ASSESSING THE ENERGY SAVINGS FROM ADVANCED ROOM THERMOSTAT CONTROLS IN A WHOLE HOUSE TEST FACILITY

October 2021

SUMMARY

A series of tests were carried out to establish the energy saving benefits of two types of advanced room thermostats that comply with the temperature control classes specified in the Energy Labelling Regulations for Space and Combination Heaters:

- **Directly Modulating Room Thermostats using either load or weather compensation (Class V and Class VI).**
- **Room Thermostat with proportional on/off load compensation (Class IV)**

The tests were carried out independently by the University of Salford and commissioned by the BEAMA Heating Controls group, the UK association for manufacturers of controls used in residential buildings, together with the OpenTherm Association

The tests were set up to measure the amount of energy used by a gas-fired heating system with radiators running for a seven-hour period when compared to the same system using a standard on/off (Class I) room thermostat. Two phases of tests were carried out to look at both standard retrofit and an ideal new boiler installation.

The results of the tests are summarised below:

Phase 1 tests: a room thermostat replacement as a standard retrofit upgrade.

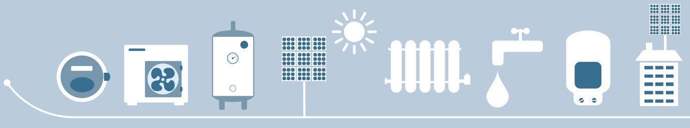
Room thermostat type compared against baseline (Class I)	Energy savings measured in tests		Energy savings estimated for a typical annual UK heating season
	Winter test (outside temperature 4.2°C)	Spring test (outside temperature 8.9°C)	
Class IV	**11%**	**9%**	**10%**
Class V	**15%**	**9%**	**12%**

Phase 2 tests: a room thermostat replacement in addition to a replacement boiler installed with detailed sizing, commissioning and system balancing.

Room thermostat type compared against baseline (Class I)	Energy savings measured in tests		Energy savings estimated for a typical annual UK heating season
	Winter test (outside temperature 4.2°C)	Spring test (outside temperature 8.9°C)	
Class IV	**2%**	**6%**	**4%**
Class V	**8%**	**7%**	**8%**
Class VI	**2%**	**7%**	**5%**

Conclusions

- Installing a Directly Modulating Room Thermostat as a direct replacement for a standard room thermostat in a central heating system can reduce the gas used for heating by 12% over the heating season.
- Installing a room thermostat with proportional on/off load compensation as a direct replacement for a standard room thermostat can reduce the gas used for heating by 10% over the heating season. This can be used where lack of communications precludes the installation of a Directly Modulating Room Thermostat.
- Thorough boiler commissioning and system balancing was observed to have a significant beneficial impact on the operation of a heating system. This is expected to improve the baseline efficiency of the system, but all the controls tested (Class IV, V and VI) will provide additional savings.
- All the advanced room thermostats tested delivered more stable control of room temperatures when compared to a standard room thermostat and this should result in improved comfort for occupants.



SECTION A

Potential Energy Savings in Homes from Directly Modulating Room Thermostats

1. BACKGROUND

What is a Directly Modulating Room Thermostat and how does it reduce energy use?

1.1 The current situation with UK central heating systems

A typical layout of a UK heating systems is shown in Figure 1 below. Hot water from the boiler is pumped through the 'flow' pipework (shown in red) into radiators, which transfer heat from the water into each room. Water from the radiators, which is then at a slightly lower temperature, passes back through the 'return' pipework (shown in blue) into the boiler to be reheated and recirculated.

Due to the way that radiator systems have traditionally been designed in the UK, boilers are usually installed into systems with a flow temperature of around 75°C and a return temperature of around 65°C.

It is a requirement in the Building Regulations for homes to have a room thermostat fitted. This provides overall control of the temperature in the house when the heating is operating. In most cases this will be a 'Class I' room thermostat, as defined by the energy labelling regulations for boilers, which maintains temperature through simple on/off control of the boiler. With this type of control, the boiler is turned on until the room reaches the temperature that the thermostat is set at (the setpoint) and then turned off until the temperature drops back below the setpoint and so on. The thermostat does this by sending a simple 'on' or 'off' signal through its electrical wiring. The effect that this has over time on the flow temperature of the water from the boiler and the return temperature of the water going back into the boiler can be seen in figure 2.

