Practical Application

This paper describes a test method that has been used to quantify the energy savings that could be achieved by installing a passive deaerator on the closed loop of a wet central heating system. Although the results indicate that the energy savings associated with using such a device are likely to be marginal, the test method described could be used to test a range of other devices that claim to improve the performance of domestic wet central heating systems, to directly compare before and after performance.

1 Context

There is widespread agreement within the scientific community that changes to the global climate are taking place, primarily due to an increase in anthropogenic greenhouse gases, and governments are prioritising attempts to limit these(1). One sector that contributes substantially to anthropogenic greenhouse gas emissions is the built environment. Globally, it is estimated that approximately one third of all anthropogenic emissions and 40% of global energy use can be attributable to the built environment(2).

In the European Union (EU), buildings are responsible for 40% of energy consumption and 36% of CO_2 emissions(3). In response to concerns regarding climate change, fuel costs, the security of energy supply and market competitiveness, the EU has set a series of ambitious climate change and energy efficiency targets. By the year 2020, the EU is committed to a 20% reduction in greenhouse gas emissions, a 20% reduction in the energy derived from renewables and a 20% increase in energy efficiency(4). These targets are set within the context of the EU's long-term decarbonisation goal of reducing greenhouse gas emissions by 80-95% by 2050(3). In order to meet these targets, the EU has introduced legislation that is designed to improve the energy efficiency of buildings. This includes the Energy Performance of Buildings Directive(5) and the Energy Efficiency Directive(4). In addition, the EU has also set a target for all new buildings to be nearly zero-energy by 2020(4).

Dwellings, of which there are more than 27 million in the UK(6), are a significant source of energy use and CO_2 emissions. Currently, they account for just over 25% of the UK's total energy consumption and the associated CO_2 emissions(7, 8). Space heating is the largest single end-use category in the domestic sector, accounting for approximately 62% of all of the energy delivered to the existing housing stock in 2011, the latest year for which there is published data available(6). In UK dwellings, a central heating system is the most popular method used to provide space heating, with 90% of dwellings incorporating such a system(6). The majority of UK central heating systems are wet central heating systems, which consist of a central heat source (boiler), a series of water pipes (distribution system) and a number of radiators (heat emitters).

Domestic central heating systems are not just a UK phenomenon, but are also commonplace across Europe. For instance, in Germany, almost all dwellings have a central heating system installed(9) and as is the case in the UK, space heating accounts for a significant proportion (70% in 2013) of the final energy consumption in German housing(10). In the Netherlands, almost all of the space heating is provided by natural gas, and the vast majority of dwellings that use gas for space heating have a gas-fired centrally heated boiler system installed(11).

A range of technologies are available that claim to be able to improve the energy and carbon performance of domestic central heating systems. In recent years, efforts in the UK have primarily concentrated on improving the efficiency of boilers, most notable through the wide scale introduction of gas-fired condensing boilers. Approved Document Part L1A of the Building Regulations(12) requires that all boilers must meet a minimum efficiency, as defined by the SEDBUK (Seasonal Efficiency of Domestic Boilers in the UK) value. Minimum SEDBUK values for various boilers are contained with the Domestic Building Services Compliance Guide(13). For instance, gas boilers are required to meet a minimum SEDBUK rating of 88%. The widespread introduction of gas-fired condensing boilers has also taken place in other EU countries, such as the Netherlands(14). However, other lower cost technological solutions are also available that are capable of improving the energy efficiency of the central heating system. These include: thermostatic radiator valves (TRV's), intelligent controllers, high efficiency circulation pumps, and passive deaerators.

This paper investigates the potential of one of these technologies, passive deaerators. These are designed to improve the efficiency by removing the dissolved air that exists within the closed loop distribution system. Dissolved air is naturally present within the water that is used to fill the distribution system in a closed loop central heating system. When this water is heated, the dissolved air is degassed, resulting in the formulation of air bubbles within the distribution pipework. These air bubbles not only reduce the rate of heat transfer from the boiler to the water in the distribution system, but they can also lead to cavitation corrosion, unwanted noise, reduced flow, blockages and reduced radiator output(15 & 16) due to the accumulation of air within the top of the radiators. Additional air can also be introduced into the closed loop distribution system if the system is drained down and then re-filled with fresh water, if the system is poorly designed(17), if there are micro leaks which allow air to be drawn into the system and via diffusion through the walls of the distribution system(18).

The amount of air that can be dissolved in water is dependent upon its temperature and pressure; the lower the temperature of the water the greater the amount of dissolved air. The majority of the absorption occurs therefore during the night when the central heating system is switched off[15]. This air is traditionally removed from the system by either *'bleeding'* the radiators or by using automatic air vents (AAV's) either installed in the distribution system pipework or incorporated within the central heat source. However, AAV's only tend to be effective in removing the larger air bubbles that are produced within the system, rather than the micro air bubbles from central heating systems[18]. In order to be able to remove the micro air bubbles, passive deaerators have been developed[19]. Manufacturers of deaerators claim that removing micro air bubbles also improves overall heating system efficiency [15], by in some cases, between 12-35%[20, 21, 22, 23 & 24]. In addition to energy savings, passive deaerators are also known to have other benefits. For instance, as the removal of dissolved air and oxygen creates an anaerobic environment in which the rusting process cannot take place, they can reduce the levels of corrosion and magnetite build-up within the closed loop system, consequently reducing the maintenance burden[15].

Although research has been undertaken that indicates that passive deaerators are effective in removing oxygen from the circulation water used in domestic wet central heating systems[16], the available evidence in relation to their energy saving potential is not yet sufficient to enable them to qualify for assistance under government funding schemes for energy efficiency in the UK[25]. It is recognised that removing dissolved air from water will improve its specific heat capacity such that more heat can be delivered per litre of water, which in turn may lead to greater heat exchanger efficiencies. However, the potential improvements that could be obtained are theoretically only slight and may not be sufficient to explain the levels being anecdotally claimed by the manufacturers of such devices. This research aims to address this knowledge gap.

Of the evidence that is currently available on domestic closed loop wet central heating systems, the majority of this has been obtained from individual *in situ* case study dwellings. In these case studies, it is difficult to directly compare the *in situ* performance of the central heating system before and after the installation of the passive deaerator, due to differences in the environmental conditions and occupant behaviours to which these dwellings were subjected to[22 & 23]. In addition, the central heating systems are often flushed during the installation of the passive deaerator device and fresh inhibitor applied. This not only makes any before and after comparisons difficult, but it also means that some of the potential benefit associated with installing the passive deaerator may actually be attributable to flushing and adding inhibitor to the central heating system rather than the deaeration process. For instance, tests undertaken by Mayer[26] suggest that the addition of an inhibitor can reduce gas consumption by between 5 to 10%. In some cases, relatively crude comparisons have been made by comparing one case study building with a passive deaerator installed to another identical building with no deaerator installed, without any understanding of the potential differences in the *in situ* fabric, services performance and occupancy of these buildings[22]. Therefore, there is a lack of published empirical evidence available based upon a directly comparable test both pre- and post-installation of a passive deaerator that is capable of establishing whether the energy saving claims can be substantiated.

