Client Report :

To study the energy efficiency benefit of low mass, low water content heat emitters.

Client report number 212607

Prepared for :

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To study the energy efficiency benefit of low mass, low water content heat emitters.

Executive Summary

The aim of this study has been to provide properly measured and quantified evidence of the improvement in thermal performance which may be achieved by using Jaga low mass, low water content heat emitters in place of traditional steel panel radiators in a typical modern UK house.

The work was carried out in the 'Standard' pair of BRE test houses and following a period of calibration, the steel panel radiators in one house were exchanged for near equivalent Jaga "Strada" low H_2O emitters.

The results show that Jaga low H_2O heat emitters gave better saving in mild weather when consumption is low than in cold weather when the house energy usage is considerably higher. Savings for the low H_2O heat emitters range from around 15% or more in mild weather down to 5% or less in cold weather. However, substituting the previously established mean winter season consumption for Test House 2, suggests that the average saving over a whole winter heating season would be in the region of 10% for a two period heating regime.

Based on the average 220 day heating season for these houses, this could result in an annual reduction in energy required for space heating of around 2,000MJ or about 550kWh. This would correspondingly reduce the house annual CO_2 emission by around 100kg. However, because of the current limitation on the data which we were able to gather, this reduction is subject to quite wide uncertainty. It would be valuable, therefore, to continue the study to cover colder weather in the test condition (winter 2003) in order to extend the data set and reduce the need for extrapolation.

The study also demonstrated the responsiveness of the Jaga system where it is clear that House 2 warms up faster with low H_2O emitters. However, the study to support the hypothesis that the start of each heating period could be delayed whilst still meeting the demand temperature at an equivalent time was a little inconclusive due to unfavourable weather conditions in the later testing period. The results support the view that a twenty minute delay in the morning start would probably enable House 2 to reach the morning target temperature as quickly as an earlier start using steel panel radiators. However, strong sunshine meant that it was not possible to verify that the one hour delay in the start of the afternoon heating period would be acceptable because both houses exhibited a fast response on start-up.

At the end of each heating period, the rate of cooling is slightly faster in the less well insulated house, however, the room temperature at the heating 'start time' is very dependent on the 'time' of the last thermostat cycle of the previous period. There is some evidence to suggest that the lower mass of the Jaga units allows House 2 to cool faster after the short morning period but this is not evident at the end of the afternoon/evening heating period.

To study the energy efficiency benefit of low mass, low water content heat emitters.

To 'visualise' the response of Jaga low H_2O emitters, an infrared camera was used to illustrate the warm up sequence for the two systems. As expected, the Jaga low H_2O emitter increased in temperature very quickly and a substantial amount of warm air can be seen emanating from the top grill after only a very short time. By comparison, in roughly the same period of time, the steel panel radiator has only just reached 'working' temperature.

To study the energy efficiency benefit of low mass, low water content heat emitters.

Contents

1 To study the energy efficiency benefit of low mass, low water content heat emitters.

Introduction

The purpose of this project is to provide properly measured and quantified evidence of the improvement in thermal performance which may be achieved by using low mass low water content heat emitters (Jaga low H_2O emitters) in place of traditional steel panel radiators in a typical modern UK house.

The work was carried out using the “Standard” pair of BRE’s ‘matched pair’ test houses so that the change in thermal performance due to Jaga low H_2O emitters can be measured independently of weather conditions prevailing at the time. Two similar test houses were calibrated against each other by monitoring conditions for a period of about one month. The traditional steel panel radiators of one house were then replaced by Jaga low H_2O emitters and the monitoring continued for a further month.

2 To study the energy efficiency benefit of low mass, low water content heat emitters.

1 Description of the project

The purpose of this project is to provide properly measured and quantified evidence of the improvement in thermal performance which may be achieved by using low mass low water content heat emitters (Jaga low H_2O emitters) in place of traditional steel panel radiators.

The work was carried out in the 'Standard' pair of BRE test houses following protocols developed and used over many years as part of our research programme for the UK government's Department of the Environment, Transport and the Regions. The principle has been that various parameters (temperature, humidity, energy use, etc, and the weather) are monitored in the two houses for a period of about one month to calibrate them against each other and against the varying weather conditions. The energy use (or other parameter) in one house is plotted on a graph against energy use in the other house at the same time (i.e. under identical weather conditions). This provides the essential base line data for subsequent monitoring.

A change is then made to one house only, the other remaining completely unchanged, and a second period of monitoring of the same parameters carried out. In this case the steel panel radiators were replaced with Jaga low H_2O emitters.

The difference between the relative performance of the houses can then be obtained quantitatively and independently of differences in weather patterns occurring in the first and second monitoring periods. In this case the main parameter of interest was the energy use in the house, but changes in other parameters such as speed of response and the wall surface temperature behind the emitters were also considered.

1.1 The BRE Standard Test Houses

The 'Standard' BRE test houses were built as identical 3 bedroom family houses typical of those being built in the UK in the late 1980s but with a slightly higher thermal insulation standard (Reference 1). The walls had a brick outer leaf, a fully filled cavity (Rockwool batts), lightweight concrete block inner leaf and dry-lining plasterboard on dabs as the internal finish. The houses have suspended timber ground floors and a conventional dual-pitched roof.

The two Standard houses are no longer identical due to previous work but were calibrated together to eliminate the effect of these differences from the study. House number one has been modified in the past and has higher levels of insulation in the walls (applied externally), floor and roof than house number two. Broadly speaking, house one reflects the U-values that came into force in the 2002 review of Building Regulation Part L whilst house two reflects U-values in force in 1995, **Figure 1**.

3 To study the energy efficiency benefit of low mass, low water content heat emitters.

Design U-values of the main elements of House 2 are:

Walls 0.30 W/m2K; Roof 0.30 W/m2K; Floor 0.25 W/m2K.

The internal ground floor plan area is 42 m^2. The currently sealed roof construction of test House 2 is a dual pitched roof with a pitch angle of 35 degrees. The ceiling below the roof is horizontal and is insulated with 150 mm of Rockwool between the joists. There is no vapour barrier in the ceiling construction.

Figure 1 Front view of the 'Standard' BRE Test Houses. Reference House 1 on the left and Test House 2 on the right

1.2 Simulated Occupancy

To mimic a real home, the houses are equipped with simulated occupancy controlled by computer. This arrangement provides practical incidental gains to the house while at the same time providing realistic loads for the heating system and controls. By programming the computer, any simulated occupancy pattern can be accomplished while eliminating variability between real families. The simulation included the following features:

People moving around the house

The use of electrical appliances and lights

Opening and closing curtains

4 To study the energy efficiency benefit of low mass, low water content heat emitters.

The duration and magnitude of the internal heat gains have been developed for a four-member family. The ‘light’ profile allows for the house to be vacated in the middle of the day with heating on in the morning (06:30 to 08:30hrs) and in the late afternoon and evening (15:30 to 22:30hrs).

1.3 Space and domestic hot water heating systems

A pressurised but conventional ‘wet’ gas fired heating system and radiators is used in the “Standard” Houses. Separate Honeywell T6060B room thermostats, with heat anticipation, are located in bedroom 1 and on the internal wall between the lounge and diner, respectively control upstairs and downstairs heating circuits. A Tribune un-vented hot water cylinder supplies the hot taps in the kitchen and bathroom. Heat is provided by a 9kW GlowWorm FuelSaver fan assisted balanced flue boiler. A Potterton Electronic programmer controls the whole system.

The radiators are Stelrad Accord steel panel fitted with DanFoss RAS Thermostatic Radiator Valve (TRV) and lockshield valve. When operating under room thermostat control, heat output from the radiators is ‘balanced’ using the lockshield valves and the TRV’s are fully open.

The traditional steel panel radiator positions and sizes are shown below:

Location	Output Watts at dt 60^{o}C	Type	Height mm	Length mm
Lounge	1424	P+ Double	300	1460
Diner	1010	P1 Single	600	1280
Hall	990	K1 Single/finned	750	640
Bed 1	1190	K1 Single/finned	600	960
Bed 2	1190	K1 Single/finned	600	960
Bed 3	1190	K1 Single/finned	600	960
Bathroom	824	P+ Double	600	480

Total 7,818Watts

5 To study the energy efficiency benefit of low mass, low water content heat emitters.

1.4 Heating Components list

Boiler:

GlowWorm FuelSaver DFB 3OF fan assisted balanced flue, 9kW.

Room Thermostat System:

Potterton EP2001 electronic programmer, two period heating/hot water scheduling with separate weekend schedule.

Honeywell T6060B room thermostat with heat anticipation.

Potterton cylinder thermostat – PTTZ.

Hot water:

120L IMI Tribune unvented hot water cylinder.

Other components:

Honeywell V4043H motorised valves.

DanFoss differential pressure reducer.

Boss 964S L ¾ inch 3-port valves.

Grundfoss UPS 15-50 circulation pump.

Clorius 1.5 EP heat meters.

1.5 Data logging and measurement

The houses are fully instrumented to measure temperature, energy consumption and humidity. Heating system operating temperatures and the switching of devices are recorded routinely. A full set of weather measurements is available including:

External air temperature, humidity and rain fall

Wind speed and direction

Barometric pressure

Solar radiation incident on exterior walls

6 To study the energy efficiency benefit of low mass, low water content heat emitters.

A system for continuous air infiltration measurement is installed in both houses. Very low concentrations of Sulpur Hexafluoride, SF_6 are supplied to each house from where a multi-point sampler dispenses individual doses through a gas analyser. There are up to eight sampling points and each line is measured every 30 minutes so that the resulting SF_6 concentration represents a measure of air infiltration throughout the day.

7 To study the energy efficiency benefit of low mass, low water content heat emitters.

2 Set-up and calibration

Experience with our pair of similar houses has shown that it is possible to get a very high correlation of energy consumption (Reference 2). This means that one house can be used to accurately predict the behaviour of the other house. Thus, once the houses are calibrated, the consequence of making a change to one of the houses can be measured with accuracy far greater than would be possible with only one house. However, because Test House 1 has been modified with higher levels of insulation, the two "Standard" houses required re-calibration to eliminate the effect of these differences. In addition, we had no previous calibration data for the houses operating under "light" simulated occupancy with a two period heating regime. This period would also provide additional reference data of the wall surface temperature behind the traditional radiators.

2.1 Preparations for the project started in mid December 2002.

The two standard test houses were set-up with the conventional (non-condensing) gas fired boiler serving the steel panel radiators with room and zone thermostat control.

In order to meet the terms set out in SAP, the heating profile (time clocks) were reprogrammed to provide a two period heat regime – 2hr on; 7hr off; 7hr on; 8hr off; seven days a week.

In the houses this approach gives the following time clock settings:

- 06:30 > 08:30 ON (2hrs on)
- 08:30 > 15:30 OFF (7hrs off)
- 15:30 > 22:30 ON (7hrs on)
- 22:30 > 06:30 OFF (8hrs off)

For experimental clarity, domestic hot water was not enabled at all.

This heating profile assumes the house is vacated during the middle part of the day, therefore, the simulated occupancy profile was reprogrammed to a "light" schedule to match this heating regime but without the added heat input from cooking.

To ensure that all the house systems were working correctly, data recording started at around the middle of December but only dependable data from this period has been incorporated into the calibration.

Throughout January, the weather at BRE was relatively cold leading to fairly high gas consumption in both houses over the calibration period. Unfortunately by the time House

2 had been re-plumbed in mid February the weather had turned milder and although there was the occasional cold day, in general the houses' overall energy consumption was somewhat less over the second half of February and the whole of March.

2.2 Re-plumbing the heating system in House 2

Jaga engineers carried out the re-plumbing in House 2 on the 10th and 11th February. The heating system was turned off and drained early on the Monday morning and preparations were made to exchange the existing steel panel radiators with Jaga low water content Strada units of near equivalent size and output, see table below. In general, the new Strada units are very close in performance to the original steel panel radiators. The most notable difference being in the lounge/diner where although the combined total is very similar there is a slight insignificant shift in output between the two sides of the room.

Location	Output Watts at dt 60^{o}C	Strada Type	Height mm	Length mm
Lounge	1159	03510010	350	1000
Diner	1385	05010010	500	1000
Hall	969	05007010	500	700
Bed 1	1159	03510010	350	1000
Bed 2	1159	03510010	350	1000
Bed 3	1159	03510010	350	1000
Bathroom	831	05006010	500	600

Total 7,821Watts

Installation of the new Jaga Strada units was completed on the first day but re-filling the system, commissioning and balancing was carried out on the second day. By mid-day on the 11th, the heating was back on and data logging restarted. However, because the house had cooled and had been disturbed, reliable data was not obtained until the end of the week.

9 To study the energy efficiency benefit of low mass, low water content heat emitters.

3 Findings

3.1 Thermal performance of Jaga Low H_2O Heat Emitters

The prime objective of this study has been to quantify any improvement in the overall thermal performance of the Test House as a direct result of using low water content heat emitters in place of conventional steel panel radiators.

The energy consumed in both House 1 and House 2 has been closely monitored over both the calibration and testing periods. Weekly 10-min data files are used for looking at specific effects within a day but for energy consumption comparisons the data are reduced to daily averages. This is done for internal temperatures, external temperatures and wind whereas daily totals are calculated for solar inputs, heat meters and gas and electricity consumption. This data together with derived data consisting of wind speed components, house volume averaged temperatures and mean 24hr temperature differences are accumulated on a daily totals file every week.

Quality control is carried out by examining the graphical output on the PC-logger most days and by producing ‘strip chart’ records of all the components every week, looking for anomalies and unexpected shifts in the data. Only days without data irregularities are incorporated into the daily files

3.1.1 Temperature matching

Before looking for differences in energy consumption as a result of changing the heating system, it is useful to examine the temperature match in the two houses during both the calibration and test periods. **Figure 2** shows the overall whole house average temperature profile for both the steel panel and low H_2O periods in House 2 with delayed start plotted against reference House 1. Although the two sets of data have been treated independently with separate regression lines, the overall trend shows very good agreement over both the reference and test periods. Clearly the warmer external conditions experienced in the testing period have produced somewhat higher internal temperatures than in the reference period, and a slightly higher internal temperature can be expected in the ‘better’ insulated House 1. Overall, however, the correlation between the houses has remained reasonably constant as would be expected considering that no thermostat settings were changed over the duration of this work.

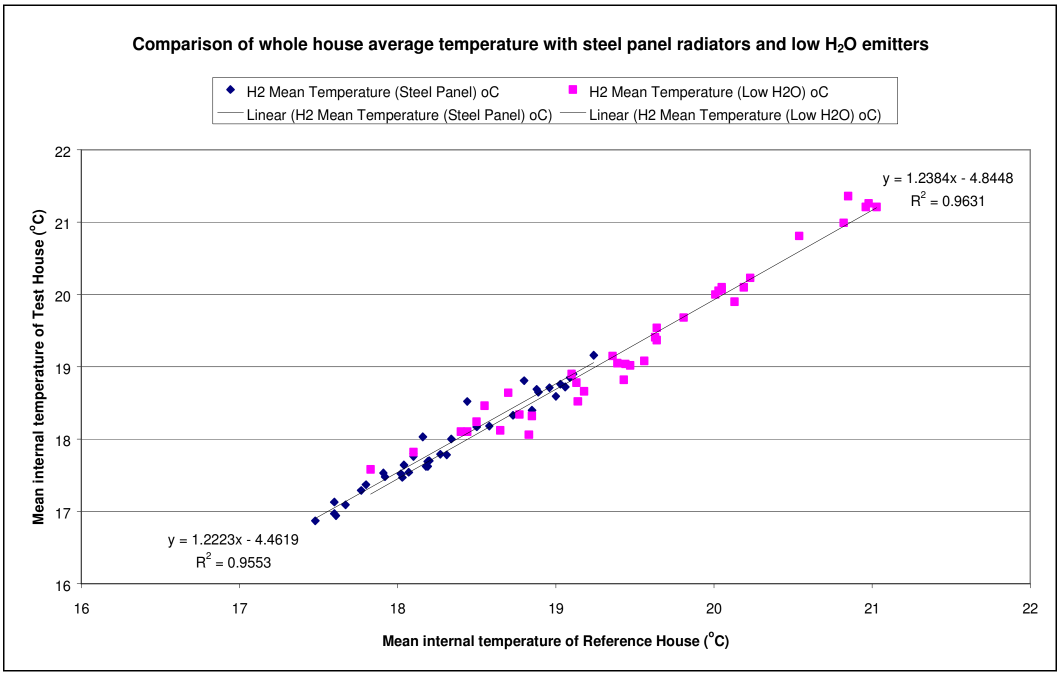

Figure 2 Comparison of daily house average temperature

3.1.2 House energy comparison

With the validity of the daily data files established, analysis of the energy consumption in the two houses can be treated in a similar way to the temperature data. However, to establish the overall daily energy consumption for each house, three main sources of heat input must be considered:

- The gas consumption – e.g. the central heating, CH.
- The electricity consumption – e.g. the simulated occupancy etc.
- The weather – e.g. solar and wind effects.

Each of these parameters, from the daily master file, is taken into account when calculating the mean daily energy intake for each house.