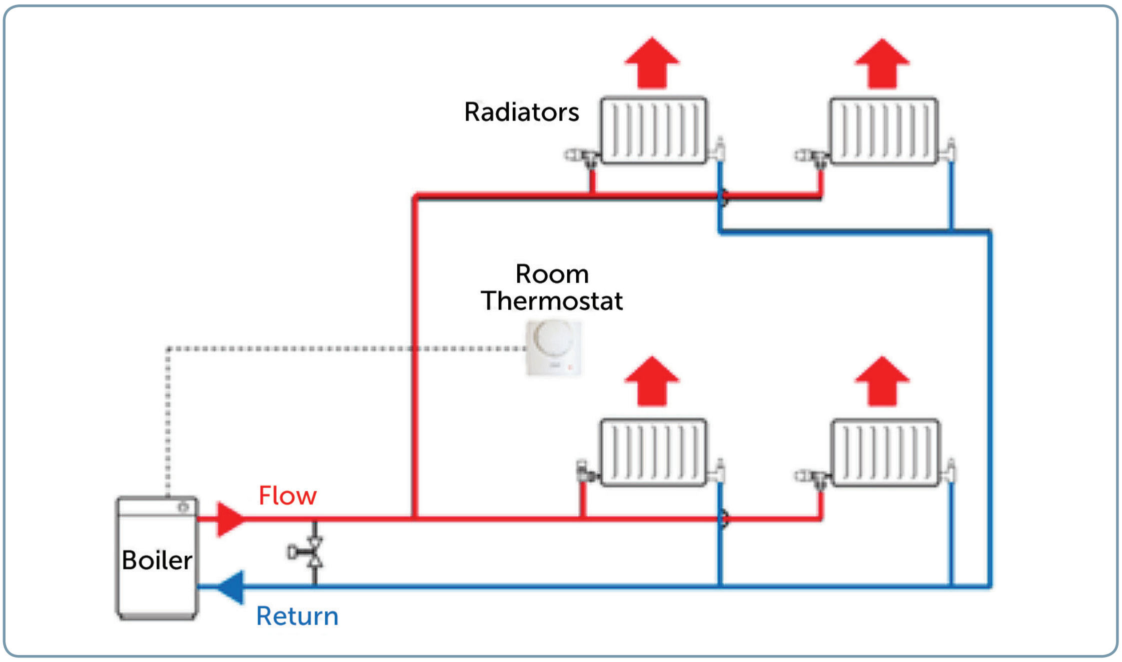


Figure 1: Schematic of a typical UK heating system

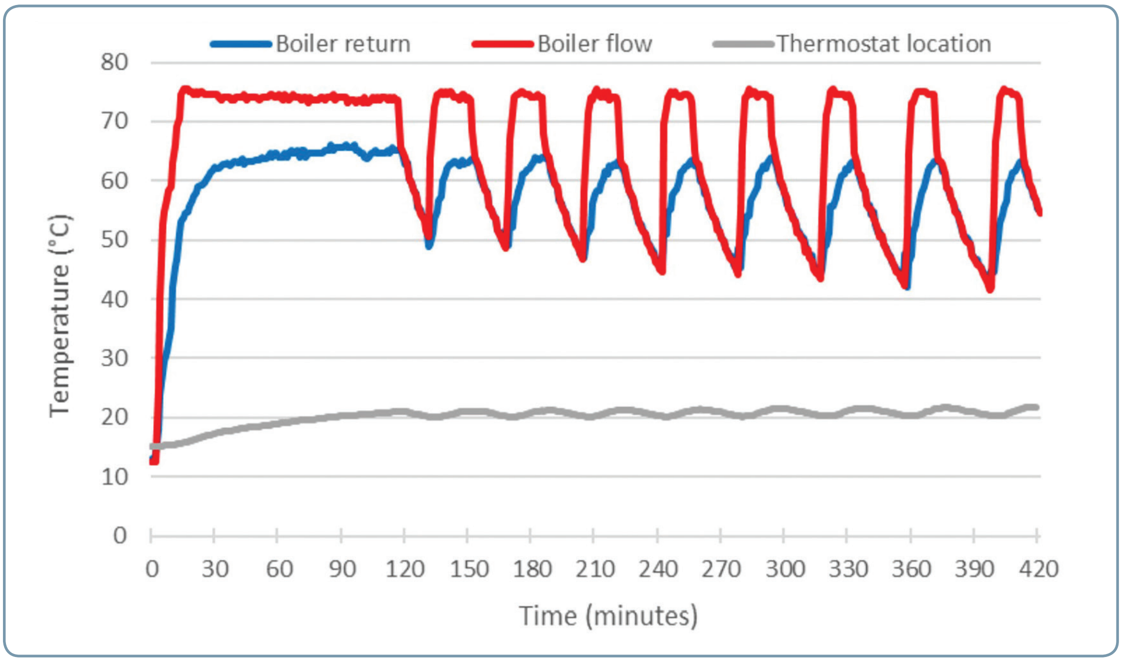


Figure 2: Temperature of water in the flow (in red) and return (in blue) pipework of a heating system over a 7-hour period when controlled by a Class I (on/off) room thermostat

This type of room thermostat remains widely used as it is familiar to installers and is effective at preventing wasted energy from overheating the house, which was traditionally the key function of a room thermostat. In fact, many 'smart' thermostats will be set up to control the temperature in this way while managing the overall operating hours of the heating system in a way that matches occupancy. However, modern technology is available that significantly improves the operation of a room thermostat so that the boiler itself uses less energy and the system maintains better comfort for the occupants.

