	16.5°C	8:00 AM	16.5°C
	3	5:00 PM	21°C	5:00 PM	21°C	5:00 PM	21°C
	4	10:00 PM	16.5°C	10:00 PM	16.5°C	10:00 PM	16.5°C

Enter Heating Program

1). Press ③ once. **PRGM SETTING** will display. "MO TU WE TH FR" (indicating weekday program) will appear in the display. Also be displayed are the currently programmed start times for the 1st heating period and the currently programmed temperature (flashing), icon  indicates 1st program period (Get up) setting.

2). Press ② to set the programmed time or programmed temperature , Press ② once (the programmed temperature will flash) , Press ▲or▼ to change the displayed temperature to your selected temperature for the 1st heating program period.

3). Press ② once (the programmed time will flash). Press ▲or▼ until your selected time appears. The time will change in 15-minute increments. When your selected time is displayed, press TIME again to return to the change temperature mode.

4). Press ③ once, icon 2 2nd program period (Go out) display, he currently programmed start time and set point temperature for the 2nd heating program period will appear
5). Repeat steps 3 and 4 to select the start time and heating temperature for the 2nd heating program period.
6). Repeat steps 3 through 5 for the 3rd and 4th heating program periods
7). Press ③ once. "SA" (indicating Saturday program) will appear in the display, along with the start time for the 1st heating period and the currently programmed temperature.
8). Repeat steps 3 through 7 to complete Saturday heating programming.
9). Press ③ once to change to SU (Sunday) heating programming and repeat steps 3 through 7 to complete Sunday programming.
10) When you have completed entering your heating program, press ④.

REVERT TO FACTORY DEFAULT PROGRAM SETTING

Press ③ button enter into program setting. Press ▲&▼ at the same time for 3 seconds. Display will show DEF blinking for 3 times and back to program setting. Press the ④ button to begin running the factory preset program. If no keys are pressed within 20 sec, the thermostat will revert to program operation.

CHECK YOUR PROGRAMMING

Follow these steps to check your thermostat programming one final time before beginning thermostat operation.

1. Press button ③ to view the 1st weekday heating period time and temperature. Each time you press button ③, the next heating period time and temperature will be displayed in sequence for weekday, then Saturday and Sunday program periods (you may change any time or temperature during this procedure).
2. Press button ④ to begin program operation.

CUSTOMER ASSISTANCE

After reading this guide, if you have any question about the operation of your thermostat, please contact your installer or Energy Utility company or service provider.

Appendix 3 – Data sheet for Cozir Ultra Low Power Carbon Dioxide Sensor

COZIR™

Ultra Low Power Carbon Dioxide Sensor

COZIR is an ultra low power (3.5mW[4]), high performance CO_2 sensor, ideally suited for battery operation and portable instruments. Based on patented IR LED and Detector technology and innovative optical designs, COZIR is the lowest power NDIR sensor available. Optional temperature and humidity sensing are available. COZIR is a third generation product from Gas Sensing Solutions Ltd – leaders in IR LED CO_2 sensing.

With measurement ranges of 0-2000ppm, 0-5000ppm and 0-1% the **COZIR Ambient** Sensor is suitable for applications such as Building Control and Horticulture.

- Ultra-low Power 3.5mW
- Measurement ranges from 0 to 1%
- Low noise measurement (<10ppm)
- 3.3V supply.
- Peak current only 33mA.
- Optional Temperature and Humidity Output

COZIR™ Ambient Sensor

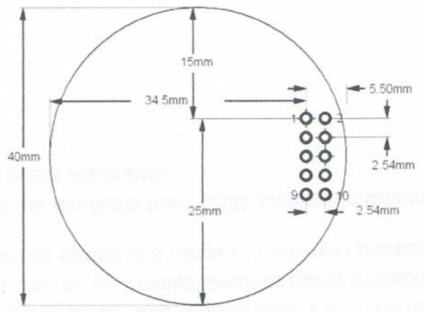
Specifications

General Performance	
Warm-up Time	< 10s. 1.2 secs to first reading.
Operating Conditions	0°C to 50°C (Standard) -25°C to 55°C (Extended range) 0 to 95% RH, non-condensing
Recommended Storage	-30°C to +70°C
CO2 Measurement	
Sensing Method	Non-dispersive infrared (NDIR) absorption Patented Gold-plated optics Patented Solid-state source and detector
Sample Method	Diffusion
Measurement Range	0-2000ppm, 0-5000ppm, 0-1%
Accuracy	±50 ppm +/- 3% of reading[1]
Calibration	Autocalibration[6]
Non Linearity	< 1% of FS
Pressure Dependence	0.13% of reading per mm Hg in normal atmospheric conditions.
Operating Pressure Range	950 mbar to 10 bar[2]
Response Time	30 secs to 3 mins (Configurable via filter type and application)[3] Reading refreshed twice per second.[3]

Electrical/ Mechanical	
Power Input	3.25 to 5.5V. (3.3V recommended). Peak Current 33mA[4]. Average Current <1.5mA[4].
Power Consumption	3.5 mW[4]

Dimensions and Wiring Connections

2x5 0.1" header. view from underside (connector side)



Note that the drawing shows details of the PCB inside the sensor casing. The outside dimension of the sensor casing is 43mm.

Function	Pin #	Pin #	Function
GND	1	2	N/C
+3.3V	3	4	N/C
Sensor Rx (in)	5	6	N/C
Sensor Tx (out)	7	8	Nitrogen Zero
Analogue O/P	9	10	Fresh Air Zero

Pin 2 should not be connected. Pins 4 and 6 do not require connection and are internally connected to GND.