Set within this context, the aim of this paper is to undertake a directly comparable *in situ* test in order to quantify the energy savings that are likely to occur by installing a passive deaerator on the closed loop of a wet central heating system installed within a test dwelling under controlled conditions.

2 The test dwelling

In order to be able to undertake a directly comparable *in situ* test, the passive deaerator was installed on the wet central heating circuit of a test dwelling. The test dwelling chosen for the *in situ* test was the Salford Energy House, University of Salford, Manchester. This dwelling was chosen as it is an existing unoccupied dwelling that has been constructed within an environmental test chamber. It is also unique in that it enables the climatic conditions surrounding the dwelling to be controlled and monitored throughout the test period. Such replication of the test conditions would not be possible to be achieved in the field, due to the natural variability of the external weather conditions and variations in occupant behaviour.

The Salford Energy House is a fully functional replica of a typical 1919 solid brick walled two bedroom two storey end-terrace dwelling[27]. It comprises a living room and kitchen/dining area on the ground floor, and has two bedrooms and a bathroom located on the first floor. Space heating is provided via a gas-fired wall-mounted modulating condensing combination boiler located in the kitchen. The boiler feeds a conventional closed loop wet central heating system that incorporates six modern double panel column radiators. The radiators are located in the kitchen, hall, living room, bathroom, bedroom 1 and bedroom 2 and are fed via two separate space heating circuits; one for the kitchen, hall and living room, and the second circuit for the bathroom, bedroom 2 and bedroom 1. Control of the central heating system is provided via a wall-mounted panel located in the kitchen which acts as an electronic programmer. The panel is linked to six electronic TRV's located on each of the radiators. TRV's were installed on all of the radiators to enable the temperature in each room of the house to be controlled separately. These TRV have internal temperature sensing elements.

The passive deaerator was installed on the primary flow from the boiler. A bypass loop was also installed on the boiler primary flow to enable the space heating circuit to be operated either with or without the passive deaerator device operating. The passive deaerator device was also installed in advance of any of the tests commencing to ensure that the hot water circulating within the closed loop distribution system was identical between the tests. As the central heating system within the dwelling was drained down and had been recently flushed prior to installation of the passive deaerator, the test is not only felt to be representative of what would happen in practice if the device was retrofitted into an existing dwelling, but it should also have relevance to new build dwellings, where the distribution system would be clear of sludge and have the appropriate amount of inhibitor added. Additionally, as the central heating system was flushed prior to the commencement of the tests, any difference between the tests can only be attributed to the operation of the passive deaerator and not to the flushing process.

3 The test method

Testing of the passive deaerator device was separated into three distinct stages. These were as follows:

a) Stage 1 (Preliminary test run) – A preliminary test on the space heating system was undertaken following the installation of the passive deaerator device to ensure that the bypass loop was operational and that no significant drop in pressure was experienced in the wet central heating system as a consequence of the deaeration process. If a significant drop in pressure had been experienced, then it is likely that the boiler would have automatically switched off, nullifying the test period. During this preliminary test, the chamber surrounding the Salford Energy House was maintained at ~3°C (is in line with the average external temperature for the midland region that is contained within the CIBSE Domestic Heating Design Guide[28]), and the existing wet central heating system was programmed to run continuously for 24 hours. Although the space heating system within the Energy House can be controlled via the wall-mounted panel, this was not used during any of the test periods. Instead, temperature control was achieved by manually adjusting the head of each of the electronic TRV's. In the living room, the TRV was adjusted to maintain a living room temperature of ~21°C, whilst all of the TRV's in the remaining rooms were manually adjusted to maintain a room temperature of ~18°C. These temperatures were selected to fall in line with the standard figures provided by the UK Government's Standard Assessment Procedure (SAP)[29]. The bypass loop was also activated during this test period, enabling the water from the wet central heating system to pass through the passive deaerator device. Following the preliminary test run, the space heating system was programmed to switch off and the dwelling was left to cool down naturally for a period of 12 hours. A cool down period of 12 hours was chosen, based upon the results of previous tests undertaken within the house, as it was deemed to be sufficiently long enough to enable the thermal mass within the Energy House to discharge. During this cool down period, the deaerated water within the wet central heating system was drained off and the system refilled with fresh naturally aerated water. The neighbouring building to the energy house (the conditioning void) was not heated during the test.

b) Stage 2 (Test period 1) – This test was undertaken to determine the baseline performance of the existing wet central heating as installed, with the passive deaerator bypassed. During this test, the bypass loop was closed to ensure that the passive deaerator device was not operational and no adjustments were made to any of the electronic TRV's or to the chamber temperature surrounding the Energy House. The wet central heating system was programmed to run continuously for 24 hours. Following this test, the space heating system was switched off and the dwelling was left to cool down naturally for a period of 12 hours. The same length of cool down time period was used prior to the commencement of test period 1 and test period 2 to ensure that the chamber and house temperatures were comparable when each test commenced. The neighbouring building to the energy house (the conditioning void) was not heated during the test.

c) Stage 3 (Test period 2) – This test was undertaken to determine the performance of the existing wet central heating with the passive deaerator device installed and operational. During this test, the passive deaerator device was activated via the bypass loop and the same process identified within Test 1 was repeated.

A range of parameters were measured during each of the test stages. These were as follows:

a) Internal air temperature in the kitchen, hall, living room, bedroom 1, bedroom 2 and bathroom (°C). Measured at the geometric centre of each of the heated rooms.

b) Globe temperature in the kitchen, living room, bedroom 1, bedroom 2 and bathroom (°C). Measured at the geometric centre of each of the heated rooms.

c) Environmental chamber air temperature (°C).

d) Surface temperature at the geometric centre of each of the six radiators (°C).

e) Total heat output from each of the six radiators (kWh).

f) Total heat output from the boiler (kWh).

g) Total gas and electricity consumption of the boiler (kWh).

h) Flow and return temperatures from the boiler (°C).

i) Flow and return temperatures for each radiator (°C).

j) Flow rate to the boiler (l/min).

k) Flow rate from each radiator (l/min).