1.2 How boiler fuel consumption can be reduced

1.2.1 Lowering the return temperature will improve boiler efficiency.

An efficient boiler will use less fuel to keep a building warm, so will have lower running costs. Boiler efficiency is measured as a percentage where an efficiency of 100% is the maximum.

The actual operational efficiency of a boiler once it is installed is directly related to the temperature of the water coming back to the boiler from the radiators. Modern boilers are known as 'condensing boilers' because the increase in efficiency is pronounced once the return temperature goes below 55°C and the boiler goes into 'condensing mode' as shown in figure 3.

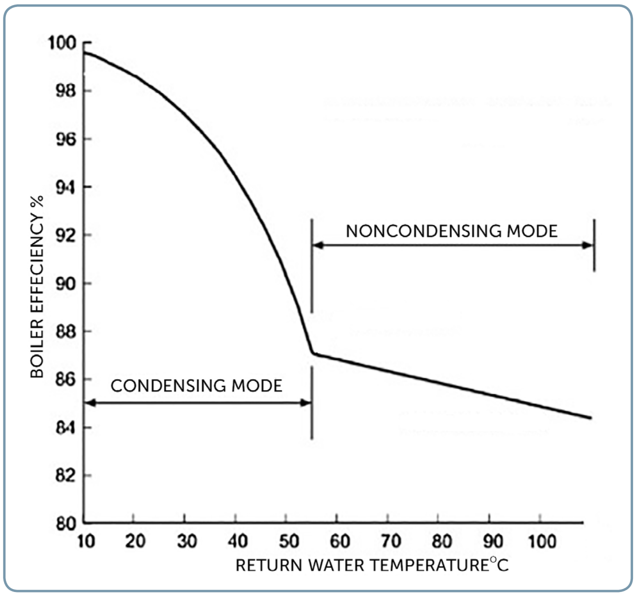


Figure 3: Effect of return water temperature on boiler efficiency

When a boiler is controlled by a Class I on/off thermostat as shown in figure 2 the return temperature will rarely be below 55°C so the boiler will spend little time in its more efficient condensing mode.

1.2.2 Turning down the boiler flow temperature will use less fuel.

Most modern boilers are also able to 'modulate', which means that they can adjust the burner rate to deliver a reduced flow temperature of water leaving the boiler. This means that the boiler effectively turns down its heat output to use less fuel.

This function is advantageous because, for most of their operation, boilers will operate at 'part load' where the amount of heat needed by the building is less than the maximum amount of heat that the boiler can provide. A boiler will need to have a large enough heat output to keep the building warm when the temperature outside is as cold as might be reasonably expected in Winter, for example -3°C in much of the UK. However, outside temperatures are actually much milder for all the months when the heating is likely to be on. For example, a boiler designed for a building at an outside temperature of -3°C would only need 69% of its output for average December temperatures, and only 48% for average temperatures in April.

In addition to this, many boilers are 'combination' boilers. These are selected for houses based on the output they need to deliver instantaneous hot water, which is often much higher than the output needed for even peak heating periods. As a consequence, the need for the boiler to modulate in its heating mode is even more pronounced.

A boiler is only able to modulate its output if it knows how much heat the building needs at a particular time. This is where sophisticated room thermostats can help.

1.3 Directly Modulating Room Thermostats and how they work

A Directly Modulating Room Thermostat will provide improved control of a boiler to ensure that it runs in condensing mode and modulates (as set out in section 1.2) whenever possible. This will minimise the amount of energy used by the boiler to provide comfortable living conditions.

They do this using one of two approaches:

Load compensation measures the internal temperature to work out how far it is from the setpoint and then communicates with the boiler to directly modulate the flow temperature of the boiler to provide just enough heat. The device may also learn from the building response over time to improve accuracy.

Weather compensation works similarly, except that it also monitors the outside temperature (either by a sensor or internet weather forecasts) and uses this information in its calculations.

Under the energy labelling regulations for boilers a Directly Modulating Room Thermostat using load compensation is a Class V room thermostat, and one using weather compensation is a Class VI room thermostat. The impact of these controls on the flow and return temperature of the heating system can be seen from figure 4, which should be compared directly with the same graph for a Class I thermostat shown in figure 2.

Figure 4 shows how a Directly Modulating Room Thermostat with load compensation control will allow high flow temperatures at the start to get the room up to the setpoint temperature in a reasonable timescale. It then communicates with the boiler to directly modulate the flow temperature down to just the level it needs to be to maintain the setpoint temperature. At the same time, the return temperature is kept low throughout so that the boiler stays in its efficient condensing mode.

Maintaining a lower temperature for longer periods is also helpful in delivering a more consistent room temperature that can improve occupant comfort.