The resulting daily whole house energy consumption has then been plotted for both the steel panel and low H_2O periods in House 2 against the reference consumption in House 1, **Figure 3**. From this graph, the regression line for the low H_2O heat emitters data set with delayed start shows a clear saving at low consumption. However, at higher use the two lines would clearly converge but the point at which they meet can only be estimated by extrapolation as there is insufficient data available to form an accurate prediction.

From the graph and the available data, it is clear that Jaga low H_2O heat emitters give better saving in mild weather when consumption is low than in cold weather when the house energy usage is considerably higher. Where the two data sets have common characteristics, the savings for low H_2O heat emitters range from around 15% or more in mild weather down to 5% or less in cold weather. However, substituting the previously established mean winter season consumption for Test House 2, suggests that the average saving over a whole winter heating season would be in the region of 10% for a two period heating regime.

Based on the average 220 day heating season for these houses, this could result in an annual reduction in energy required for space heating of around 2,000MJ or about 550kWh. This would consequently, reduce the house annual CO_2 emission by around 100kg. However, because of the current limited data which we were able to gather, this reduction is subject to quite wide uncertainty and it would be valuable to continue the study to cover colder weather in the test condition in order to extend the data set and reduce the need for extrapolation.

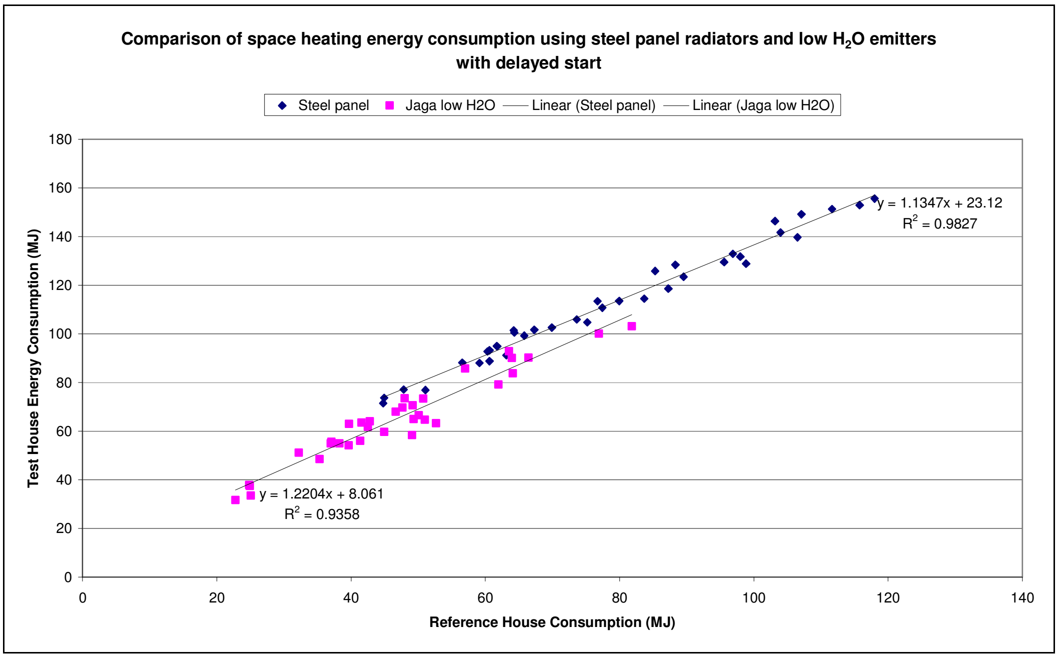

Figure 3 Fully corrected comparison of daily house energy consumption

3.1.3 Seasonal disparity

As discussed earlier, the weather conditions prevailing during the calibration and testing periods were rather dissimilar leading to somewhat skewed the results. Whilst the match pair house technique can, to a large extent, reduce the impact of weather conditions between houses, it cannot eliminate a bias. In the case of these two study periods, the weather conditions prevailing with the low H_2O emitters were less cold than that with the steel panel radiators. This bias has resulted in lower energy requirement in both houses over the February/March test period and the same high demand seen in the reference period in January was not replicated during the test period. The effect of the ‘warmer’ weather can be seen in both the whole house temperature graph and the energy graph. Clearly, it would have been beneficial to have had some higher energy demand in the test period to match the 150MJ+ that was consumed in the calibration period.

3.2 Heating system responsiveness

The other main aim of this study has been to investigate any improvement in thermal responsiveness as a direct result of using low water content heat emitters in place of conventional steel panel radiators. Then, if appropriate, modify the heating start and stop times such that the temperature set point is still reached and maintained to match that achieved by the steel panel radiators.

The following graphs show the results of these measurements. As the Test Houses have independently controlled heating zones, the temperature profiles have been plotted using the room comfort temperature (Globe temperature) nearest to the controlling thermostat, i.e. in the lounge/diner for the ground floor and in bedroom 1 for the first floor.

The first six graphs, Figures 5 to 8, show the temperature profile in the two houses in the reference condition; with traditional steel panel radiators. The second six graphs, Figures 10 to 15, show the temperature profile in the two houses in the test condition; with traditional steel panel radiators in House 1 and low H_2O emitters in House 2 but with the same heating periods. The next six graphs, Figures 17 to 22, also show the temperature profile in the two houses in the test condition but with the start of the heating periods in House 2 delayed in the morning by 20 minutes and in the afternoon by 1 hour.

The final three graphs, Figures 23 to 25, show the responsiveness of the low H_2O emitters in House 2 with data recorded from near the ground and first floor zone thermostats at 1 minute logging intervals rather than the normal 10 minutes.