All of the above parameters were logged at one minute intervals. In addition, thermal images of each radiator were also taken during each of the tests.

4 Results and discussion of the passive deaerator tests

4.1 Air and globe temperature measurements

The internal room air and globe temperatures measured over each of the test periods are illustrated in Figures 1 & 2 and Table 1. Internal air temperatures were monitored to ensure that there was consistency in the internal conditions between the two separate test periods (test period 1 and test period 2). Globe temperature was also measured to ascertain whether the installation of the passive deaerator was likely to have any positive impact on the thermal comfort conditions experienced within the test dwelling.

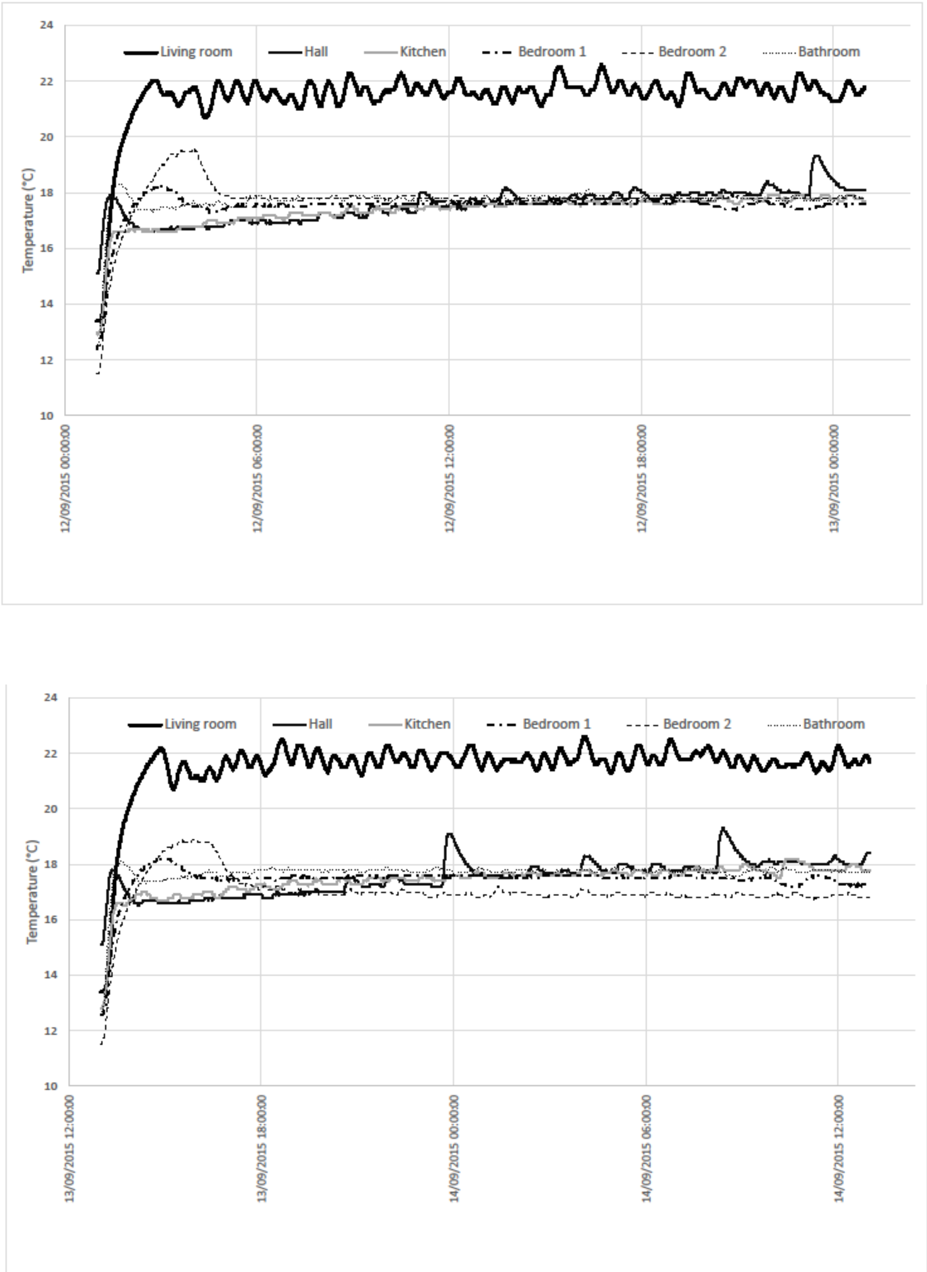
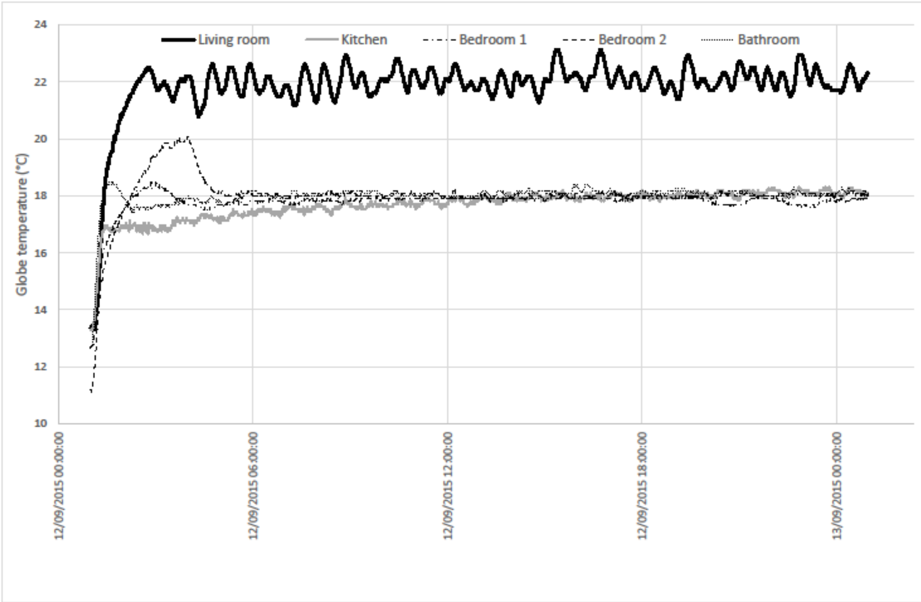


Figure 1. (a) Internal room air temperatures during test period 1; (b) internal room air temperatures during test period 2.