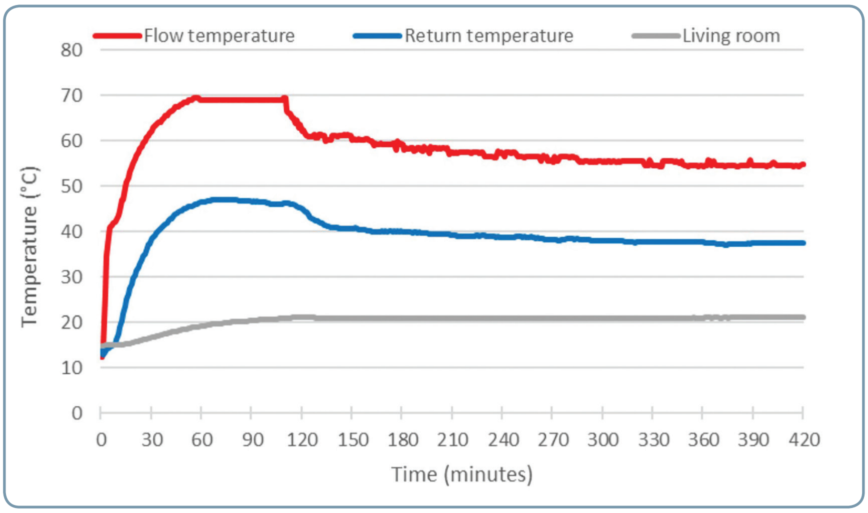


Figure 4: Heating flow (in red) and return (in blue) temperatures over a 7-hour period when controlled by a Directly Modulating Room Thermostat

2.

Tests to establish the Energy Savings from Directly Modulating Room Thermostats

The BEAMA Heating Controls group commissioned research to be carried out independently by the University of Salford in their Energy House facility to assess and compare the energy saving potential of Directly Modulating Room Thermostats. The advantage offered by the Energy House is that it allows for the effect of heating controls to be robustly measured without the need for theoretical assumptions as it is effectively a real house with a real heating system within a laboratory.

2.1 The Salford Energy House test facility

The Salford Energy House is a full-sized test house, built within an environmental chamber. It is a test facility that bridges the gap between laboratory-based product testing and outdoor field trials, which may or may not include occupants. The house is a traditionally constructed Victorian end-terraced building, with a conditioning void to represent a neighbouring property. It has a wet central heating system with radiators fed by a gas condensing combination boiler. All of this can be changed to suit the testing requirements. The house is a traditional UK 'two-up, two-down' Victorian solid wall property of a type that currently number approximately 6.6 million in the UK.

The external environment surrounding a dwelling makes a significant difference to how much energy is required to heat the building. The chamber can recreate a range of external weather conditions: Temperature can be controlled from -12°C to +30°C (with an accuracy of ±0.5°C). This controlled environment allows for consistent temperatures to be used, which is particularly useful for validating approaches such as whole house heat tests.

The Salford Energy House test facility

2.2 Test methodology

The control types tested were based on the defined temperature control classes in the EU Energy Labelling regulations[1] for boilers, as used elsewhere in this report to distinguish between room thermostat types.

2.2.1 Test set-up

Each test ran for seven hours, which is consistent with the usual UK heating pattern for afternoon/ evening and the SAP calculation methodology[2]. Each control under test was set to maintain a

---

[1] Commission Delegated Regulation (EU) No 811/2013 supplementing Directive 2010/30/EU of the European Parliament and of the Council with regard to the energy labelling of space heaters, combination heaters, packages of space heater, temperature control and solar device and packages of combination heater, temperature control and solar device

[2] https://www.bregroup.com/sap/

temperature of 21°C in the living room and were positioned at the same location within the living room at a height of 1.2 m from floor level on an internal partition wall. The temperature of other rooms was maintained by Thermostatic Radiator Valves set to maintain 18°C; again consistent with SAP.

All control types were tested at two different 'outside' temperatures, maintained within the environmental chamber. The first was a 'Winter' test at 4.2°C outside, which is average UK temperature in December. The second was a 'Spring' test at 8.9°C outside, which is the average UK temperature in April. Both temperatures were taken from SAP.

A set-back temperature of 15°C was selected for the intervening period between tests. This was to ensure repeatability between test periods, by providing similar internal conditions at the beginning of each test, and to maintain a state of dynamic equilibrium across the test programme. Thermostatically controlled electric resistance heaters were used for this purpose.

2.2.2 Baseline

The baseline test was on a Class I control, which is a standard on/off room thermostat.

2.2.3 Control types tested

Comparative tests against the baseline were carried out using a Class V room thermostat with load compensation and a Class VI room thermostat with weather compensation. Both these controls are Directly Modulating Room Thermostats[3] and communicated with the boiler using the OpenTherm communication protocol[4].

2.2.4 Monitoring

The Energy House test facility monitoring system was used to record the following:

- Air temperature measured at the geometric centre of each room, at the location of the room thermostat controller in the living room, and within the environmental chamber.
- Metered gas consumption.
- Boiler energy output.
- Boiler flow and return temperature.
- Boiler electricity consumption.
- Flue gas temperature.

2.3 Test phases

Tests were carried out in two phases.

Phase 1 was based around the scenario of a control replacement in an existing house and a typical installer simply replacing a Class I on/off room thermostat with a Class V or Class VI Directly Modulating Room Thermostat. No additional advice or support was provided to the installer other than that available through usual guidance. No specific commissioning or balancing of the system was specified other than what might be expected under normal installations.