3.2.1 Temperature profiles in houses 1 and 2 with traditional steel panel

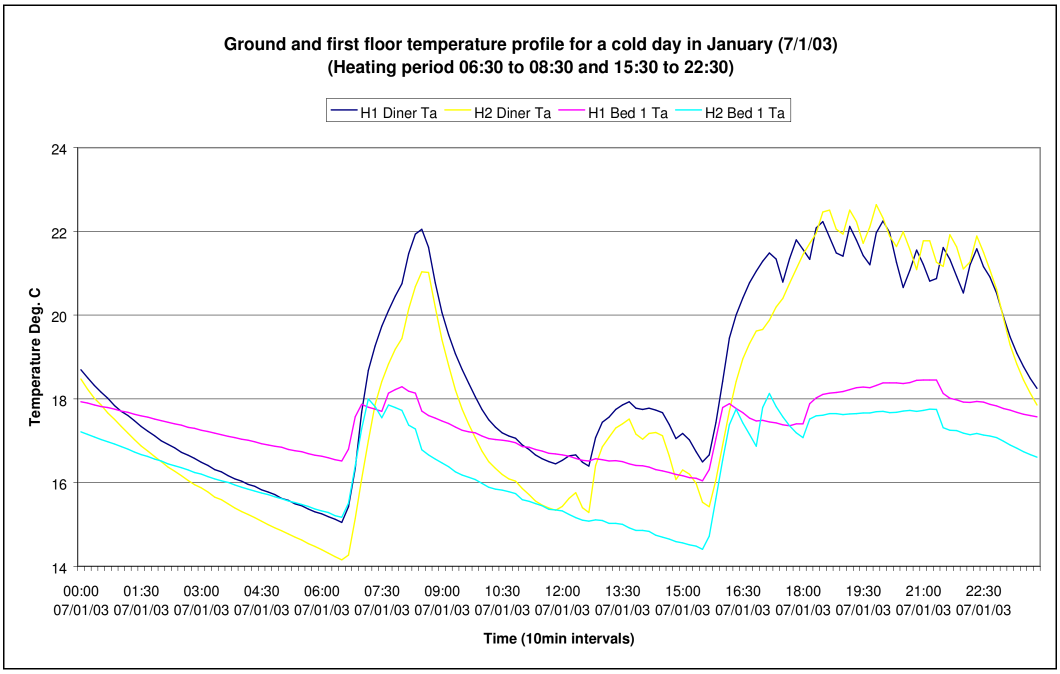

Figure 4 A 24hr profile on a fairly cold day in January

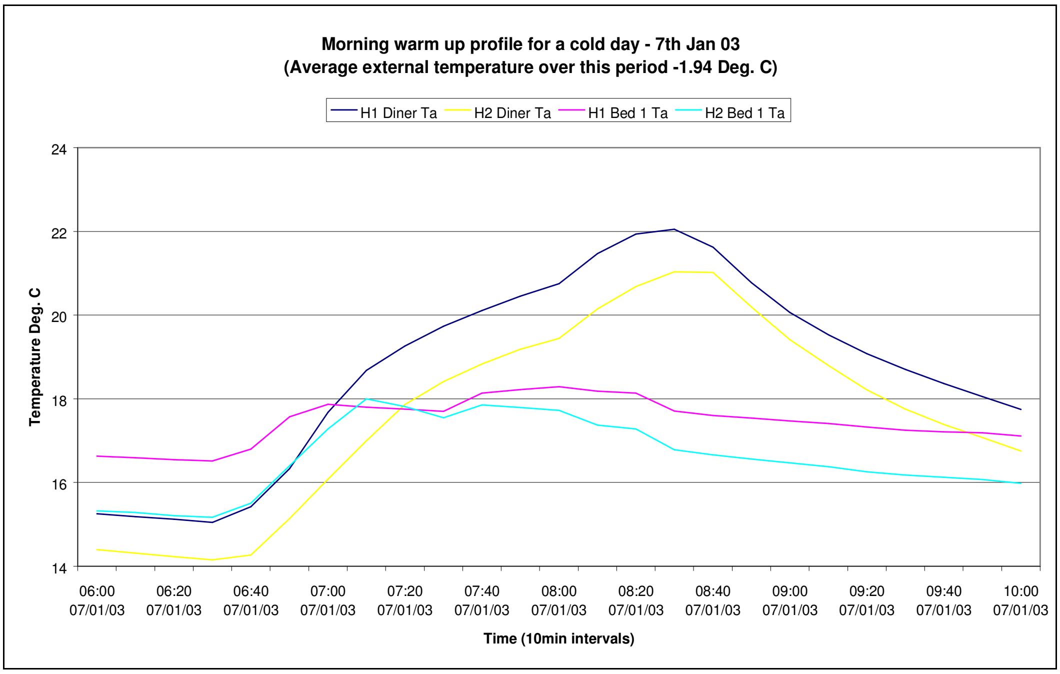

Figure 5 Enlarged span of the morning warm-up profile on the cold day

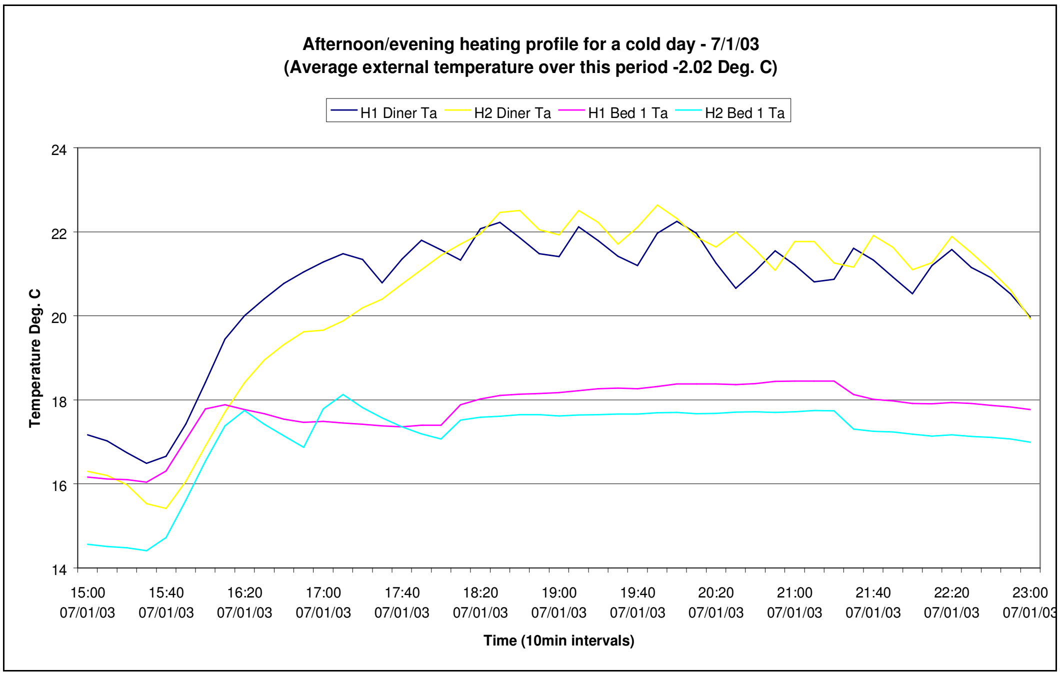

Figure 6 Enlarged span of the afternoon/evening profile on the cold day

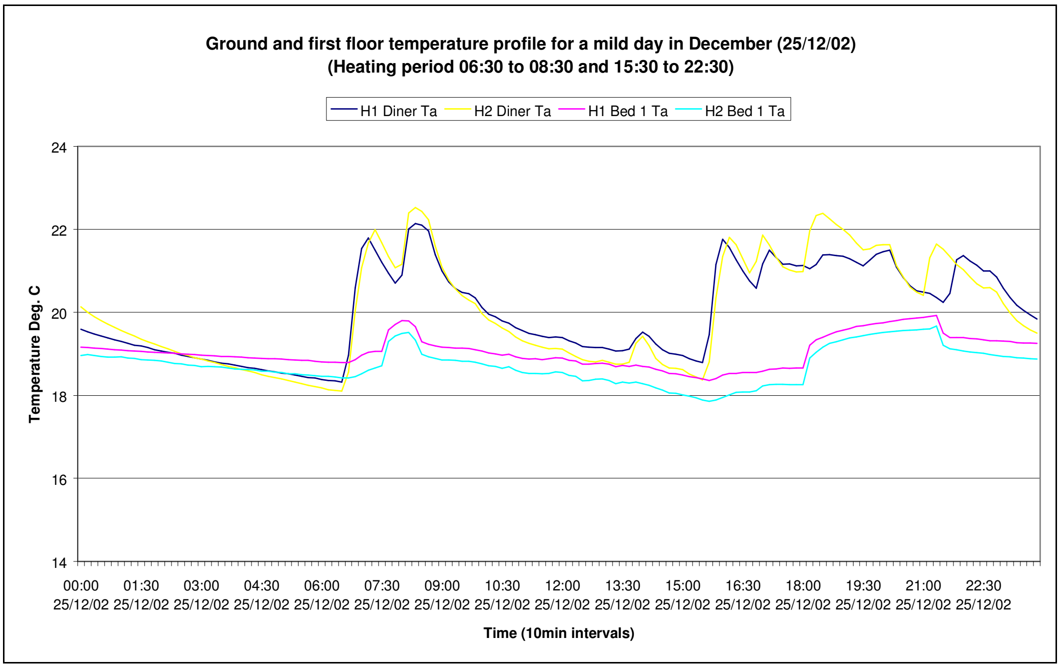

Figure 7 A 24hr profile on a fairly mild day in December

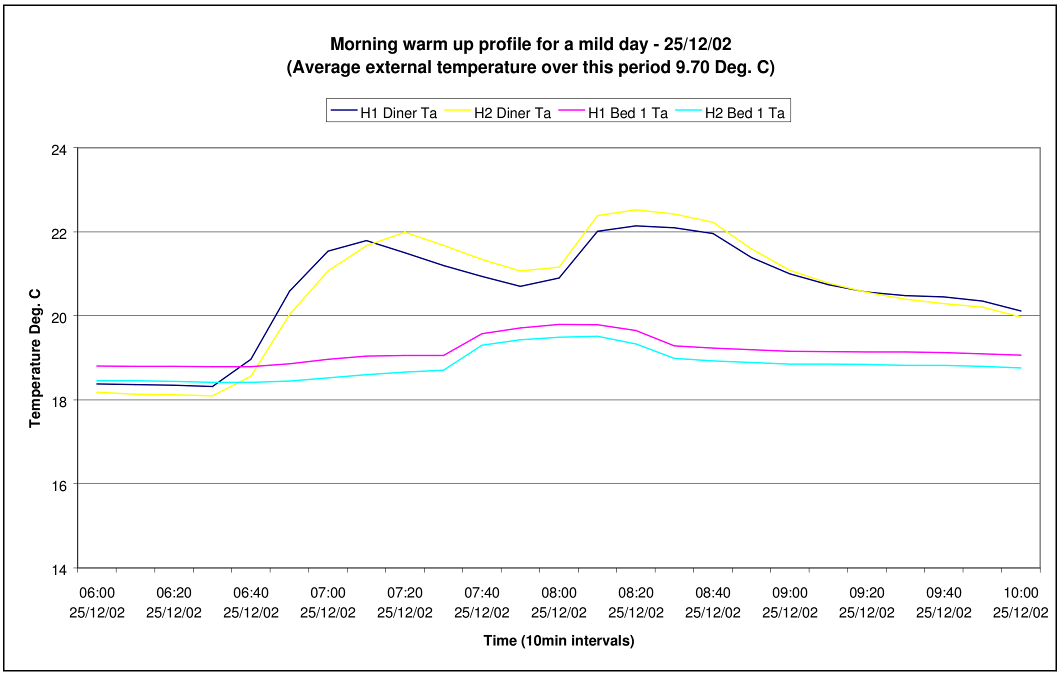

Figure 8 Enlarged span of the morning warm-up profile on the mild day

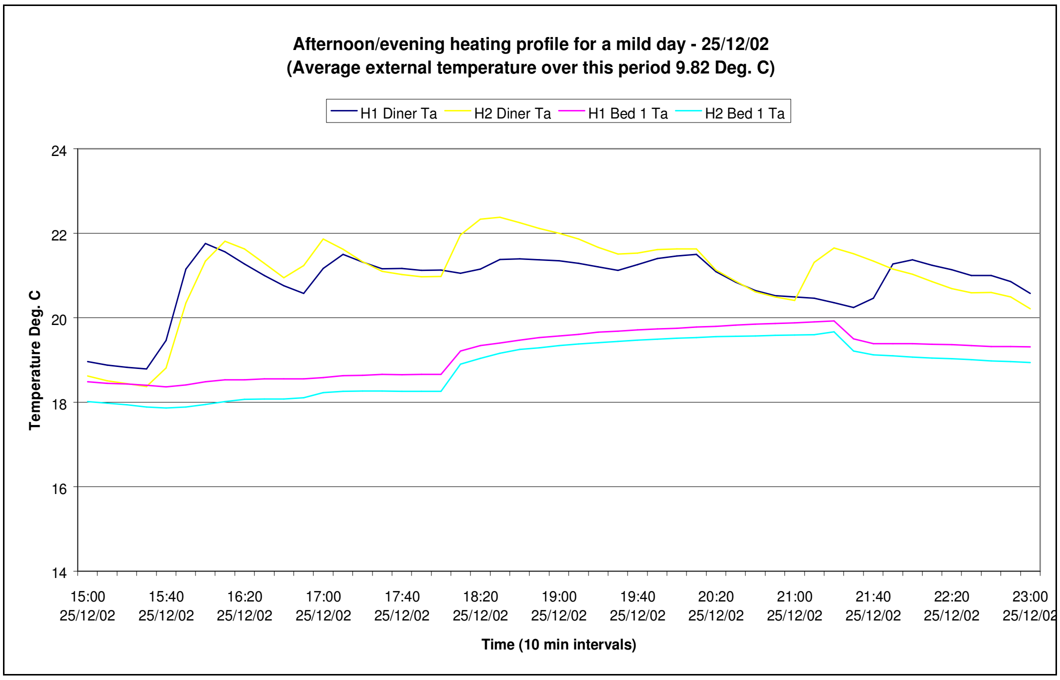

Figure 9 Enlarged span of the afternoon/evening profile on the mild day

The main observations to draw from these graphs are:-

1. The better insulated House 1 warms up more quickly than House 2.
2. In cold weather, there is only one thermostat cycle in the morning and even then, House 2 only just reaches the temperature set point and in the afternoon, House 2 set-point is reached about an hour after House 1.
3. First floor heating is only brought on by the zone thermostat in 'cold' weather.
4. In mild weather, both houses warm up at a similar rate and there are clearly two thermostat cycles in the morning heating period.
5. Whilst the rate of cooling is slightly faster in the less well insulated house, the room temperature at the heating start time is also very dependent on the 'time' of the last thermostat cycle of the previous period.

3.2.2 Low H_2O with standard time setting

The following graphs show the performance of the Jaga low water content heat emitters using the same standard heating periods as used with the previous steel panel profiles.

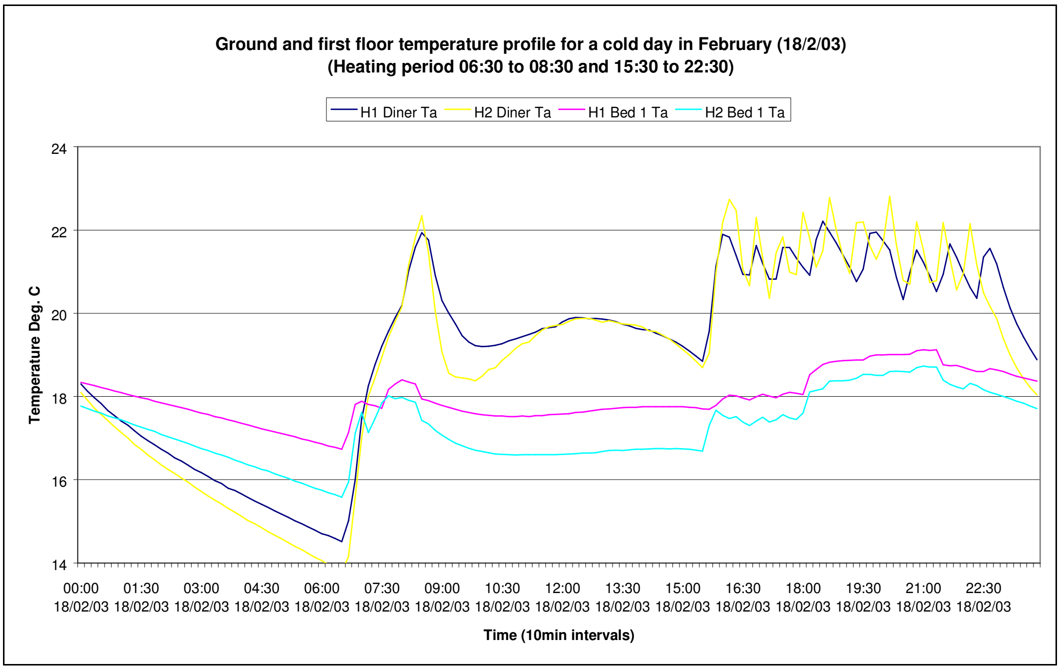

Figure 10 A 24hr profile on a fairly cold day in February

17 To study the energy efficiency benefit of low mass, low water content heat emitters.

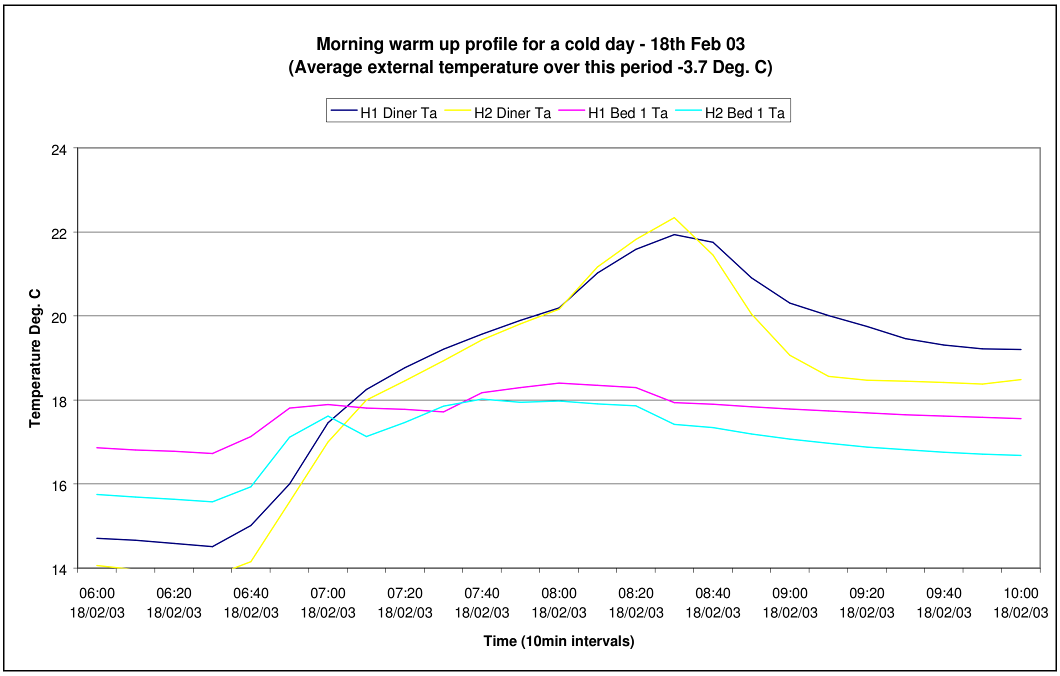

Figure 11 Enlarged span of the morning warm-up profile on the cold February day

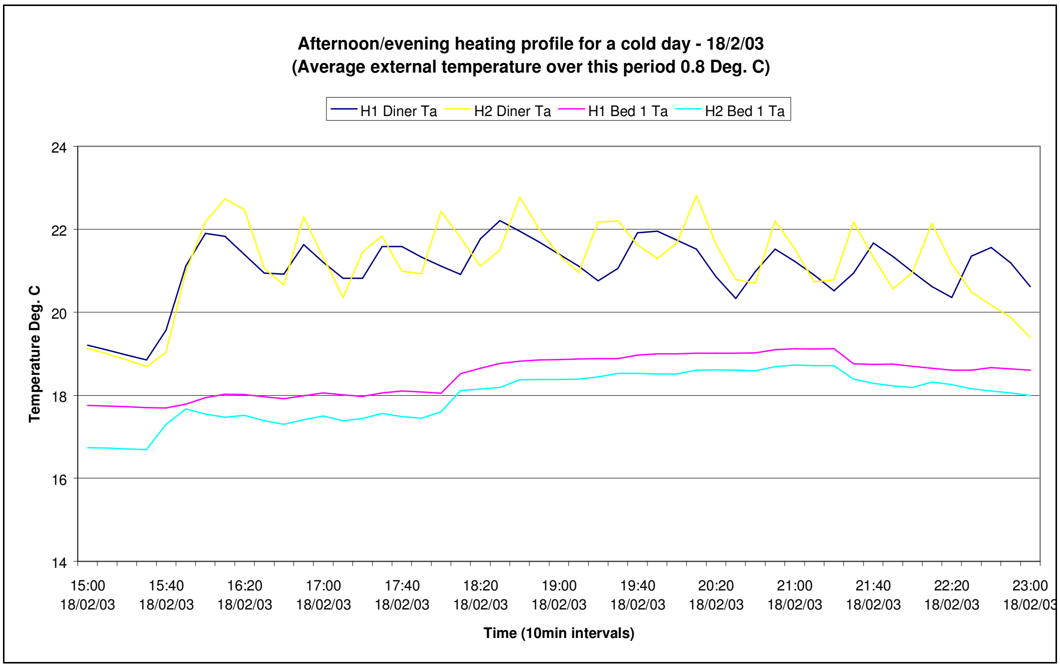

Figure 12 Enlarged span of the afternoon/evening profile on the cold February day

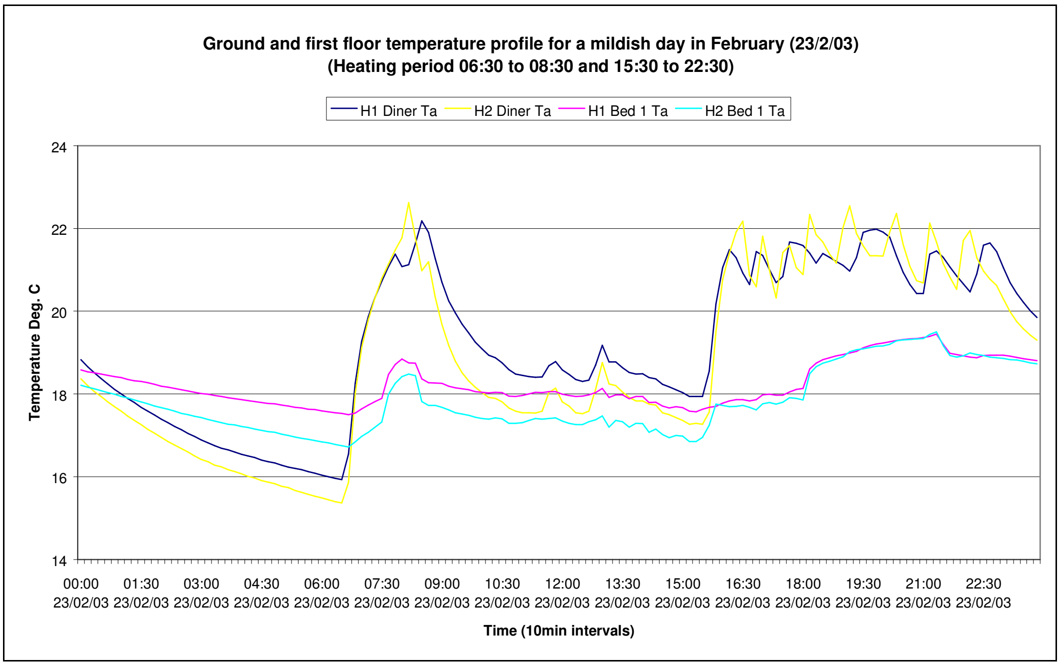

Figure 13 A 24hr profile for a fairly 'mildish' day in February

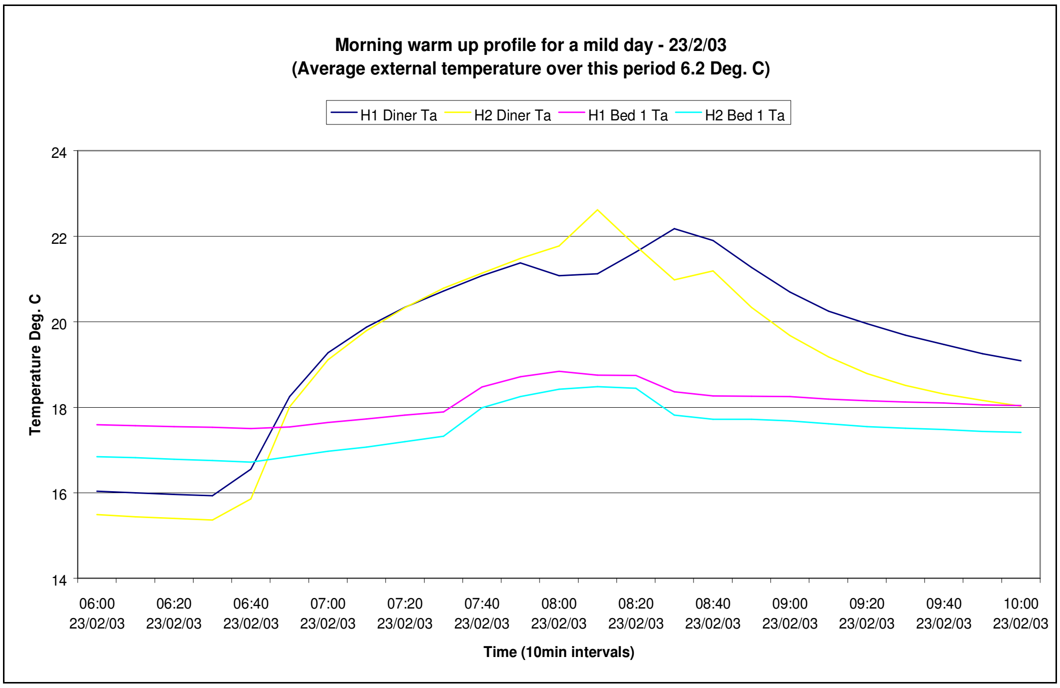

Figure 14 Enlarged span of the morning warm-up profile on the 'mildish' February day

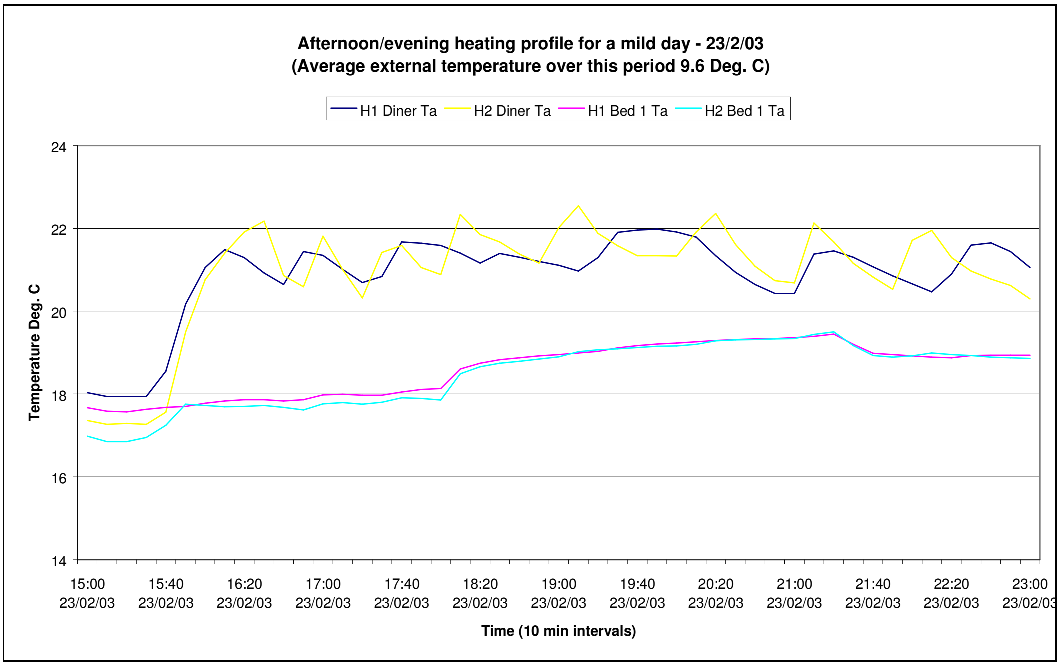

Figure 15 Enlarged span of the afternoon/evening profile on the 'mildish' February day

The main observations to draw from these graphs are:-

1. In these examples, the thermal response of House 2 is now closer to the better insulated House 1.

2. In cold weather, there is still only one thermostat cycle in the morning but now both houses easily reach the temperature set point. In the afternoon, House 2 set-point is reached at the same time, if not slightly earlier, than House 1.