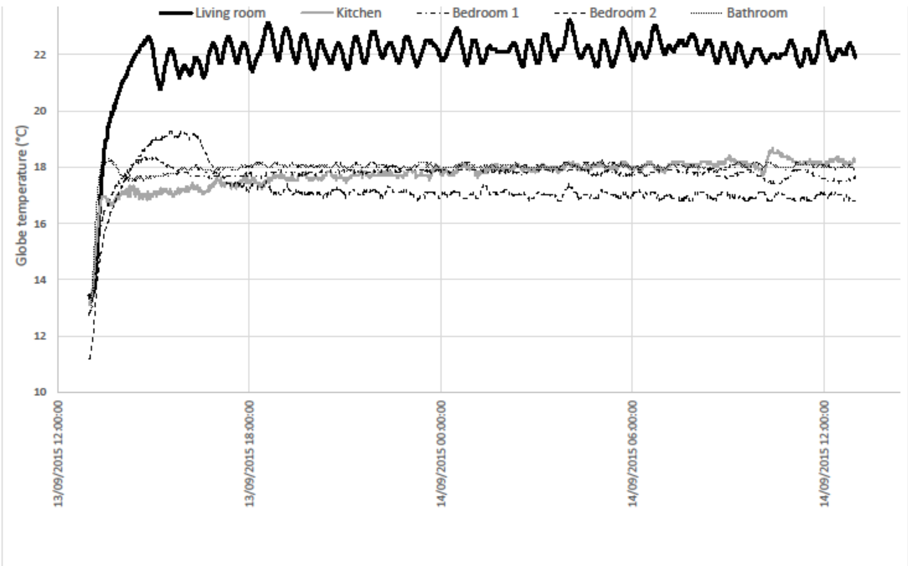


Figure 2. (a) Internal room globe temperatures during test period 1; (b) internal room globe temperatures during test period 2.

	Mean temperature (°C)			
	Air test period 1	**Air test period 2**	**Globe test period 1**	**Globe test period 2**
Living room	21.5	21.5	21.9	21.9
Hall	17.5	17.5	-	-
Kitchen	17.4	17.4	17.7	17.7
Bedroom 1	17.5	17.5	18.0	17.7
Bedroom 2	17.7	17.0	17.8	17.2
Bathroom	17.8	17.7	18.0	18.0

Table 1 Mean internal room air and globe temperatures over the test periods, accuracy = ±0.5 (°C).

It can be seen from Figures 1 & 2 and Table 1, that there is a high degree of consistency in the internal air and globe temperatures measured in each room between test period 1 and test period 2, with the exception of bedroom 2. In terms of bedroom 2, analysis of the data indicates a mean internal room air temperature difference of ~0.7°C between test period 1 and test period 2. Unfortunately, it was only once the tests were complete, that this difference in air temperature was discovered. Thermal images of the bedroom 2 radiator undertaken after completion of the tests with the space heating system switched back on revealed an uneven surface temperature distribution, with the bottom of the radiator being almost 30°C warmer than the top of the radiator (see Figure 3). Investigations revealed that this difference in temperature was caused by an air pocket which had lodged in the top of the radiator. Once the radiator had been bled, the surface temperature of the radiator increased and the heat became more evenly distributed (see Figure 3). The reason for the existence of the air pocket within the radiator during test period 2 is thought to have been caused by a ‘micro leak’ through a loose radiator bleed valve supporting nut that was observed on the end of the radiator. Unfortunately, the reasons why the air entered the radiator in test period 2 rather than in test period 1, is not known and could not be established using the non-destructive testing methods available to the research team during the testing periods. The micro leak appeared to occur between the first and second hours of test period 2. As the passive deaerator device was the only variable that had altered between the two test periods, it suggests that the process of deaeration may be responsible, possibly due to the reduction in pressure in the system.

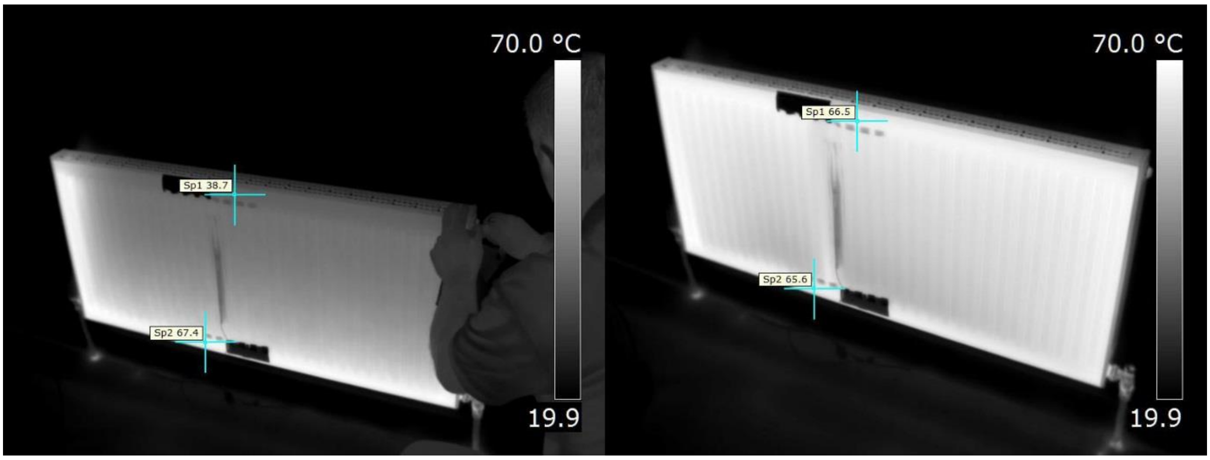


Figure 3 Thermal image of bedroom 2 radiator post testing pre (left) and post bleeding (right).

The impact that the slightly lower air temperature recorded in bedroom 2 has had on the comparability of the two test periods is likely to be minimal for four reasons. First of all, the difference in the air temperature measured between each test period is small (average of ~0.7°C). Secondly, bedroom 2 represents only a small proportion of the overall dwelling floor area and volume, therefore any difference in air temperature experienced within this room will have minimal impact on the air temperatures experienced throughout the rest of the dwelling. Thirdly, as all of the internal doors were open during both test periods, there will have been some movement of air between the rooms which will have reduced the impact that the slightly lower surface temperature of the radiator in bedroom 2 will have had on the test. Finally, although there was air within the radiator during test period 2, the top of the radiator was still able to obtain a surface temperature of ~39°C during the test, so heat will still have been provided to this room, although at a reduced rate.