The zeroing options are for hardware zeroing (both active low). These functions can also be implemented by sending a serial command (recommended).

Typical connections for digital interface are GND, 3.3V, Rx and Tx. Note that the Vh for the serial Tx line will be 3V regardless of the supply voltage.

The analog (voltage) output is available only when specified. Otherwise, N/C.

Temperature & Humidity Measurement[5] Optional Temperature and Humidity sensor (only available as digital output)	
Sensing Method	Humidity: Capacitive Temperature: Bandgap
Measurement Range	-25 to +55 °C 0 to 95% RH
Resolution	0.08 °C 0.08% RH
Absolute Accuracy[5]	+/- 1 °C 0°C to 55°C. +/- 3% RH 20°C to 55°C. +/- 2 °C over the full temperature range. +/- 5% RH over the full temperature range.
Repeatability	+/- 0.1 °C +/- 0.1 % RH

Note 1: All measurements are at STP unless otherwise stated.
Note 2: External Pressure calibration required.
Note 3: User Configurable Filter Response.
Note 4: Power measurements for standard CO2 sensor with 2 readings per second. Temperature and humidity measurements increase the power consumption.
Note 5: Temperature and Humidity derived from Sensirion SHT21 chip. Please request data sheet for full details.
Note 6: Autocalibration is enabled by default on COZIR-A (after Nov 2012). For correct operation, the sensor must experience fresh air once every week. For details request the application note "COZIR Autocalibration".

Appendix 4 – Other electric infrared heating trials in progress

In both cases, comparison is drawn between the 2012/3 heating season and the previous year:

University of St Andrews – Three properties constructed as dwellings (approx. 200 years old) that are now used as office accommodation are having their energy use monitored. Two very similar properties (approx. 150m^2 over 3 floors) had storage heaters, but in one of the properties Infranomic heaters have been installed (wall mounted, 11 heaters, 9.1kW in total) operated on an intermittent heating pattern suited to office hours. The third property is smaller (84m^2) and is centrally heated using a 1990's combi boiler, with secondary heating from electric fires. David Stutchfield (Energy Officer at the University of St. Andrews) reports that though the electricity use is 13% higher since installation of the radiant heaters, the level of comfort in the building is substantially higher than previously delivered by the storage heaters. He also highlights the number of degree days over the winter was substantially higher in 2012/13 than 2011/12 (2423 compared to 2021). The energy use in the property still using storage heaters was 11% lower than the previous year and in the gas centrally heated property 1% more units were used (year on year comparison).

In terms of general feedback, he reported the controllers (understood to be the same as at Scotstarvit) are difficult to adjust.

As a further trial, the University of St Andrews are contemplating installing radiant panels into a 3 bed tenanted mid-20th Century bungalow currently heated by storage heaters.

StAndEn (St. Andrews Energy Network) – Infranomic panels have been fitted into a 3 bedroom, owner-occupied property (semi-detached, 1950's, rendered, cavity wall insulation and loft insulation). The property is occupied by a single retired person and was previously under heated using only two storage heaters. The radiant panels are fitted on ceilings predominantly, apart from the hall and landing where they are wall mounted (9 panels, totalling 5.6kW for the whole dwelling). The occupant has not had experience of thermostatic controls previously and has found this aspect of the equipment difficult. With assistance, they have chosen a pattern of high living room temperatures (24 hours a day), but a cool bedrooms. The property was previously under heated and the occupant is expressing high levels of thermal comfort with the radiant heating system.

The heaters are operated on a combination of peak and off-peak electricity. Making direct comparison between pre and post installation, Jane Kell of StAndEn reports the number of units used increased by 12% after the installation of radiant heating but the electricity bill increased by 85% but due to the increased use of peak electricity. StAndEn are exploring the use of new tariffs which are becoming available and have a restricted use of energy in certain periods of the daytime in order to reduce the overall expense.

Historic Scotland Technical Papers

Available at www.historic-scotland.gov.uk/technicalpapers

1. Thermal performance of traditional windows
2. In situ U-value measurements in traditional buildings – *Preliminary results*
3. Energy modelling analysis of a traditionally built Scottish tenement flat
4. Energy modelling in traditional Scottish Houses (EMITSH)
5. Energy modelling of a mid 19th century villa
6. Indoor air quality and energy efficiency in traditional buildings
7. Embodied energy in natural building stone in Scotland
8. Energy modelling of the Garden Bothy, Dumfries House
9. Slim-profile double glazing – *Thermal performance and embodied energy*
10. U-values and traditional buildings – *In situ measurements and their comparison to calculated values*
11. Scottish Renaissance interiors – *Facings and adhesives for size-tempera painted wood*
12. Indoor environmental quality in refurbishment
13. Embodied energy considerations for existing buildings
14. Keeping warm in a cooler house – *Creating thermal comfort with background heating and locally used supplementary warmth*
15. Assessing insulation retrofits with hygrothermal simulations – *Heat and moisture transfer in insulated solid stone walls*
16. Green Deal financial modelling of a traditional cottage and tenement flat
17. Green Deal, Energy Company Obligations and traditional buildings
18. Evaluating energy modelling for traditionally constructed dwellings
19. Monitoring Thermal upgrades to ten traditional properties
20. Slim-profile double-glazing in listed buildings – *Re-measuring the thermal performance*
21. Data sources for energy performance assessments of historic buildings in the United Kingdom – *Identifying data sources for the EFFESUS project*
22. Scotstarvit Tower Cottage - *A study of infrared electric heating installed in a refurbished 19th Century dwelling*