3. Again, the first floor heating is only brought on by the zone thermostat in 'cold' weather.

4. In mild weather, both houses warm up at a very similar rate even though House 2 starting temperature is always lower than House 1. Again, there are clearly two thermostat cycles in the morning heating period.

5. Clearly, while the rate of cooling is slightly faster in the less well insulated house, the room temperature at the heating start time is still very dependent on the 'time' of the last thermostat cycle of the previous period. There is some evidence to suggest that the lower mass of the Jaga units allows House 2 to cool faster after the short morning period but this is not evident at the end of the afternoon/evening heating period.

6. On the whole, there are more thermostat cycles with the low mass, low water content system and this is particularly apparent over the longer afternoon/evening heating period. This faster response could lead to tighter temperature control if exploited by a control system that can respond faster than the traditional room thermostat with heat anticipation.

3.2.3 Low H_2O with delayed start

The following graphs show the warm up profiles for the Jaga heat emitters but with delayed start times.

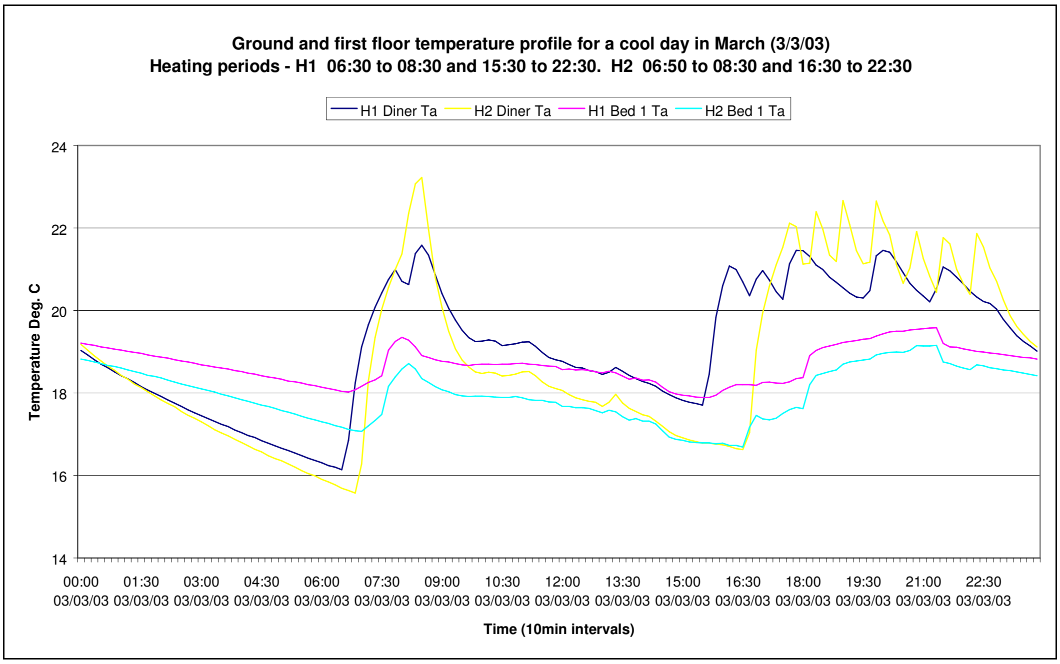

Figure 16 A 24hr temperature profile for a fairly cool day in March with Jaga Low H_2O heat emitters and delayed start heating periods in House 2

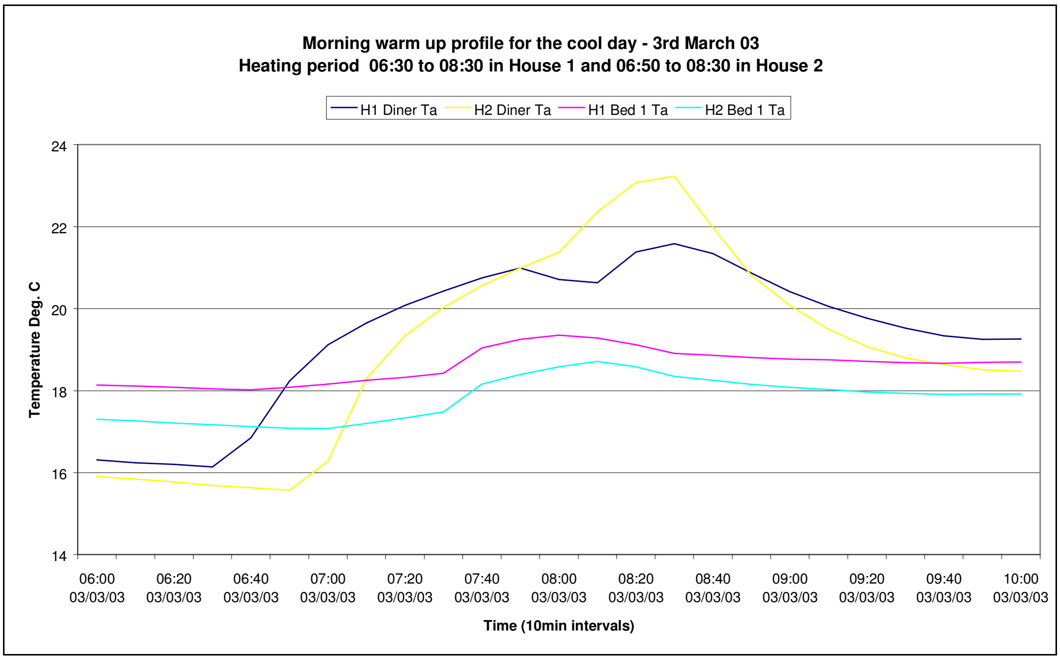

Figure 17 Enlarged span of the morning warm-up profile on the cool March day with delayed start

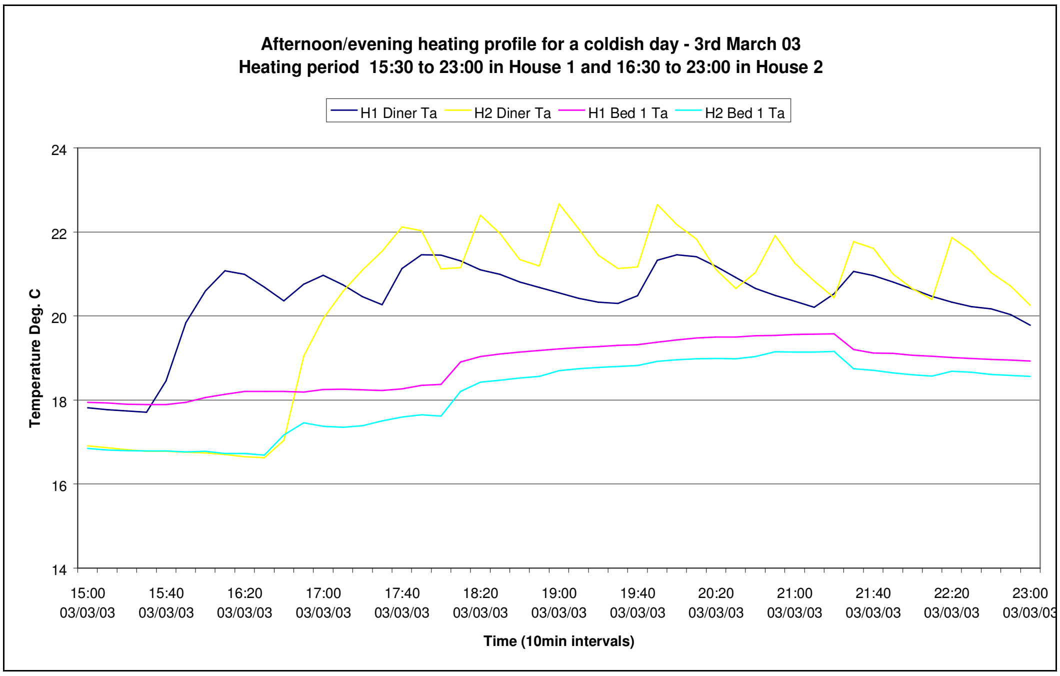

Figure 18 Enlarged span of the afternoon/evening profile for the cool March day with delayed start

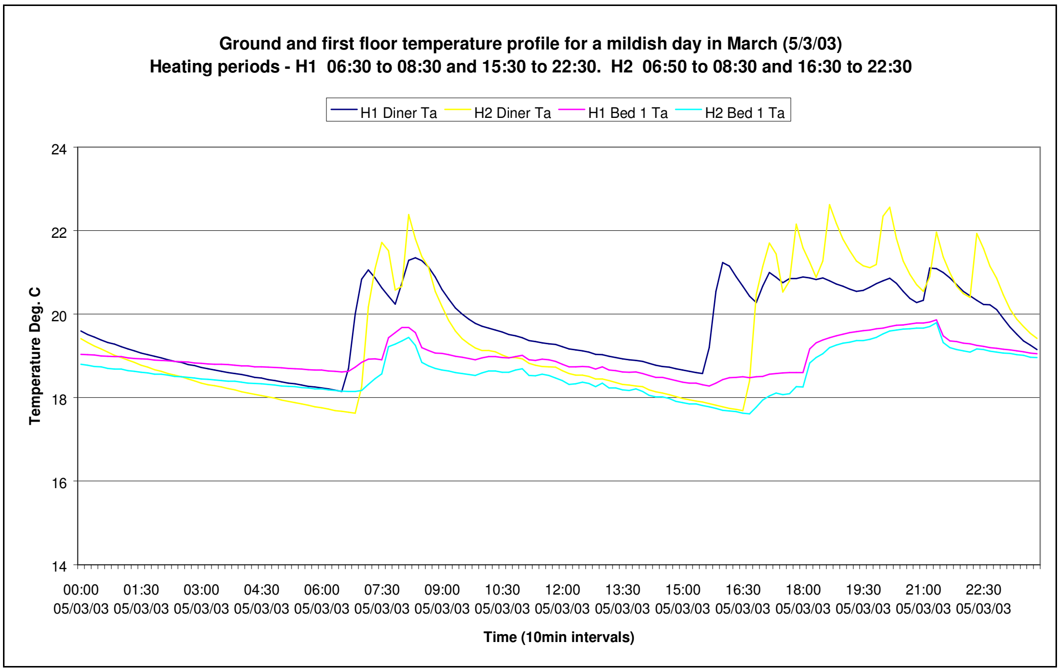

Figure 19 A 24hr profile for a fairly mild day in March with Jaga Low H_2O heat emitters and delayed start heating periods in House 2

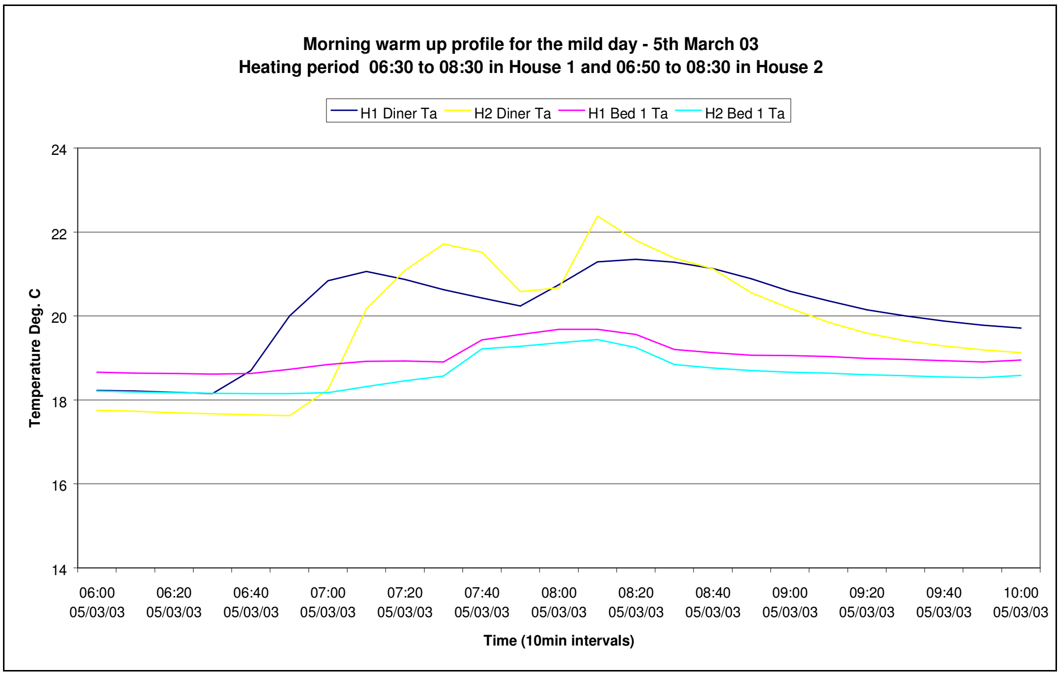

Figure 20 Enlarged span of the morning warm-up profile on the mild March day with delayed start

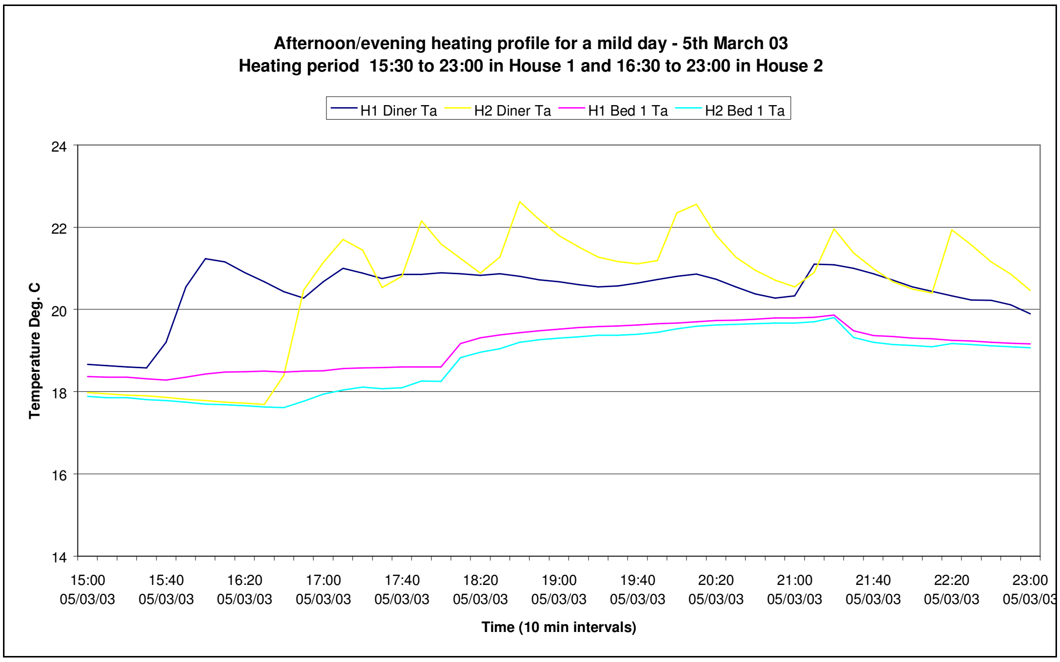

Figure 21 Enlarged span of the afternoon/evening profile for the mild March day with delayed start

The aim of this period of testing was to demonstrate that by using Jaga low H_2O heat emitters, the heating start time could be delayed while still achieving satisfactory thermal performance when compared to the conventional steel panel radiators. The measure of the time delay (20 minutes in the morning and 1 hour in the afternoon) was selected based upon the results gained from the earlier tests and was thought to be the maximum acceptable delay.

Unfortunately, over this test period the weather was relatively mild, bordering on warm, and with high solar radiation. The effect of these conditions meant that there was a fast heating response in both houses. It is difficult, therefore, to draw conclusions about the response other to say that:-

In the morning of the 'cold' day, House 2 with the Jaga units reached the set point of 21°C at the same time as House 1. But in the afternoon, the required temperature rise in both houses was so small that the one hour time delay resulted in House 2 reaching the set point an hour latter.

This temperature profile effect was more or less repeated on the milder days where both houses showed an equally fast response.

It is evident from the graphs, however, that the Jaga low H_2O units produced a slightly greater overshoot in room temperature when compared to the steel panel radiators. This result was a little unexpected but is probably brought about because the graphs are plotted from data recorded at the room globe thermometers and these have different response characteristics when compared to the room thermostats.

The next set of graphs show example profiles from plain air temperature sensors at the thermostat locations but recorded at the higher frequency of one minute intervals.