To investigate whether the small difference in the internal air temperature measured within bedroom 2 during test period 2 is likely to be important, the internal room air temperature data have also been used to devise a simple arithmetic mean internal air temperature for the dwelling. This data reveals very little difference (mean of 0.12°C over the entire test period) between the mean internal air temperatures experienced during each test period. If the temperature data are used to produce a floor area weighted mean internal air temperature for each test period (see Figure 4), then the difference reduces even further (mean of 0.05°C over the entire test period).

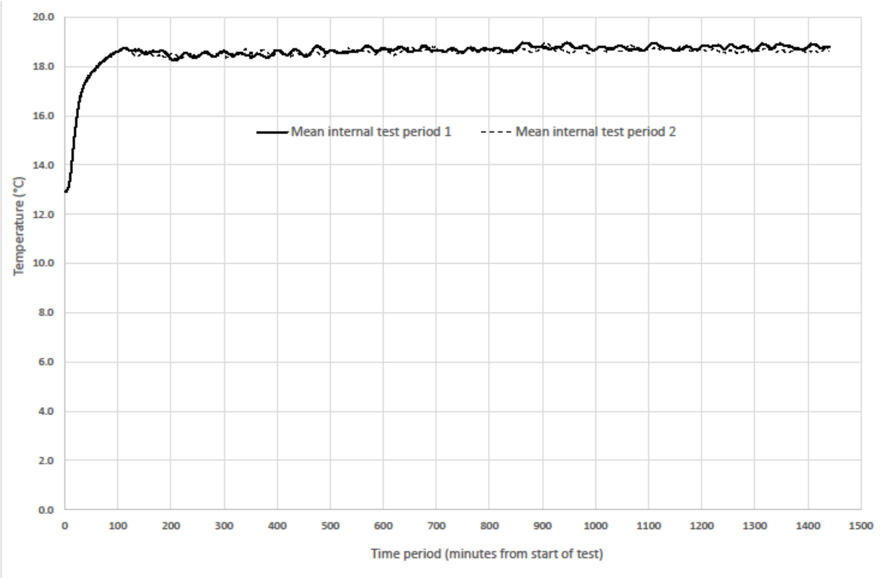


Figure 4. Mean floor area weighted internal air temperature during test periods 1 and 2

In addition to internal air temperature measurements, the air temperature in the chamber surrounding the house was also measured at three separate locations (the front, rear and gable wall of the test dwelling) over both test periods. The measurements revealed a high degree of consistency in the chamber air temperatures between test period 1 and test period 2 (see Table 2). In addition, if the three separate chamber air temperatures are used to produce a simple arithmetic mean chamber air temperature for each test period and the results compared (see Figure 5), there is very little difference in the air temperatures measured between each test period.

	Mean air temperature (°C)	
	Test period 1	**Test period 2**
Front	3.5	3.5
Gable	2.8	2.8
Rear	2.5	2.5

Table 2 Mean external chamber air temperature over the test periods, accuracy = ±0.5 (°C)

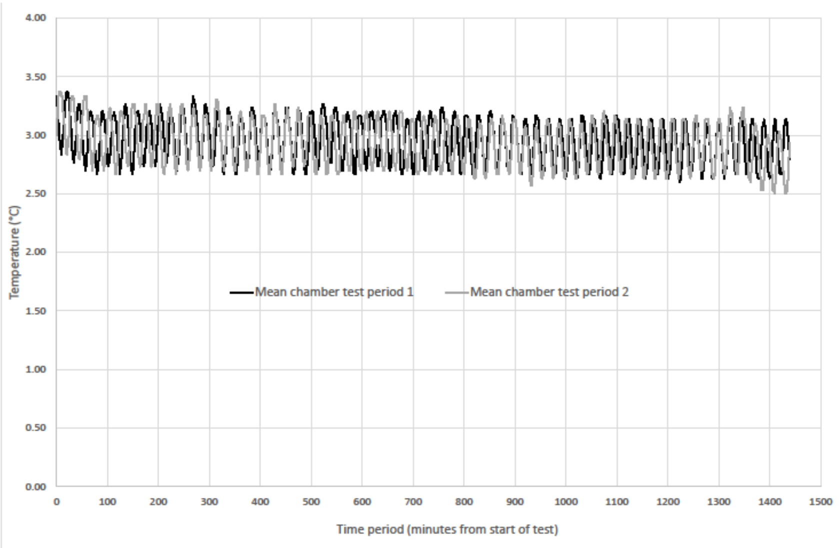


Figure 5. Mean external chamber air temperature during test periods 1 and 2.

In summary, the analysis of the internal room and external air chamber temperature data reveals that despite the existence of air within bedroom 2 radiator during test period 2, both tests were undertaken under very similar internal and external temperature conditions. This means that it is possible to directly compare the surface temperature and gas consumption figures for both test periods with one another without any corrections having to be made to account for differing conditions within each test period. Having said this, it is an important observation that the use of deaerators without proper commissioning may result in micro leaks that could affect the performance of some radiators. This could have been mitigated against during the testing if thermal images of the radiators had been undertaken once the test was running.

4.2 Radiator surface temperatures

In addition to the air and globe temperatures, the surface temperature at the geometric centre of each radiator was measured over each test period. As the surface temperature of the radiator will be dependent upon the temperature of the water entering the radiator, which is controlled by the electronic TRV, along with the amount of heat lost to the room (this should be the same between each test period as the ΔT between the inside and outside is the same), then it would be expected that there would be little variation in the surface temperatures measured between each test period. However, the data reveal that there are some small variations in the surface temperatures measured across all of the radiators between each test period. Excluding bedroom 2, where the surface temperature of the radiator is consistently lower during test period 2 due to the existence of the entrapped air, this variation in surface temperature is most noticeable in the living area and the hall (see Figures 6 and 7).