Two issues were identified with the tests. Firstly, the Class VI tests did not maintain comparable room temperatures and so were unable to be compared to the baseline. This was due to set up issues and is explained further in section 4.1. Secondly, the modulating controls were reverting to on/off control in the Spring tests where there was a lower heat load. This is explained further in section 4.3. To overcome these issues a second phase of tests was commissioned.

Phase 2 was based around the scenario of a boiler replacement in an existing house carried out by an installer with specific training on and experience with compensation controls, and who would spend more time on commissioning and balancing the system in accordance with best practice to optimise performance at low heat loads. To this end BEAMA funded a specialist installer to work with and support the University of Salford during the tests.

---

[3] The overall test regime also included Class IV room thermostats and the results of these are covered in section C.

[4] https://www.opentherm.eu/opentherm-protocol/what-is-opentherm/

2.3.1 Additional set up and commissioning work carried out in phase 2

In line with the phase 2 scenario the installation was reviewed and the following work was carried out:

The existing Ideal Vogue Gen2 32 kW combination boiler (7:1 turndown ratio[5]) in the Energy House, while not considered an unrealistic scenario in real life, was deemed to be oversized and replaced with an Intergas Xclusive 24 kW combination boiler (7:1 turndown ratio).

A boiler expert undertook the following work prior to the commencement of the test programme:

- The FBES Heating System Review document (undertaken October 2019) was reviewed and the building heat loss recalculated at 4.2°C & 8.9°C external conditions to see if the system was capable of lower flow temperatures than the report stated. 70/50 (60C radiator MWT) was deemed acceptable. 70/50 is the maximum recommended design temperature for condensing boilers in accordance with the CIBSE Domestic Heating Design Guide.
- The boiler was range rated to the properties calculated heat loss at -3C (circa 8kW).
- Using the mass flow rate calculation kW/(SHC*System Temp Differential) the maximum & minimum boiler flow rates were calculated and pump speeds were adjusted to obtain the correct flow rates in litres/hour. This included consideration of pressure drops across the heat exchanger and system pipework/radiators.
- The boiler parameters were adjusted to match the Salford Energy House attributes, in terms of burner anti-cycle times and the modulation controls' ability. The boiler flow temperature was electronically restricted to 70C max.
- The radiators were balanced to ensure 20C ΔT when the room temperatures were at their respective design temperatures.
- The system was operated to check performance and ensure all zones achieved required temperature setpoints (as specified by SAP). Radiator flow rates were adjusted where large temperature drops across the pipework were affecting the Mean Water Temperature (MWT) of the radiators.

---

[5] The turndown ratio, also known as the modulation ratio, is a measure of the degree to which a boiler can reduce its heat output. For example, a 7:1 ration means that the boiler can turn down to 1/7th of its maximum heat output.

3.

Test results

3.1 Phase 1 results – Impact of Directly Modulating Room Thermostats

Class	Control type	Gas savings (kWh)		Mean living room temperature (°C)	
		Winter	Spring	Winter	Spring
I	**On/off room thermostat**	**-**	**-**	**21.3**	**21.9**
V	**Directly Modulating Room Thermostat (load compensation)**	**15%**	**9%**	**21.7**	**21.9**
VI	Directly Modulating Room Thermostat (weather compensation)	23% (Unverified)	19% (Unverified)	19.0	18.0

Table 1: Comparative tests of Class V and Class VI controls against a baseline Class I test in phase 1

The results for Class VI are marked as unverified because comparable room temperatures were not achieved (see below). Analysis of calculated boiler efficiencies is covered in Appendix 1.

Conclusions

- The Class V thermostat delivered significant energy savings compared to the Class 1 on/off room thermostat while maintaining similar mean living room temperatures.
- The Class VI thermostat also showed significant savings but failed to match the mean living room temperatures. This was due to set up issues and is explained further in section 4.1.

3.1.1 Estimate of seasonal savings from the Class V Directly Modulating Room Thermostat

The Class V control reduced boiler gas consumption by 15% in the 'Winter' tests and 9% in the 'Spring' tests compared to the Class I room thermostat. The impact of the control in terms of maintaining a low return temperature and modulating the boiler (the factors affecting boiler fuel consumption as described in section 1.2) can be seen in figure 5 below:

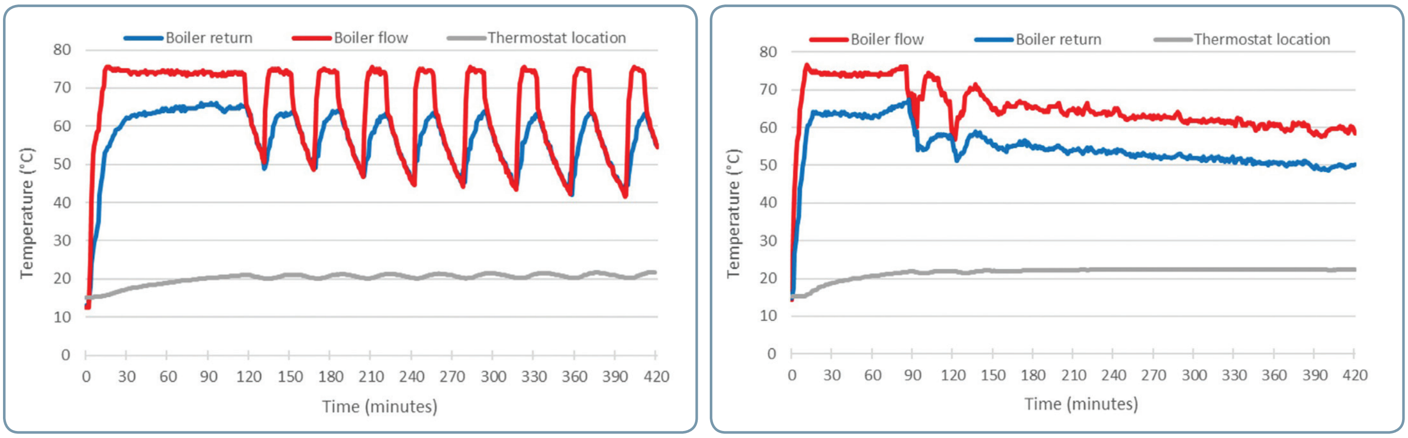


Figure 5: Graphs of Flow and return temperature for Class I (left) and Class V (right) in Winter tests

An estimate of the energy saving potential across the course of a typical heating system was carried out by plotting the two measured test results, together with a third point at the design outside temperature (-3°C) where, theoretically, the boiler would be working at full capacity and no savings would be possible. In practice there would still be savings at -3°C outside as the boiler is still oversized (as covered in section 1.2.2) but this means that the limited data graph is likely to underestimate rather than overestimate the seasonal savings.

The graph produced by this is shown in Figure 6, and the potential savings for each month taken from this graph are shown in Figure 7. The average outside temperature for each month of the heating season is taken from the SAP calculation methodology[6].

This analysis gives the estimated heating energy saving over the course of the heating season as **12%.**

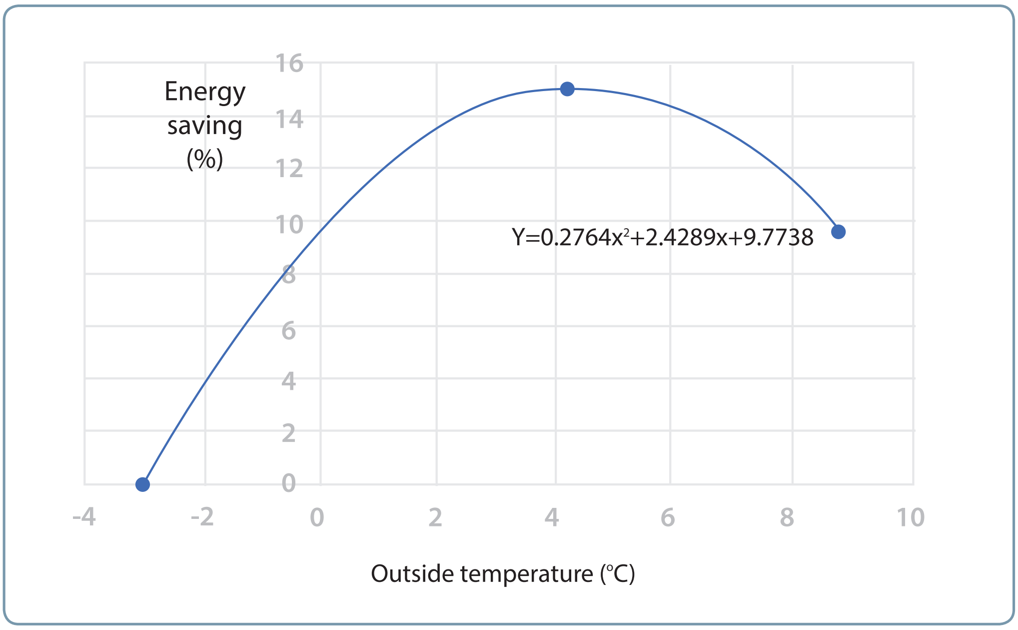


Figure 6: Graph of estimated energy savings against average outside temperature

---

[6] https://www.bregroup.com/sap/

	Heating season average temp (deg^{C})	Estimated saving (%)
October	10.6	4.5
November	7.1	13.1
December	4.2	15.1
January	4.3	15.1
February	4.9	15.0
March	6.5	13.9
April	8.9	9.5
Average		**12.3**

Figure 7: Estimated savings from average monthly outside temperature

3.2 Phase 2 results

3.2.1 Impact of commissioning the boiler and balancing the heating system on the baseline tests.

While the intention of commissioning and balancing the boiler and heating system in the phase 2 tests was primarily to try to avoid the boiler failing to modulate, this work also improved the performance of the boiler in the Class I baseline tests. As a result, we cannot directly compare the phase 1 and phase 2 tests and this is explained further in Section B.