3.2.4 Fast response measurement – temperature data at 1min logging interval

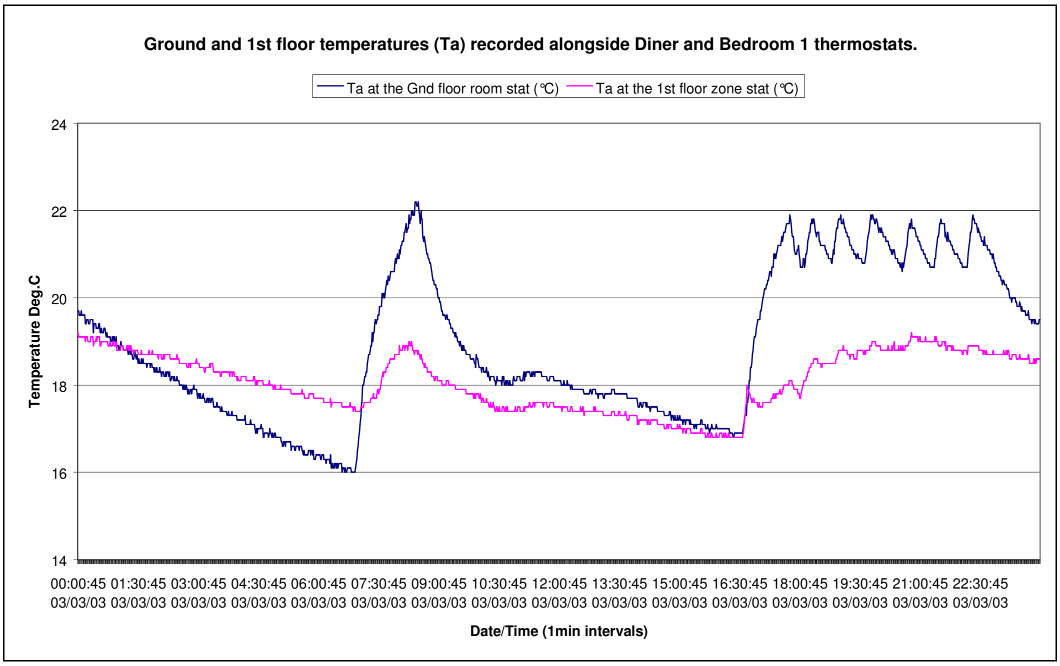

Figure 22 House 2 temperatures with Jaga Low H_2O heat emitters and delayed start heating periods. The profile was recorded at 1min intervals from air temperature sensors at the two thermostat locations. Corresponds to Figure 18

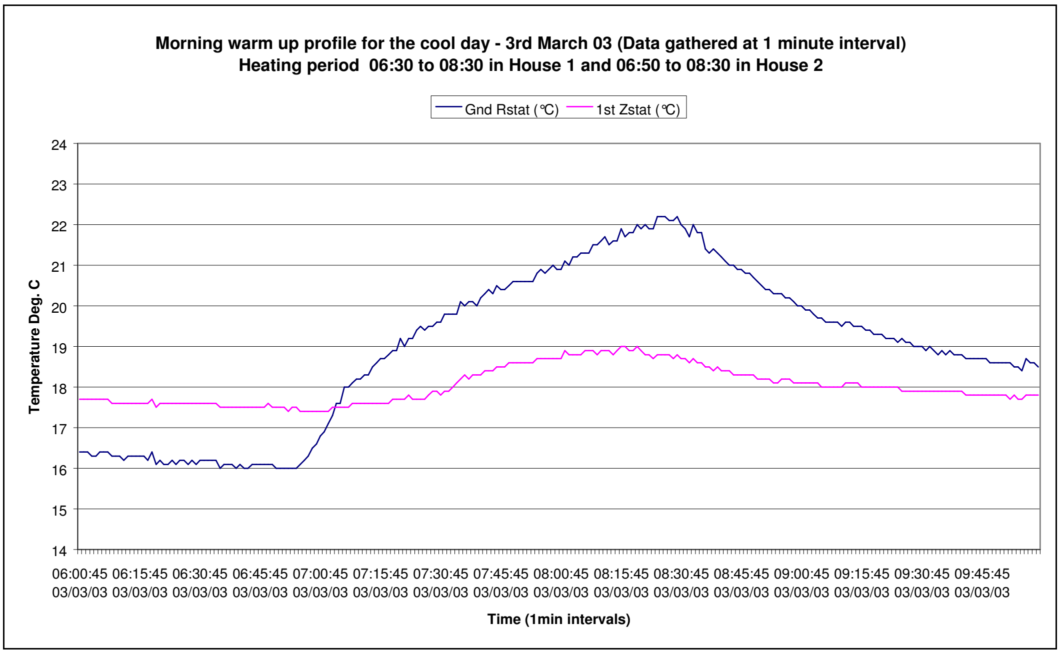

Figure 23 Enlarged span of the morning warm-up profile at 1min logging interval

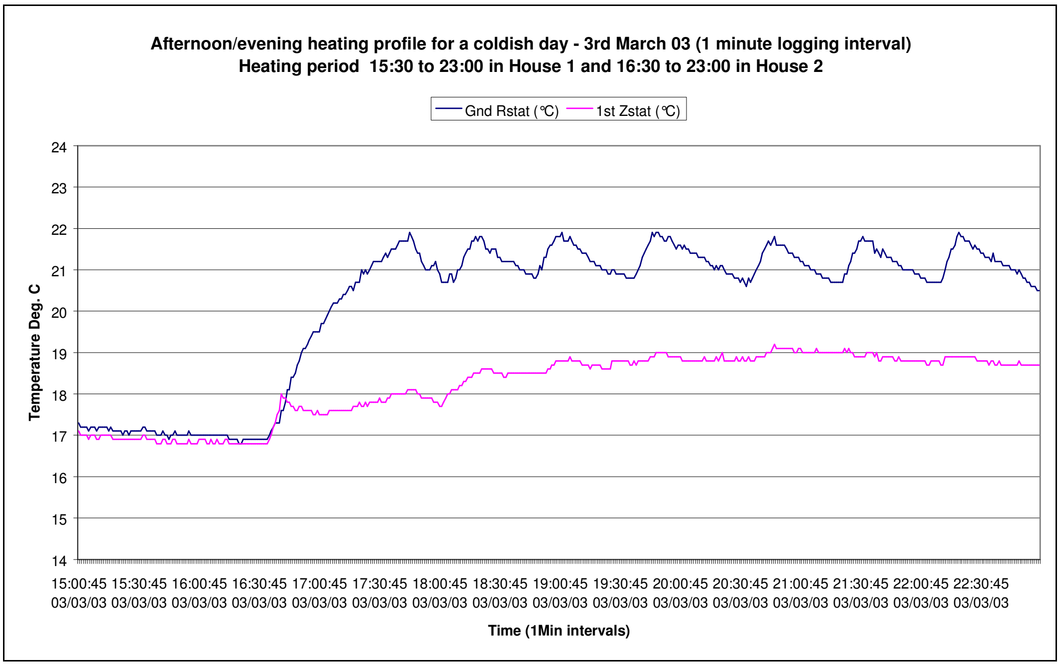

Figure 24 Enlarged span of the afternoon/evening profile at 1min logging interval. Corresponding to Figure 20

The main observations to draw from these graphs are:-

1. Reassurance that the temperature profile obtained from the normal 10 minute logging cycle are representative of the response characteristics of the houses.

2. Air temperatures measured close to the two thermostat locations correspond to the target set point temperature for that zone, i.e. 21^{o}C for the lounge/diner and 18^{o}C for Bedroom 1.

3.2.5 Temperature profile behind the heaters

Another area of interest examined during this study was the measurement of surface temperature of the wall immediately behind both types of heater. The wall behind a conventional steel panel radiator can get quite hot in normal use and this can lead to increased heat loss over this area. By placing a sensor in contact with the wall, the surface temperature of the wall behind both the radiator and the Jaga unit could be recorded.

The following two graphs, Figures 26 and 27, show examples of findings. The results clearly show that, while there are some small daily variation, overall the profiles are very similar and would lead to similar heat loss. However, it is fair to say that for an equivalent thermal output, the Jaga low H_2O units generally occupy, and thus heat, a smaller area of wall.

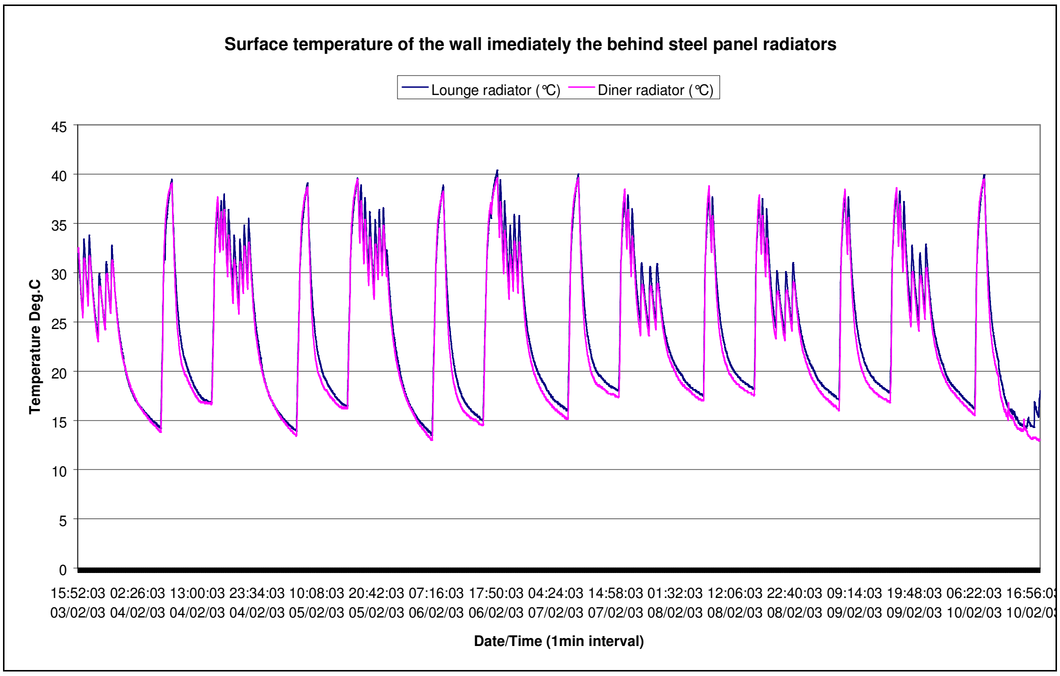

Figure 25 Seven day record of surface temperature of the wall behind steel panel radiators in the lounge and dining room of House 2 before refurbishment with the Jaga units

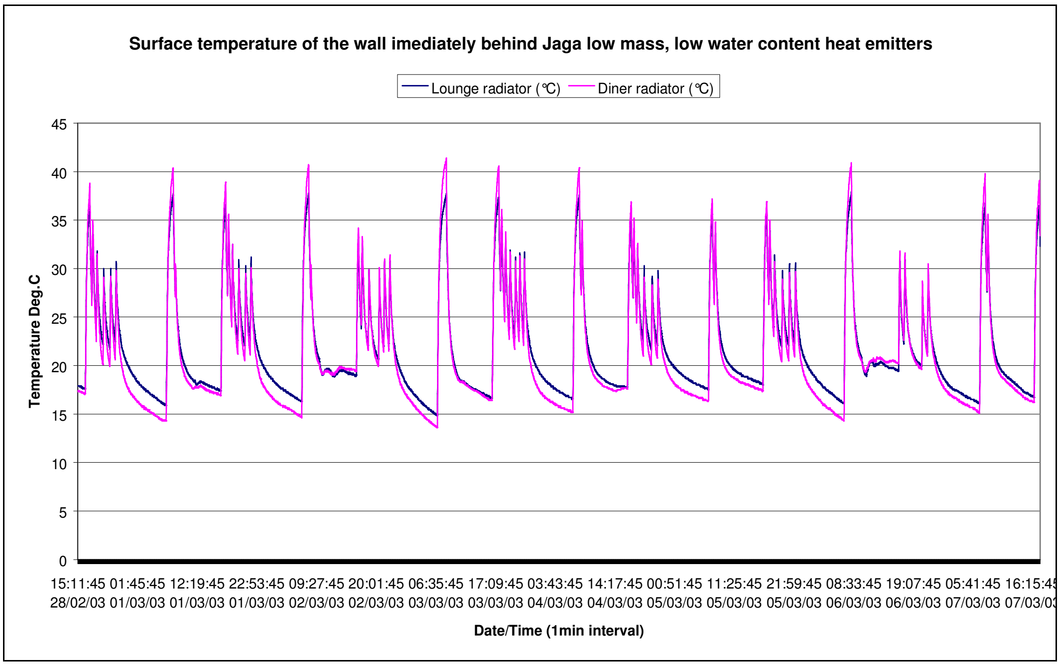

Figure 26 Seven day record of surface temperature of the wall behind Jaga heat emitters in the lounge and dining room of House 2

Conclusion and recommendations

Over the period of the study, the houses were exposed to quite diverse weather patterns. For the calibration phase, the weather was fairly cold leading to reasonably high consumption. Over the testing phase in February, the weather was less cold and rather unsettled, however, in March and April the air temperature was generally above average with a considerable amount of sunshine. Using the matched pair house technique, however, the relative performance of the houses is unaffected and a quantified evaluation of the performance of the new heating system obtained independently of the weather conditions. However, as will be discussed later, it would be of some benefit to gather further data using the Jaga low H_2O emitters in cold weather.

The purpose of this study has been to provide evidence of the improvement in thermal performance which may be achieved by using low mass low water content heat emitters (Jaga low H_2O emitters) in place of traditional steel panel radiators in a typical modern UK house.

Other considerations in the study were:

- To investigate the thermal responsiveness of the low H_2O emitters
- Establish whether by using Jaga low H_2O heat emitters, the heating start time could be delayed while still achieving satisfactory thermal performance when compared to the conventional steel panel radiators.
- Maintain satisfactory thermal equality in the house over the different periods.

Following the re-plumbing of House 2, the testing period was specifically designed to establish whether Jaga low H_2O emitters would reduce the overall energy consumption of the house. The results show that Jaga low H_2O heat emitters gave better saving in mild weather when consumption is low than in cold weather when the house energy usage is considerably higher. Savings for the low H_2O heat emitters range from around 15% or more in mild weather down to 5% or less in cold weather. However, substituting the previously established mean winter season consumption for Test House 2, suggests that the average saving over a whole winter heating season would be in the region of 10% for a two period heating regime.

Based on the average 220 day heating season for these houses, this could result in an annual reduction in energy required for space heating of around 2,000MJ or about 550kWh. This would consequently, reduce the house annual CO_2 emission by around 100kg. However, because of the current limited data which we were able to gather, this reduction is subject to quite wide uncertainty and it would be valuable to continue the study to cover colder weather in the test condition in order to extend the data set and reduce the need for extrapolation.

Over the testing period, some modifications were made to the start time of the two heating periods. However, analysis of the temperature match within the heated envelope suggests that there had been very little overall change in the whole house average temperature. But clearly, the warmer weather towards the end of the test period produced somewhat higher internal temperatures in both houses.

From the study designed to demonstrate the responsiveness of the systems, it is clear from the data available that House 2 warms up faster with Jaga low H_2O emitters. The study proceeded to consider whether the start of each heating period could be delayed while maintaining comparable room temperatures. The results support the view that a 20minute delay in the morning start would probably enable House 2 to reach the morning target temperature as quickly as an earlier start using steel panel radiators. However, due to the strong sunshine experienced towards the end of this testing period, it was not possible to establish that the 1hour delay in the start of the afternoon heating period would be acceptable because both houses exhibited a fast response on start-up.

Also of interest is the speed at which the houses cool after the heating is turned off. While it is clear that the rate of cooling is slightly faster in the less well insulated house, the room temperature at the heating ‘start time’ is still very dependent on the ‘time’ of the last thermostat cycle of the previous period. There is some evidence to suggest that the lower mass of the Jaga units allows House 2 to cool faster after the short morning period but this is not evident at the end of the afternoon/evening heating period

The wall area behind panel heaters can get quite warm, and this can lead to increased heat loss when heaters are sited on external walls. During this study, the opportunity was taken to record the temperature of the wall behind both types of heater. The results indicate that, while there is some daily variation, overall the temperature profiles were very similar and would thus lead to similar heat loss. However, it is fair to say that for an equivalent thermal output, the Jaga low H_2O units generally occupy, and thus heat, a smaller area of wall.

In order to ‘visualise’ the response of Jaga low H_2O emitters, the infrared thermographs in Annex A illustrate a warm up sequence for the two systems. As expected, the Jaga low H_2O emitter increases in temperature very quickly and a substantial amount of warm air is given off after only a very short time. By comparison, in roughly the same period of time, the steel panel radiator has only just reached ‘working’ temperature.

Annex B shows the results of some data gathered right at the end of the project after the Jaga emitter in the lounge was fitted with a prototype ‘Dynamic Boost’ feature. Dynamic Boost uses small fans to increase speed of response once the heater is warm. Preliminary results suggest that the prototype is achieving this aim even though the control mechanism was on time only.