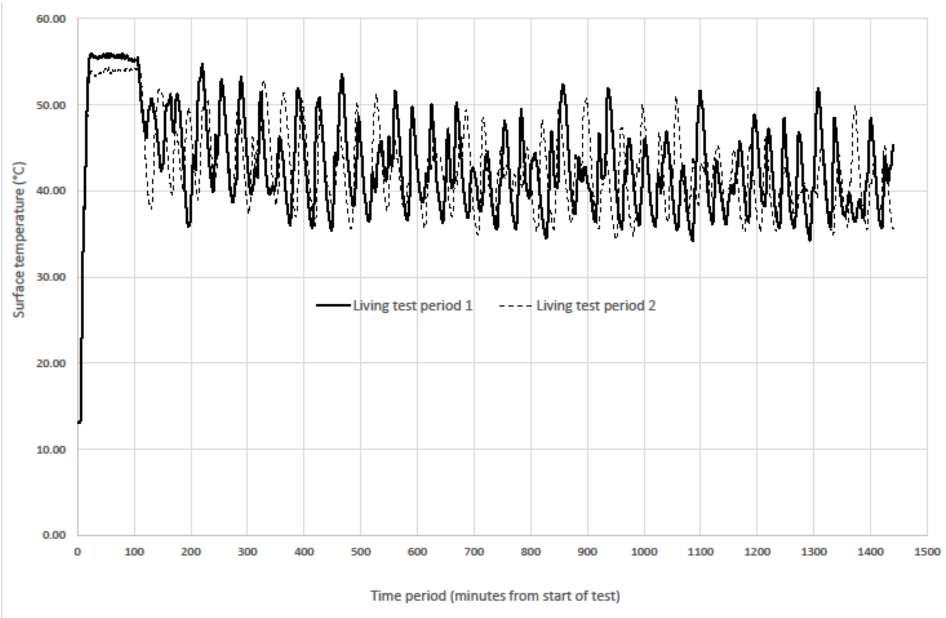


Figure 6. Surface temperature of the living room radiator

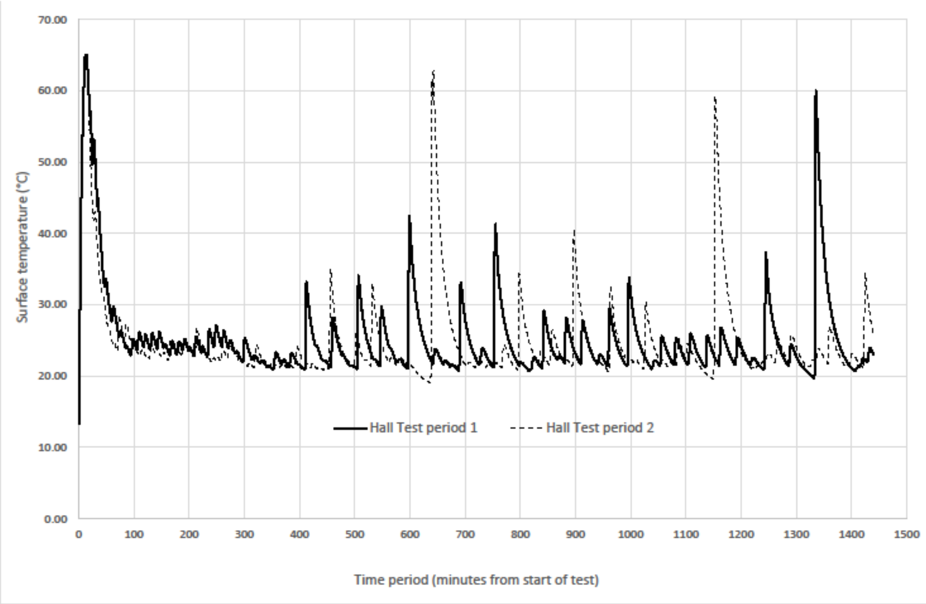


Figure 7. Surface temperature of the hall radiator

If the surface temperatures measured during each test period are used to devise an aggregate mean internal surface temperature for each radiator over each test period (see Table 3), it is clear that the difference between the aggregate figures is marginal for the living area, hall, kitchen and bedroom 1 and no difference was observed for the bathroom. As expected, there is a much larger and significant difference in the surface temperature of the radiator in bedroom 2, where the average difference in aggregate temperature was 5°C. Despite this difference in surface temperature, the radiator in this bedroom still maintained a mean surface temperature of 32.5°C during test period 2, so still made a contribution to heating this room. In addition, the radiators in the living area, hall, kitchen and bedroom 1 all managed to maintain the air temperature within these rooms at the same level as was obtained in the baseline test period 1, despite a very slight reduction in surface temperature when the deaerator was active in test period 2.

	Mean surface temperature (°C)	
	Test period 1	**Test period 2**
Living	43.2	42.8
Hall	25.2	24.9
Kitchen	25.3	24.8
Bedroom 1	39.3	38.8
Bedroom 2	37.5	32.5
Bathroom	28.2	28.2

Table 3 Mean surface temperature of radiators over the test periods, accuracy = ±0.5 (°C)

4.3 Heat output from the radiators

Total heat output from all six radiators was measured using an EN 1434 MID approved heat meter with class 2 measurement accuracy. This device is calibrated to measure the heat output from the radiators when naturally aerated water is circulated around the wet central heating system. As the passive deaerator device is designed to remove dissolved gases from the circulating hot water, the reduction in these gases will result in an increase in the specific heat capacity of the water within the central heating circuit and therefore there may be some discrepancies in the actual temperatures and those being recorded when the deaerator is in operation.

One of the limitations associated with the test was the fact that it was not possible to either measure the specific heat capacity of a sample of the central heating circuit water following test period 2, or measure the amount of dissolved gas removed from the central heating circuit. Consequently, it is not known what change in the specific heat capacity of the water, if any, is likely to have occurred during test period 2. If the specific heat capacity of the water did increase, then the heat meters will underestimate the amount of heat delivered, i.e. test period 2 may actually be using more heat than was actually measured. Therefore, caution should be exercised when considering the results discussed below, as it has not been possible to make any corrections to the recorded heat meter readings. Despite this limitation, measurements undertaken by Jessel[30] suggest that any change to the specific heat capacity of the water is likely to only be very small.

The total heat output from each the individual radiators for each test period is illustrated in Figure 8. It is clear that during test period 2, less heat is output from the radiator located in bedroom 2 (as to be expected due to the entrapped air pocket), but there is also very slightly less heat output from the radiators located in the kitchen, bedroom 1 and the hall. This is noteworthy since the kitchen is directly below bedroom 2, and bedroom 1 is linked to bedroom 2 via the hall radiator and may have been anticipated to have higher outputs in Test 2 to compensate for the slight reduction in the heat output from the radiator located in bedroom 2. The marginally lower heat output from these radiators coincides with the slightly lower surface temperatures recorded for these radiators.