Figure 8 shows the impact of this in relation to the flow and return temperature of the heating system when the boiler was controlled by the Class I thermostat. This shows that with the 'tuned' boiler in the phase 2 tests the boiler was able to operate with a low return temperature, so that it stays in its more efficient condensing mode, even when controlled by a Class I on/off thermostat. It also exhibits a smoother flow temperature demonstrating that its output is more closely matched to the building heat loss. By contrast, the boiler under the same form of control in the phase 1 tests shows a pronounced on/off profile, with the return temperature increasing up to around 65oC with each peak.

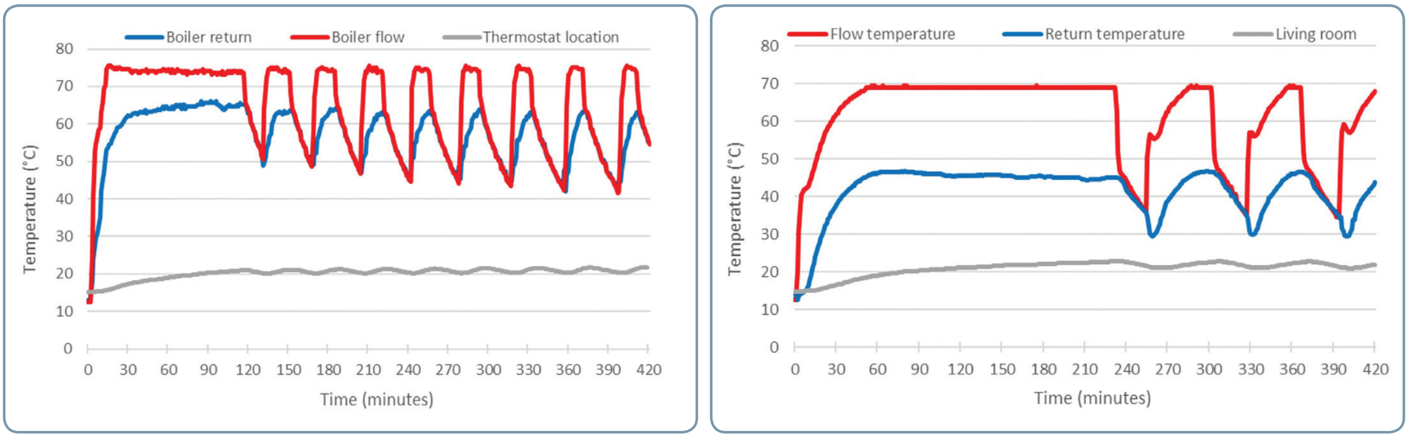


Figure 8: Graphs of flow and return temperature for the Class I baseline tests in the Phase 1 (left) and Phase 2(right) Winter tests

For our tests comparing the energy savings of different types of controls it is obvious that the measured impact of Direct Modulating room thermostats will be less in phase 2 than in the phase 1 tests as the Class I baseline, against which we are comparing, already includes some of the potential energy savings due to lowering the return temperature.

This means that the key aims of the phase 2 tests are to establish what energy savings are possible with Directly Modulating Room Thermostats with a heating system that has already been optimised, and also to show the energy saving potential from a Class VI weather compensation that has been correctly set up (as was not the case in the phase 1 tests.)

3.2.2 Phase 1 results – Impact of Directly Modulating Room Thermostats

The results of the phase 2 tests for Class V and Class VI controls compared to this improved baseline are shown in Table 2 below. Analysis of calculated boiler efficiencies is covered in Appendix 1.

Class	Control type	Gas savings (kWh)		Mean living room temperature (°C)	
		Winter	Spring	Winter	Spring
I	**On/off room thermostat**	**-**	**-**	**21.0**	**21.3**
V	**Directly Modulating Room Thermostat (load compensation)**	**8%**	**7%**	**20.3**	**20.8**
VI	Directly Modulating Room Thermostat (weather compensation)	2%	7%	21.2	21.0

Table 2: Comparative tests of Class V and Class VI controls against a baseline Class I test in phase 2

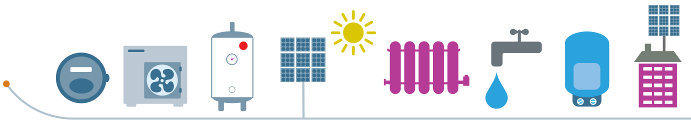
Conclusions

- Directly Modulating Room Thermostats will deliver additional reductions in gas consumption on a heating system that has already been optimised for low energy use.
- The Class VI thermostat showed savings while also maintaining similar mean living room temperatures, demonstrating that set up issues encountered in phase 1 can be overcome.
- The Class V thermostat delivered higher energy savings in the 'Winter' tests, but also maintained a slightly lower living room temperature that could account for some of the savings. This is explained further in section 4.2.