It is recommended, therefore, that as well as gathering additional data next heating season (Winter 2003) to extend the test period consumption graph, further work is carried out on the ‘Dynamic Boost’ feature to study its performance in colder weather.

30 To study the energy efficiency benefit of low mass, low water content heat emitters.

References

1. “The DoE/BRE energy and environment test houses”. Robert Rayment and John Hart, N 192/92.
2. “Re-calibration of the DoE/BRE standard test houses”. Robert Rayment, Derek Whiteside and John Hart, N 73/94.
3. “A practical guide to infrared thermography for building surveys”, John Hart, BR 176. Garston, CRC Ltd. 1991.

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Annex A – Infrared survey

To illustrate and visually compare the thermal performance of the both the Jaga low H_2O emitters and the steel radiators, an Infrared survey was carried out on examples of both units as they heated up from cold.

Infrared thermography is a valuable tool for evaluating the thermal performance of whole buildings and for assessing the thermal performance of building components (Reference 3).

Being a remote sensing technique, a thermographic survey can be carried out with minimal disturbance and with the added benefit that inaccessible locations or ‘sensitive’ components can be studied without disturbance or physical obstruction.

As a technique, infrared thermography can be simply defined as ‘seeing heat’. However, it is important to distinguish between infrared (thermal) photography and electronic thermography.

Infrared photography can be used to capture images using a photographic emulsion sensitive to radiation just beyond the red end of the visible part of the electromagnetic spectrum. This specialist emulsion has many scientific and artistic uses but operating in the ‘near infrared region’ (0.8 to 3µm) it is not suitable for building thermography.

In order to ‘see heat’ in the temperature range say, -10^{o}C to 30^{o}C, an alternative form of imaging must be used and this is known as infrared thermography using an electronic “infrared camera”. The camera used for this survey operates in the far infrared region (8 to 14µm).

The basic task of the infrared camera is to detect thermal radiation from an object surface and display the result as visible light on a TV type display as a thermal image in black and white or graduated colour. As there is no ‘natural’ colour associated with infrared, all colour thermograms are reproduced using a false colour scheme. For this survey, the colour rendering is known as the “Iron” scale where the blue/black colours are cooler than the yellow/white end of the scale.

The twelve images in this report are the product of two surveys carried out to show the warm-up and heat output characteristics of both the traditional steel panel radiator and the low H_2O emitter.

The images are generally self explanatory and each sequence was recorded over a period of eight or nine minutes.

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A1. Jaga low H_2O emitter warm-up sequence over a period of around eight minutes.

Figure 27 Visual picture of the Jaga low H_2O heat emitter in Bedroom 1 of House 2

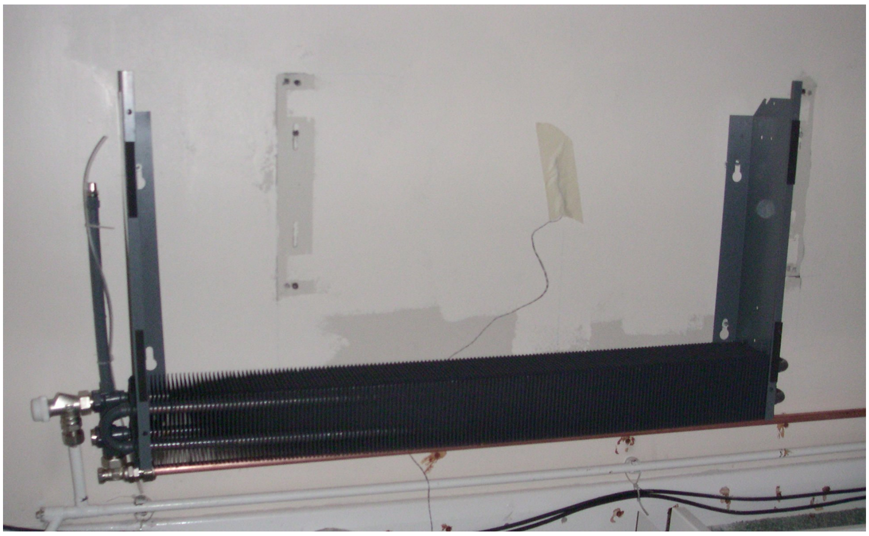

Figure 28 A Jaga low H_2O emitter with casing removed (note the thermocouple affixed to the wall recording surface temperature).

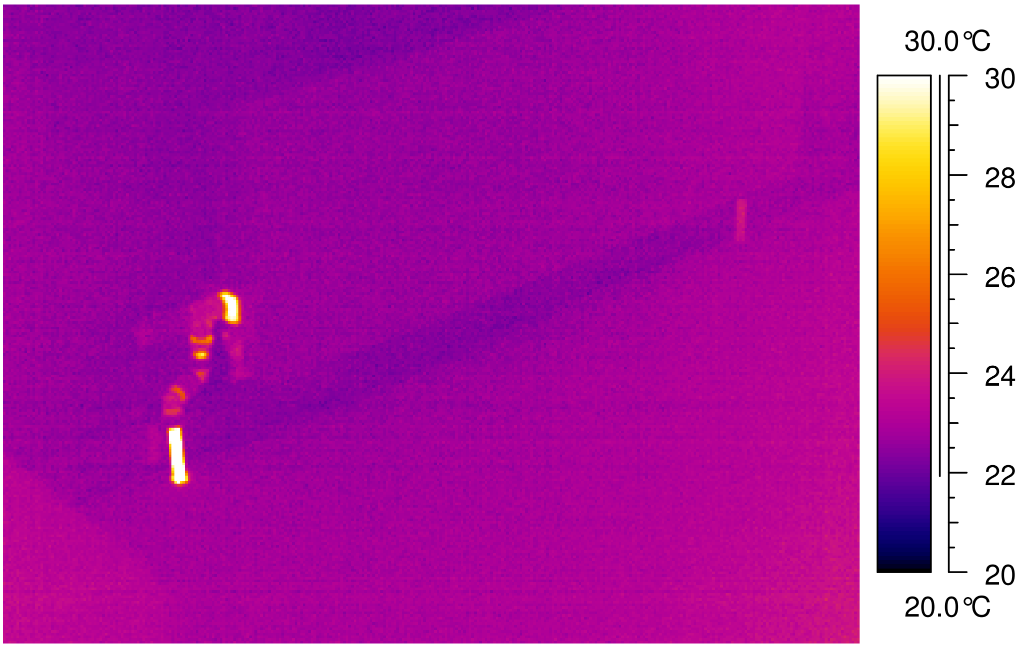

Figure 29 From a cold start, heat reaches unit after about 1 minute from boiler ignition.

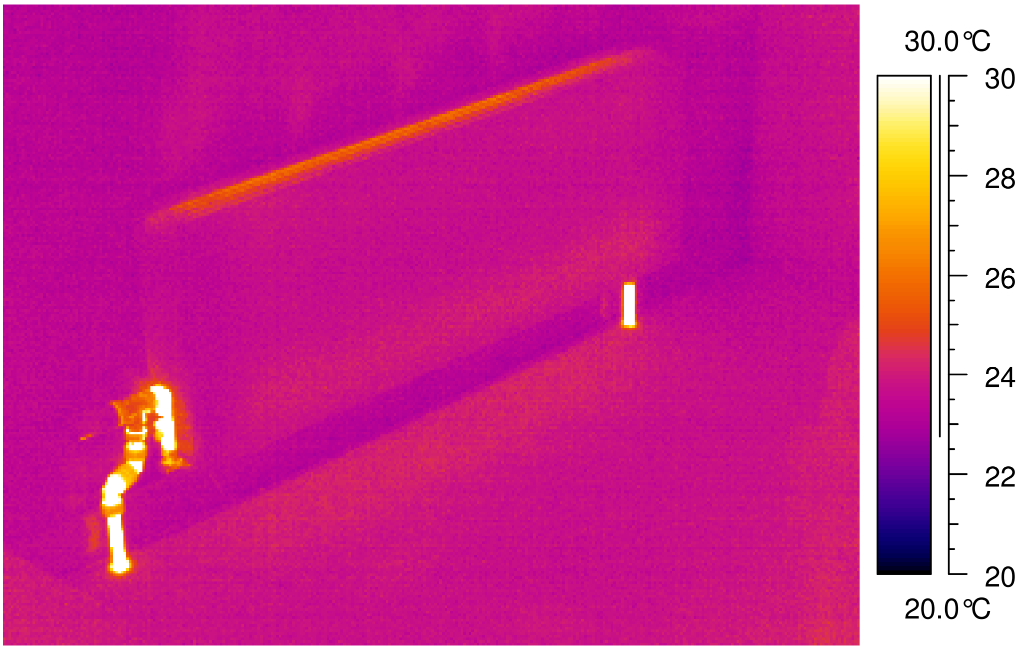

Figure 30 After 2 minutes, heat has reached the return and warm air can be seen at the output grill.

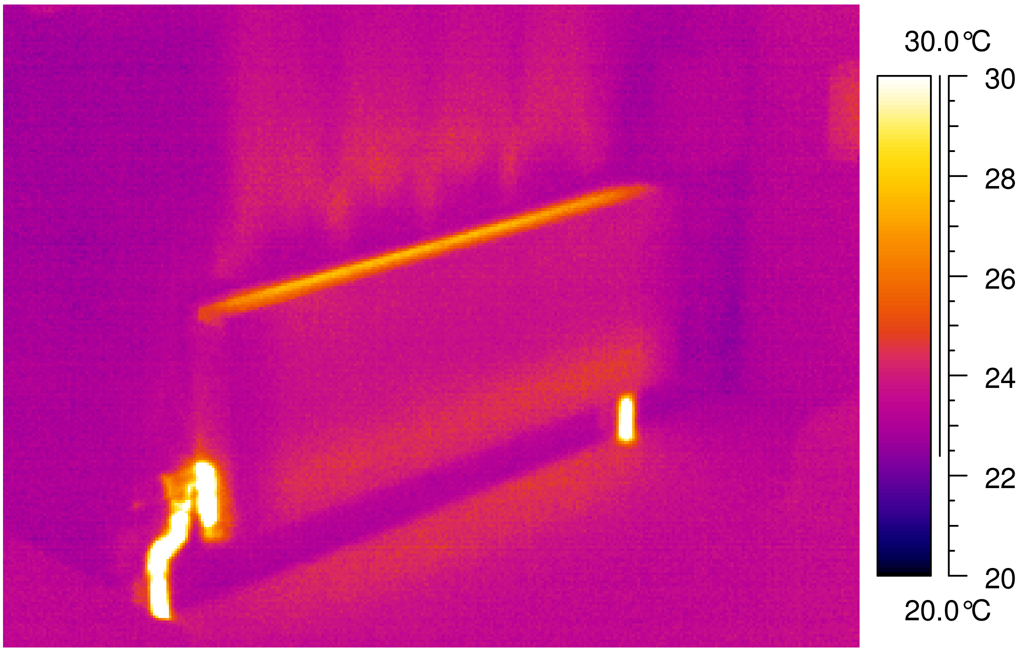

Figure 31 After 4 minutes the flow and return are thoroughly hot and the outline of the fins can be seen at the bottom of the unit. Plumes of warm air can be seen from the top.

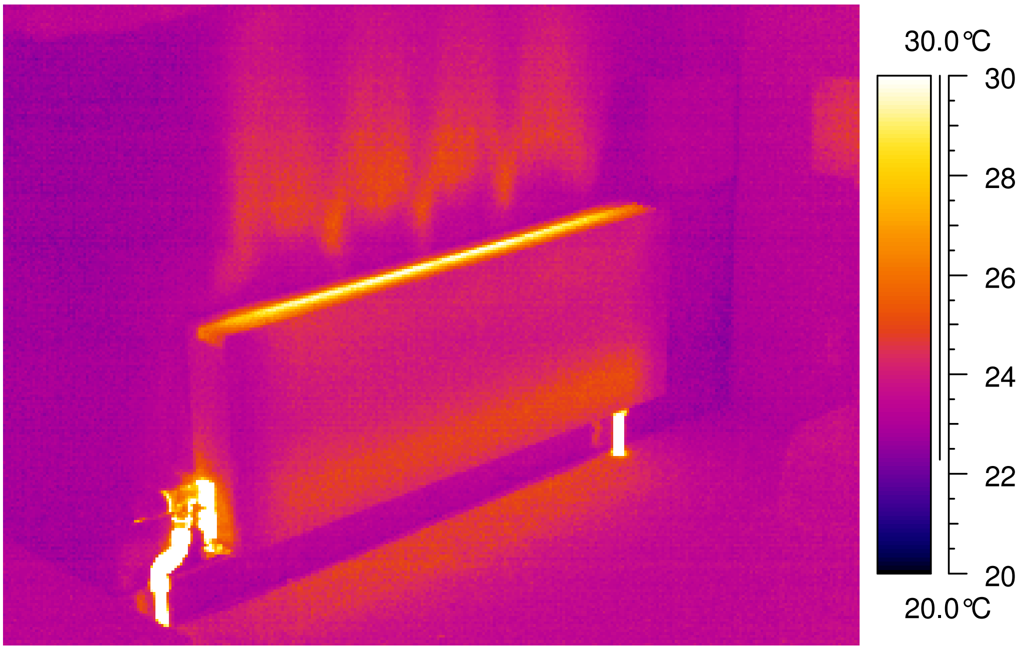

Figure 32 After 4½ minutes, the temperature of the unit continues to rise rapidly with a corresponding increase in output.

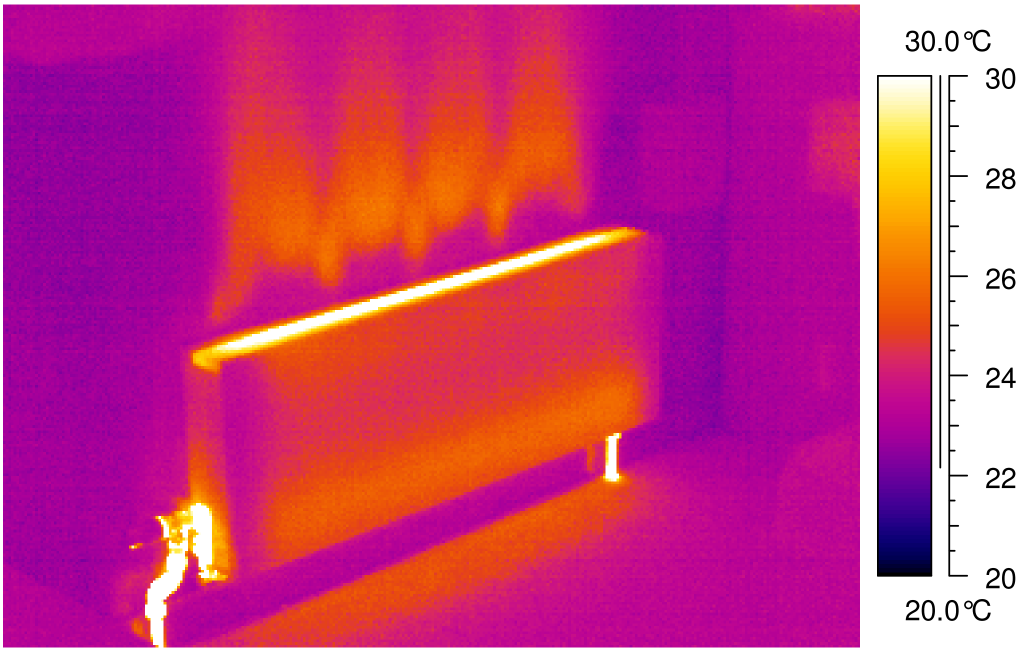

Figure 33 After 5½ minutes, the temperature of the unit continues to rise rapidly. The top grill is now over 30°C with a corresponding increase in output.

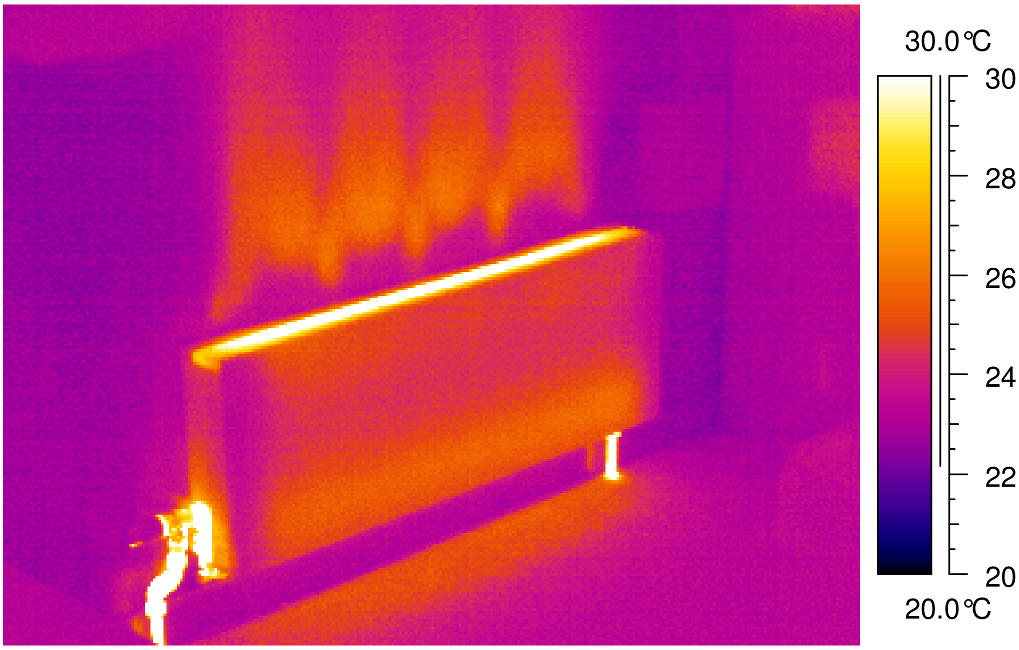

Figure 34 After 7 minutes, the temperature of the unit is rising less rapidly. The top grill is now well over 30°C with a corresponding increase in output.