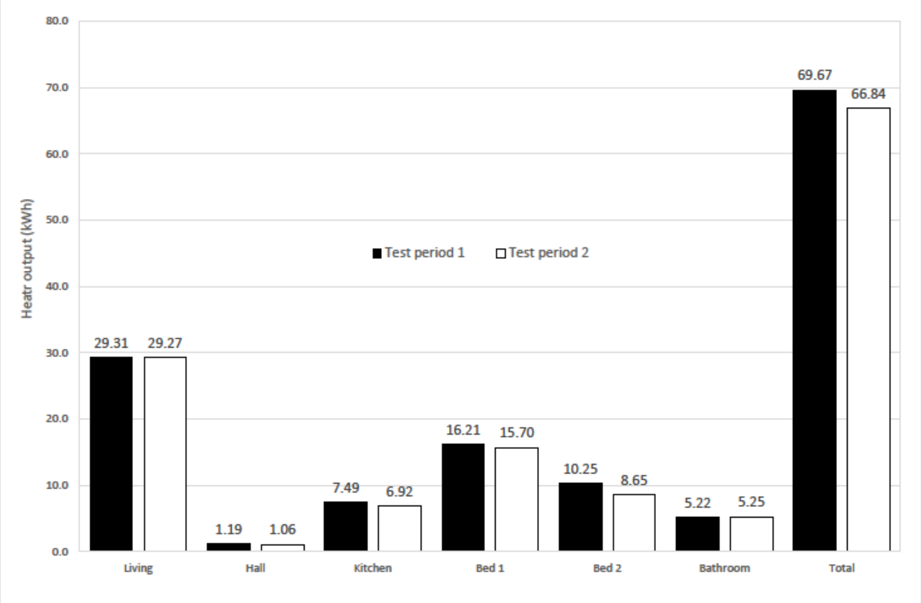


Figure 8. Heat output from each of the radiators.

An analysis of the flow and return temperatures and the flow rates associated with these radiators was also undertaken. This revealed that in the kitchen and bedroom 1, there was no noticeable difference in the flow and return radiator temperatures or the flow rates between the two test periods. However, in the hall, although no difference in the flow rates was measured between the two test periods, there were some distinct periods where the flow and return temperatures varied considerably between the two test periods. This is illustrated in Figure 9.

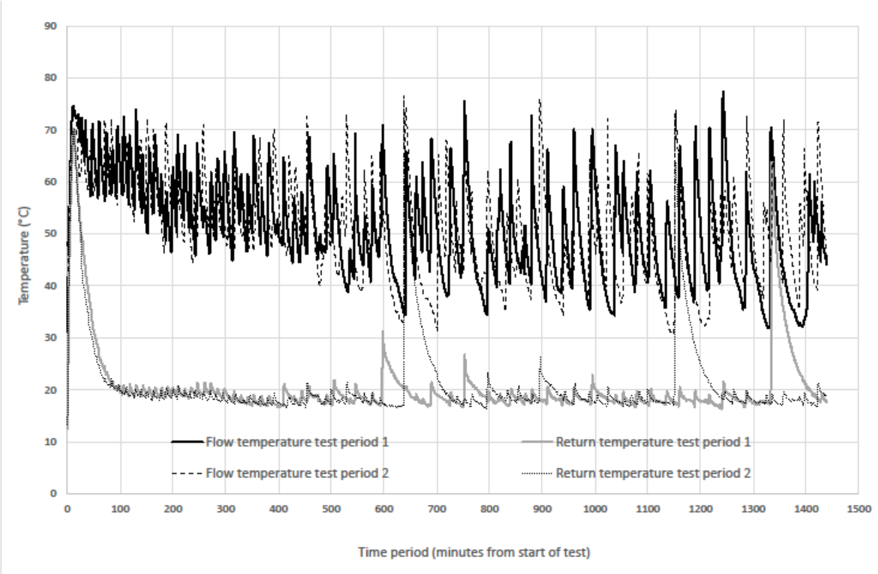


Figure 9. Flow and return temperatures for the hall radiator during test periods 1 and 2.

Overall, the aggregate reduction in the heat output from the radiators in test period 2 is 2.8 kWh less than that measured during test period 1 (representing a reduction of 4%). Although a significant proportion of this reduction (more than half; 1.6 kWh) can be attributed to the lower output from the radiator located in bedroom 2, these reductions in heat output have been achieved without any comparable difference between the air temperatures measured between the two test periods.

4.4 Heat output from the boiler

Total heat output from the boiler was also measured using an EN 1434 Class 2 MID approved heat meter. As previously discussed in Section 4.3, caution should be exercised when interpreting the results discussed below due to the potential inaccuracies associated with measuring heat flow when the passive aerator device is operating.

In terms of the total heat output from the gas-fired condensing combination boiler, during test period 1 the heat output was 91.9 kWh and during test period 2 the heat output was marginally lower at 88.7 kWh. This represents a difference in heat output of 3.2 kWh (3.5%) between these two test periods. Almost all of this heat (2.8 kWh) can be attributed to differences in the heat output from the radiators between the test periods. The remaining 0.4 kWh of heat, representing ~0.5% of the total measured, can be attributed to a reduction in heat output from the boiler.

4.5 Total electricity and gas consumption of the boiler

The electrical consumption of the boiler was measured using a DIN rail mounted electricity meter with an active energy accuracy of class B (Cl. 1). This revealed no difference in the boiler electricity consumption between test period 1 and test period 2. In terms of gas consumption, the total amount of gas used by the gas boiler was also measured. The gas consumption in m^3 was converted to kWh using a standard calorific value for natural gas and a default correction factor(31). During test period 1, the total amount of gas used by the boiler was 115.7 kWh, whilst for test period 2 it was 115.1 kWh, representing a difference in gas consumption of 0.5%. However, given that at domestic temperatures the accuracy of this meter can be +/- 1%(32), then this difference may just be a result of measurement noise. If these figures are combined with the total delivered heat output figures for the boiler, then a simplified gas boiler efficiency can be determined for each test period. This has been achieved by dividing the total heat output figure for the boiler in kWh by the total gas consumption of the boiler in kWh. During test period 1, the efficiency of the boiler was calculated as being 79.4% and during test period 2 the efficiency of the boiler was slightly lower at 77.0%. This suggests that the installation of the passive deaerator device has had a small detrimental impact on the efficiency of the gas-fired combination condensing boiler.

A closer analysis of the measured data has also been undertaken to determine the possible reasons for the reduction in the efficiency of the boiler. This analysis indicates that when the passive deaerator device is operating, the heat output is more variable and there are a number of large spikes in the heat output that do not occur when the device is bypassed (see Figure 10). In the majority of cases, these spikes in heat output correspond with the higher surface temperatures measured in the hall (see Figure 7). Another interesting observation from the data is that the majority of the lower heat output points also occur when the passive deaerator device is operating. This suggests that the boiler is switching on and off more frequently (short cycling) when the passive deaerator device is used. Short cycling the boiler will have an adverse effect on the efficiency of the gas boiler and on gas consumption. Hence, this could explain the reason why the boiler is slightly less efficient when the passive deaerator device is operating.