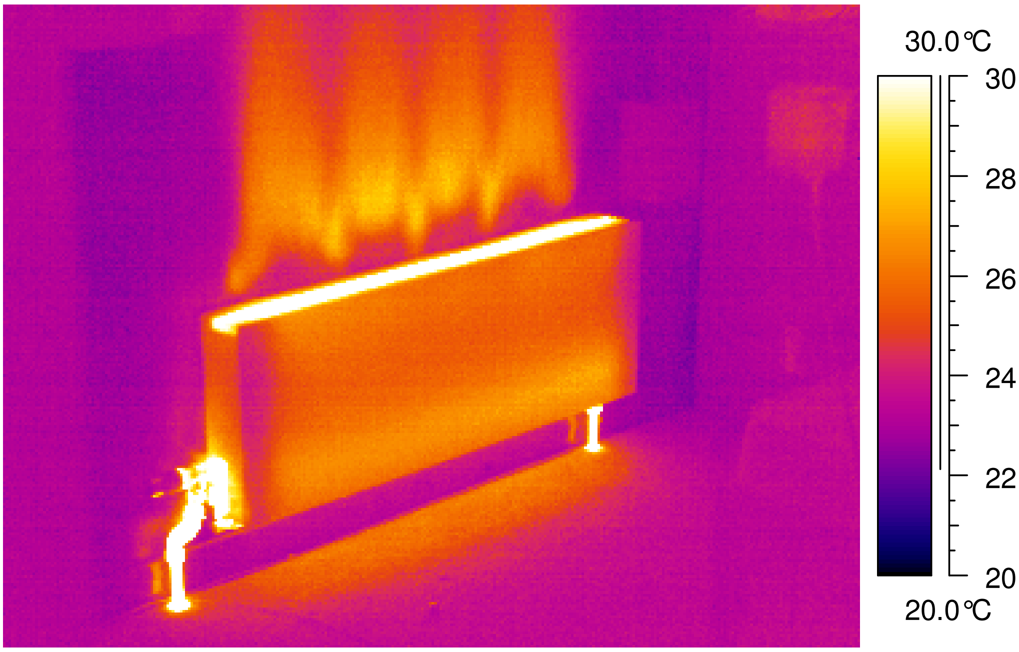

Figure 35 After 8 minutes, the temperature of the casing is now moderately uniform at around 27°C and the output plumes show a substantial output.

To study the energy efficiency benefit of low mass, low water content heat emitters.

A2. Steel panel radiator warm-up sequence over a period of around nine minutes

Figure 36 Visual picture of the traditional steel panel radiator in the lounge of House 1

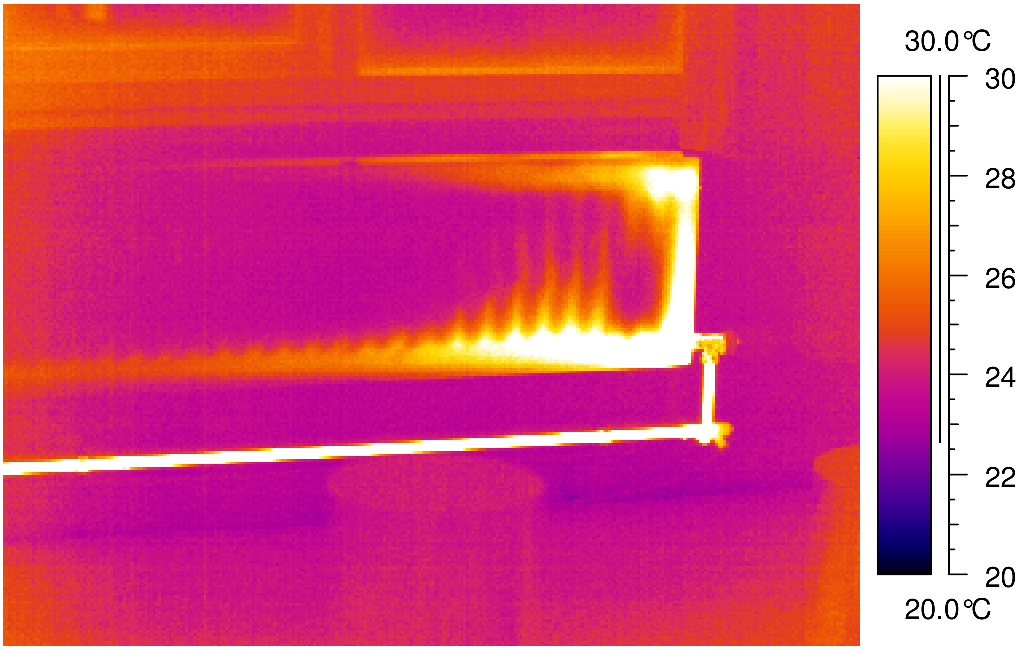

Figure 37 From a cold start, heat reaches unit after about 3 minute from boiler ignition.

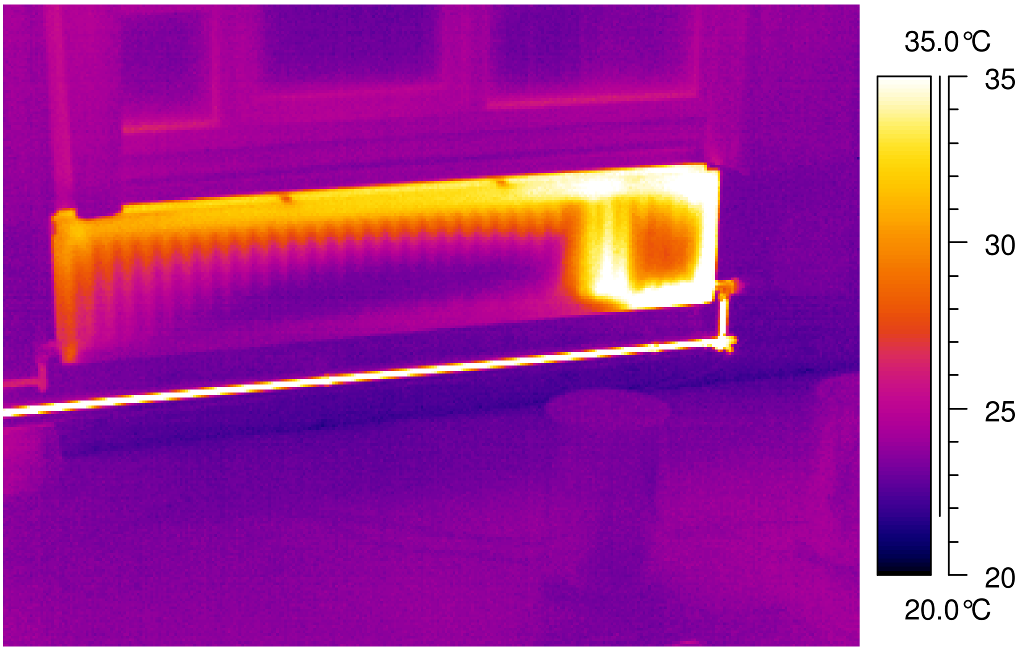

Figure 38 After 4½ minutes, the temperature of the radiator continues to rise at the flow end and across the top, but the return is still cold.

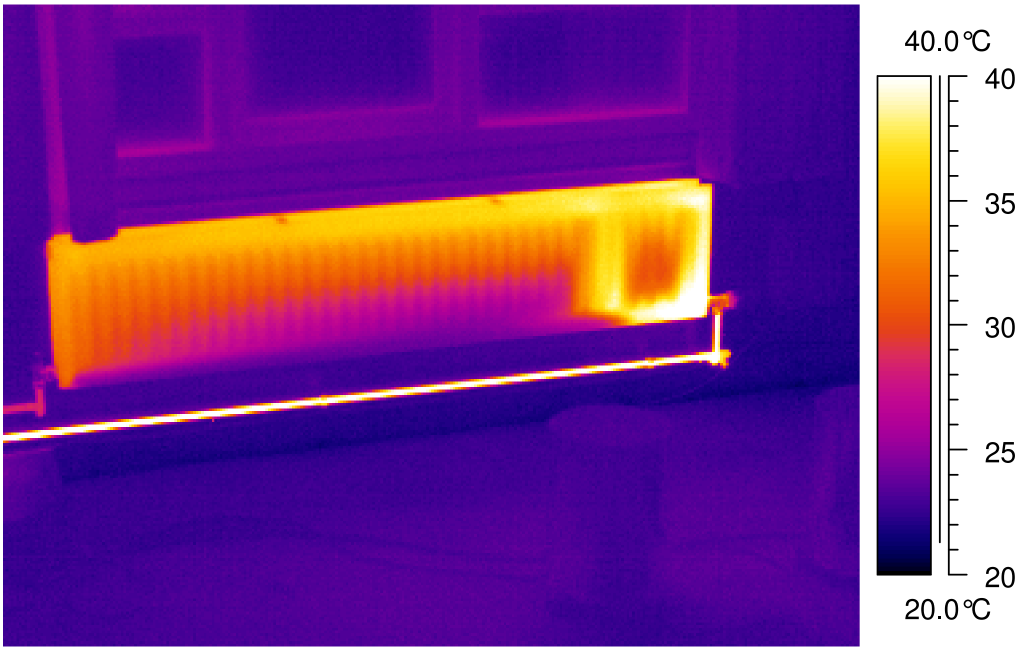

Figure 39 After 5½ minutes, the temperature of the radiator continues to rise at the flow end and the majority of the radiator has reached around 30°C. The return is just getting warm.

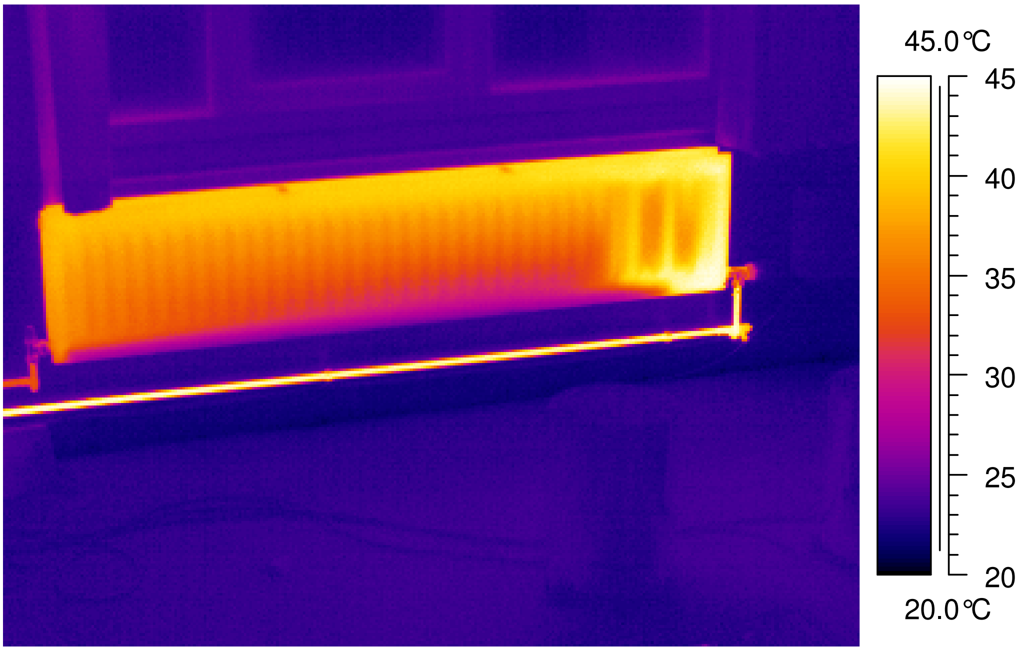

Figure 40 After 6½ minutes, the majority of the radiator has reached around 40°C.

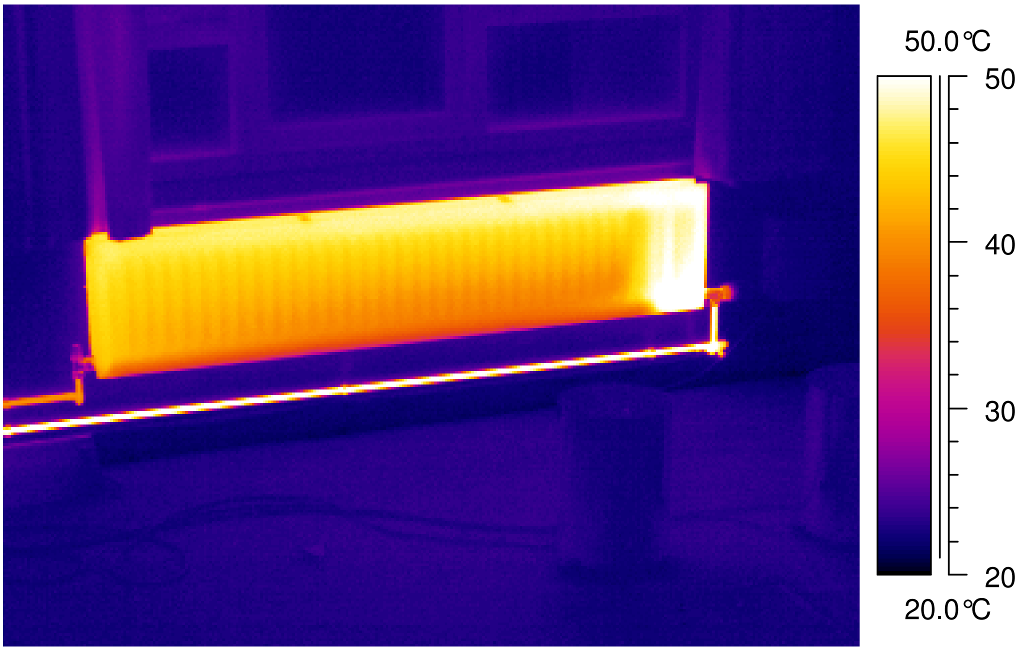

Figure 41 After 9 minutes, the majority of the radiator has reached around 45°C but there is still a substantial drop in temperature between the flow and return.

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Annex B – Dynamic Boost

This very short study was carried out at the end of the original investigation after the 'Dynamic boost' (DB) feature was fitted to the lounge emitter from Monday 14th April. The experiment only ran for four days and the prototype control system was set up to start the Dynamic Boost fans by time approximately 5 minutes after the start time of each heating period.

It is clear from the limited data available that the warm-up response is now very fast even leading to some apparent overshoot of the room temperature. However, it should be noted that although overnight temperature was relatively cool for mid April, the Spring weather did not generally impose a high heat requirement for the houses.

It is recommended, therefore, that further work is carried out on the 'Dynamic Boost' feature to study its performance in colder weather.

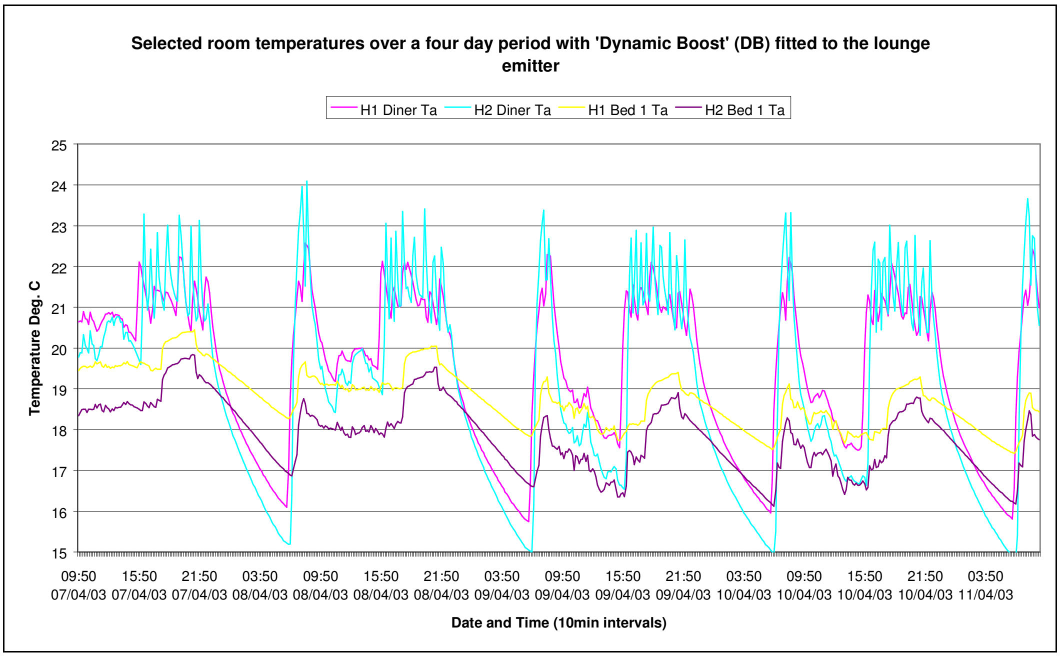

Figure 42 Temperatures over a short four day test period with Dynamic Boost fitted to the lounge emitter.