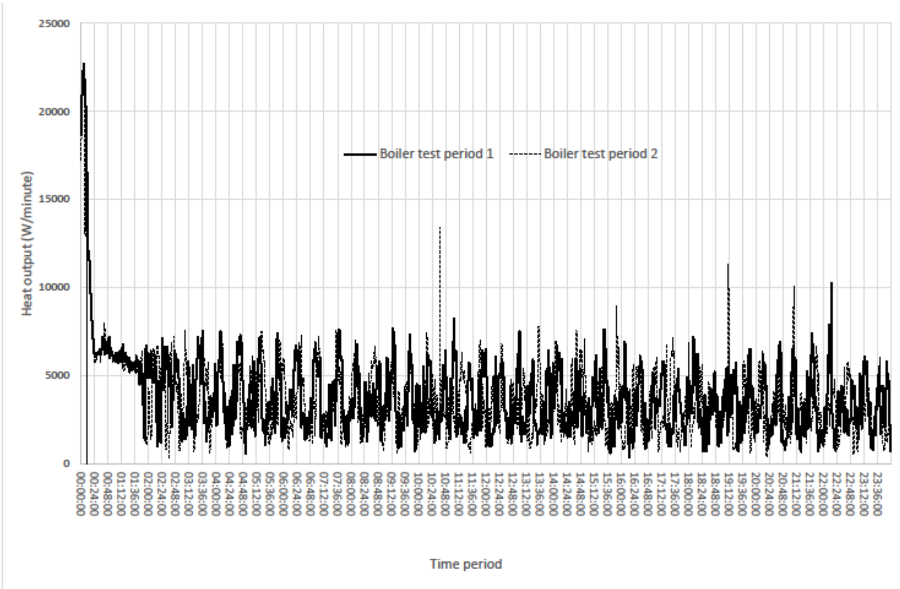


Figure 10. Heat output from the boiler during test periods 1 and 2

An analysis of the boiler flow and return temperatures and flow rates has also been undertaken. This reveals that when the passive deaerator device is operational, there is no obvious difference in the flow rates from the boiler. Although there are some very subtle differences in the flow and return temperatures between each test period (see Figure 11), overall the mean flow and return temperatures for each test period are within ~0.5°C of one another. This suggests that although the boiler appears to short cycle more frequently when the passive deaerator device is functioning, this does not manifest itself in a difference in the flow temperatures or flow rates from the boiler.

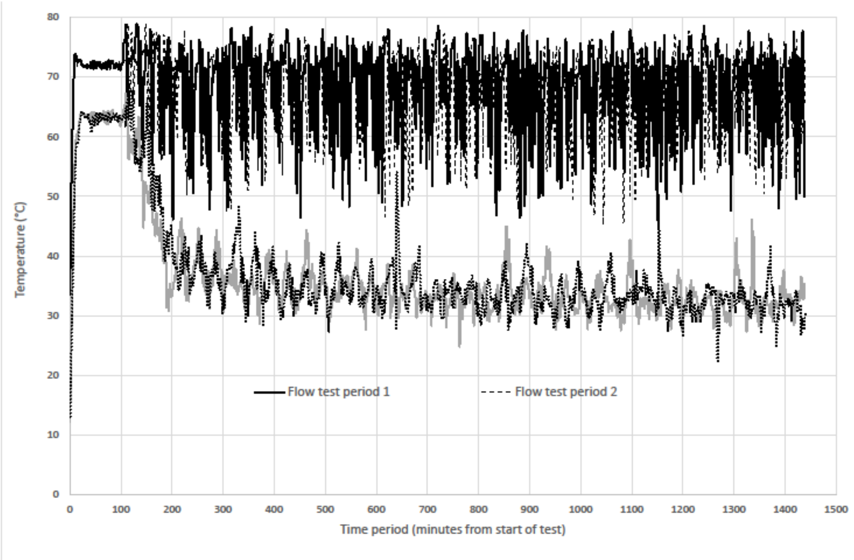


Figure 11. Flow and return temperatures from the boiler during test periods 1 and 2.

5 Conclusions

This report has outlined the results of a series of directly comparable *in situ* tests undertaken on the space heating system installed within the Salford Energy House under controlled conditions. The aim of these tests was to quantify the energy savings that are likely to be achieved by installing a passive deaerator on the closed loop of a wet central heating system. The results reported are thought to be equally applicable to new build dwellings or existing dwellings where the central heating system has been drained down, flushed and re-filled as part of the passive deaerator installation process. However, it should be noted that a degree of caution is required when interpreting the heat output results obtained from the heat meters when the passive deaerator device is operational, as it is not known what impact the device has on the accuracy of the heat flow measurement. In addition, the results are based upon two constant space heating test periods only – one with and one without the passive deaerator device operational. Further testing should be undertaken to establish whether the results reported within this paper can be replicated under a much wider range of space heating regimes.

Analysis of the data obtained has revealed that although there were some very small differences in one of the individual room temperatures measured between the tests (bedroom 2), caused by entrapped air within the radiator, the scale of the temperature difference was such that it was felt to have a negligible impact on the overall test results. Consequently, it has been possible to directly compare the results obtained from test period 1 with those obtained from test period 2.

Most importantly, the measurements revealed that although a marginally lower boiler heat output was required (3.5%) to maintain very similar internal temperature conditions when the passive deaerator device was operational, this reduction in heat output does not necessarily translate into a corresponding reduction in overall gas consumption for the boiler. The reason for this appears to relate to the fact that when the passive deaerator device is operating, the boiler short cycles more frequently, and in doing so, is slightly less efficient (result in a reduction in efficiency of ~2.5%). In consequence, any small reductions in overall heat output from the boiler that are obtained when the passive deaerator device is operational are more or less out weighted by the fact that the boiler is producing heat less efficiently. Therefore, the overall reduction is gas consumption achieved by utilising the passive deaerator device is only of the order of 0.5%. This figure is so small that it is not possible to be confident that this represents an actual reduction in gas consumption that can be attributed to the installation of the passive deaerator device. Instead, it may simply be a consequence of measurement noise.

This paper has also highlighted some important lessons to be considered when installing and testing passive deaerators in the field. For instance, any comparisons need to be undertaken on a like-for-like basis to ensure that the savings achieved can be confidently attributed to the installation of the device rather than any other variables that may have changed after the installation of the device. In addition, checks should also be undertaken to ensure that the system is properly commissioned once the passive deaerator is installed to ensure that there are no micro leaks in the system that could have an adverse effect on the performance of the radiators. These checks could involve undertaking thermal images of all of the radiators once the central heating system is running to ensure that there are no cold spots in any of the radiators installed within the test dwelling.

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