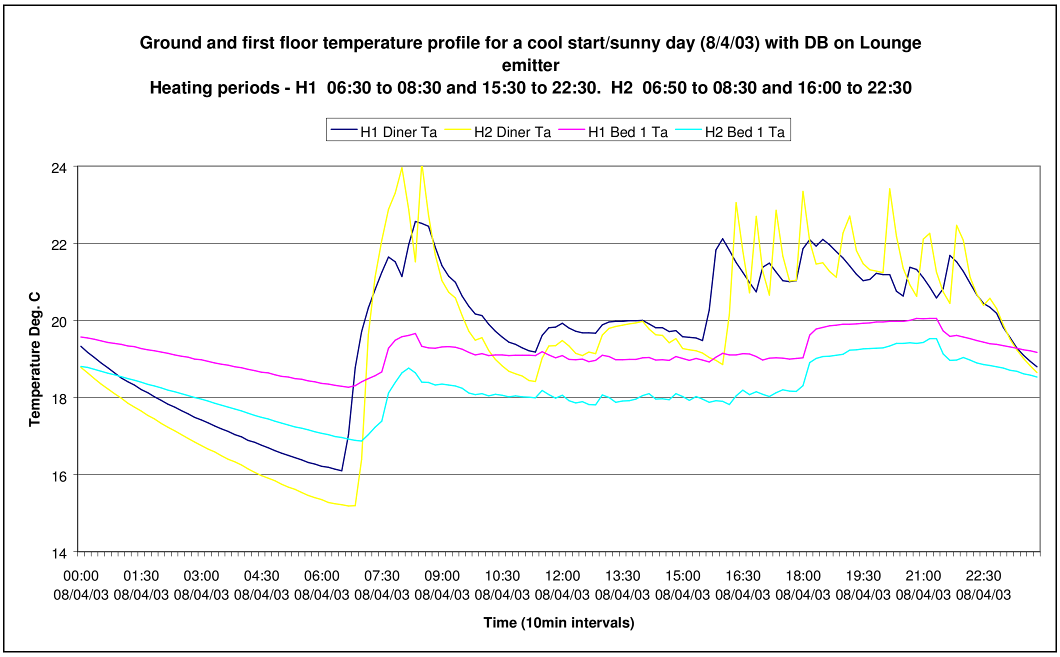

Figure 43 A 24hr temperature profile for a cool start, sunny day with Jaga Low H_2O heat emitters, delayed start heating periods in House 2 and Dynamic Boost.

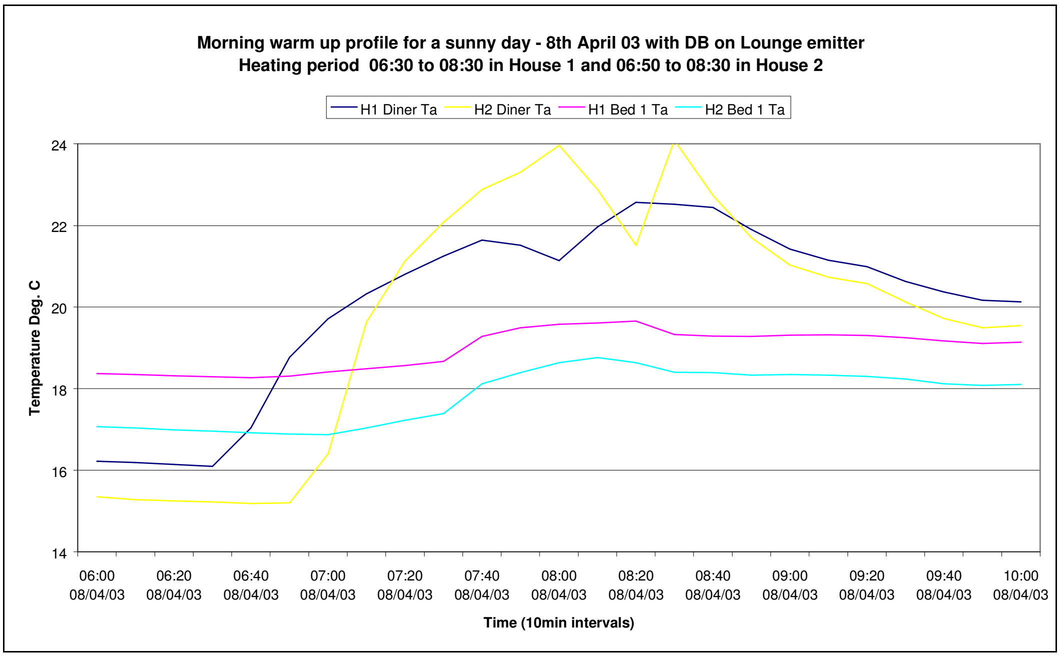

Figure 44 Enlarged span of the morning warm-up profile shown in Figure 43

To study the energy efficiency benefit of low mass, low water content heat emitters.

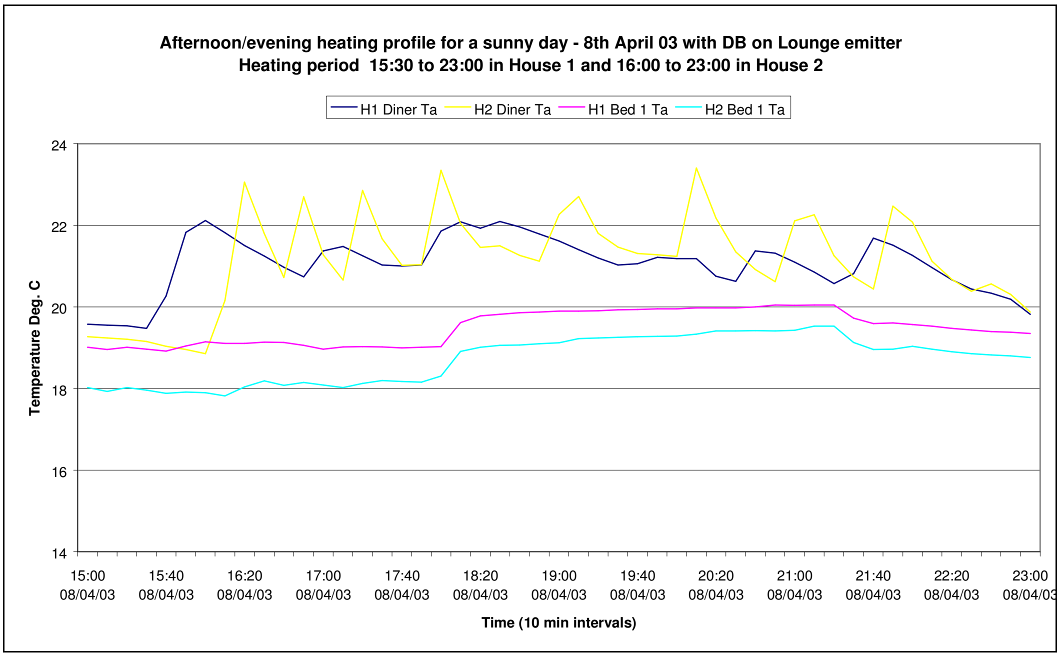

Figure 45 Enlarged span of the afternoon/evening profile shown in Figure 43

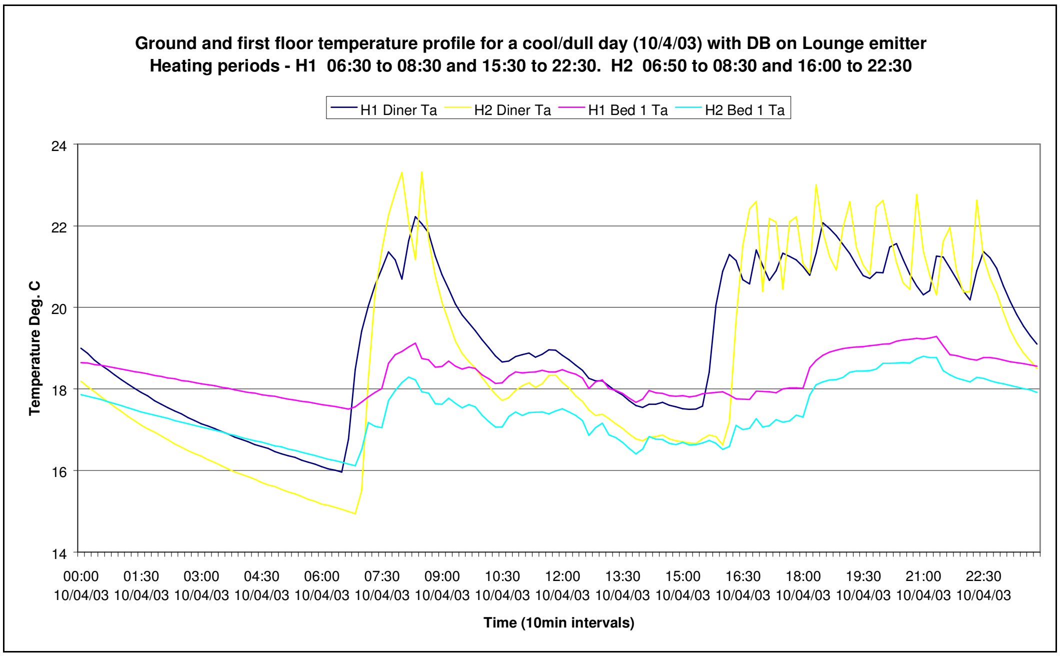

Figure 46 A 24hr temperature profile for a cool dull day with Jaga Low H_2O heat emitters, delayed start heating periods in House 2 and Dynamic Boost.

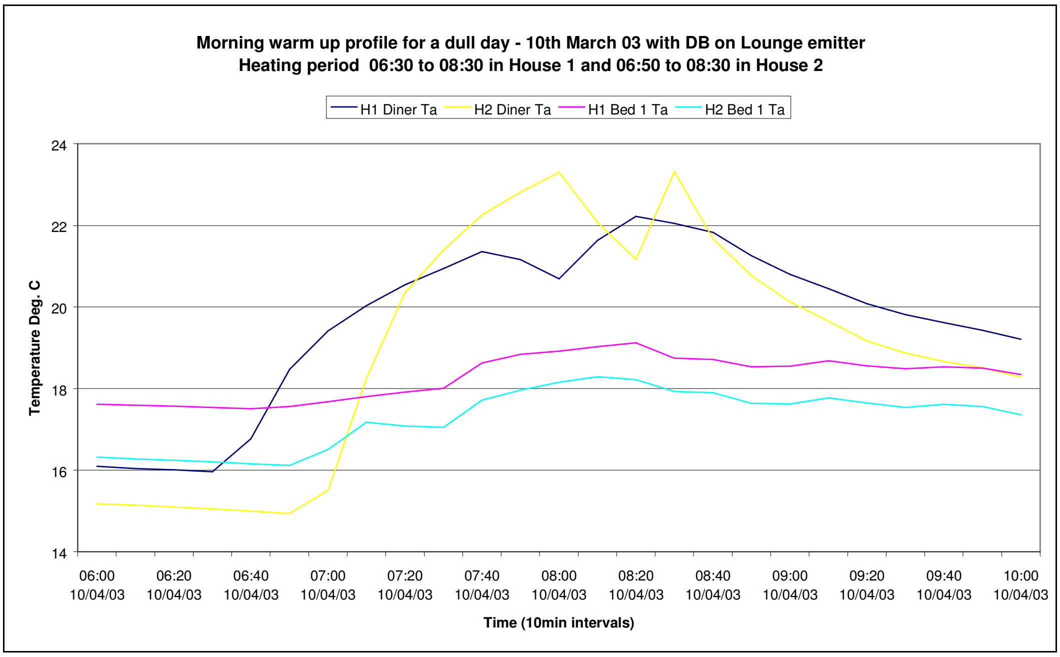

Figure 47 Enlarged span of the morning warm-up profile shown in Figure 46

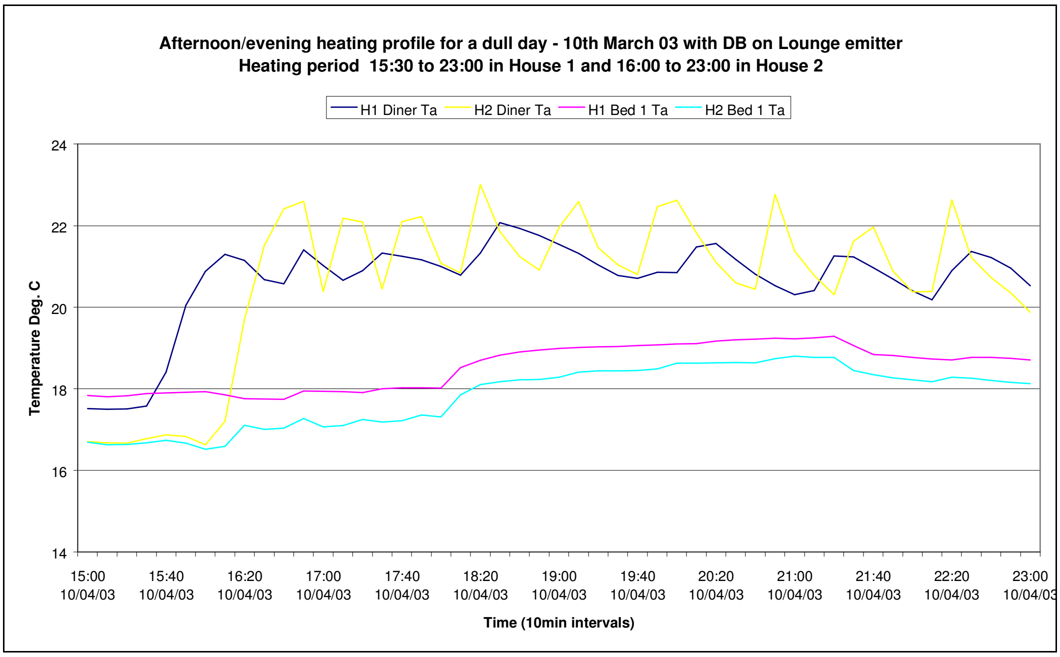

Figure 48 Enlarged span of the afternoon/evening profile shown in Figure 46

To study the energy efficiency benefit of low mass, low water content heat emitters.

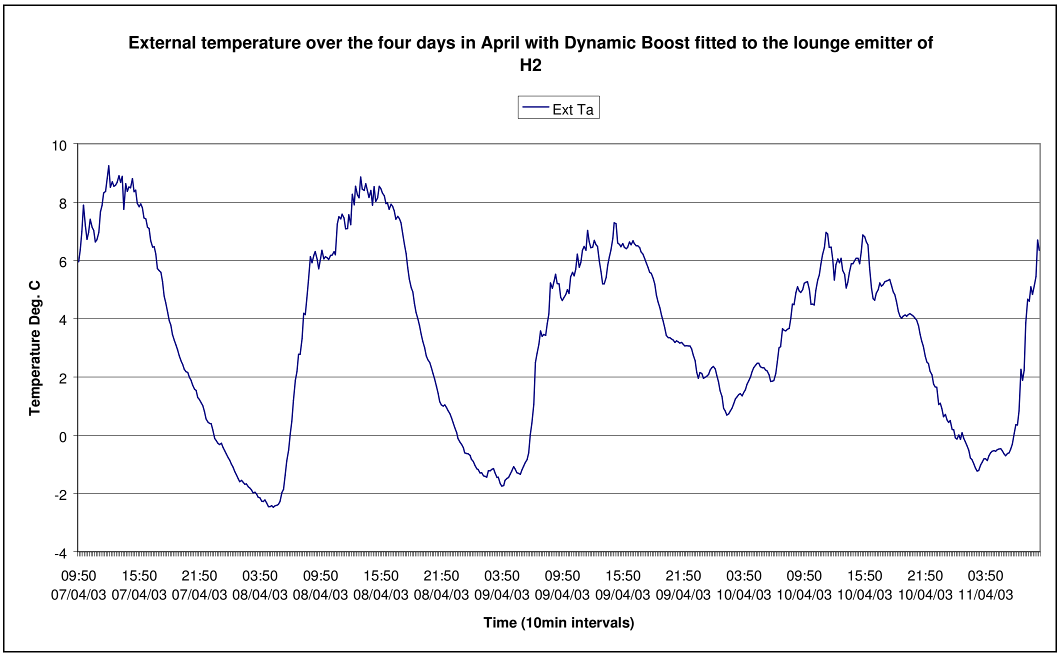

Figure 49 External temperature profile for the four day Dynamic Boost study.