3.2.3 Estimate of seasonal savings from the Phase 2 tests on a Class VI Directly Modulating Room Thermostat

A similar analysis was carried out for the phase 2 tests results for the Class VI as that described in section 3.1.1 to estimate the seasonal saving potential. As explained previously this is likely to be an underestimate. We have not estimated a seasonal saving for the Class V control in this test due to the difference in the winter test room temperature as explained in section 4.2. However, the consistency in the Spring tests results means we have confidence that both control types can achieve similar savings when set up and operating consistently.

This analysis gives the estimated heating energy saving over the course of the heating season for a Class VI control with an optimised heating system as **5%.**



4.

Analysis of Test Results

4.1 Set up issues with Class VI control in phase 1 tests

As described above, we were unable to compare savings for the Class VI control in the phase 1 tests as it failed to get the room temperature up to a comparable level with the Class I baseline. Weather compensation control such as this relies on the installer setting an appropriate heating curve for the controller. In this case the room temperature setting on the boiler was set to 21 °C and the heating curve was set to maintain a flow temperature of 74 °C at the heating system design temperature of -3 °C. It was noted by the University of Salford research team that they were unable to find clear guidance on the selection of an appropriate heating curve that considers the characteristics of both the heating system and building fabric. It should also be noted that the control used in this test was a Class VI control manufactured by the boiler manufacturer and therefore should not be subject to any compatibility issues. The flow and return temperatures of the system with this control can be seen in figure 9 below.

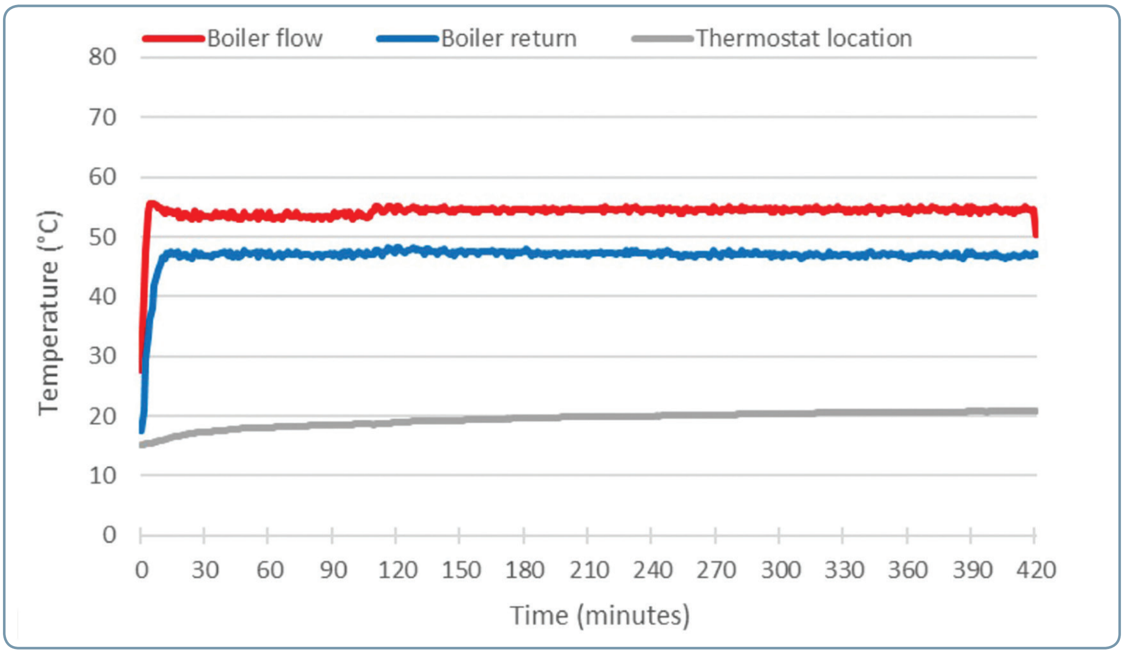


Figure 9: Graph of flow and return temperature for Class VI control in the phase 1 Winter test

Unlike the Class V control (figure 5) the flow temperature does not start at a high level to prioritise getting the room to temperature. Instead, it sets itself at an optimum temperature to efficiently maintain the room temperature, but this is not sufficient to lift the temperature under the typical UK heating profile that we were testing against[7] and the living room did not actually reach the setpoint of 21°C until near the end of the 7-hour test period.

This clearly demonstrates a problem that is known to exist for UK installers, which is a lack of familiarity with weather compensation and the lack of suitable guidance to help them get it right. Anecdotally, it is believed that this problem has been resolved in real homes by simply disconnecting the weather compensation. There is therefore a clear requirement for training and information to support the application of weather compensation, and a need to make sure that the boiler and control will prioritise getting the room to setpoint if not used in a continuous heating mode.

---

[7] In other European Countries it can be more common for heating to operate continuously, with only setback rather than 'off' periods. This control approach could be appropriate in such scenarios.

4.2 The difference between Class V and Class VI in the phase 2 tests.

As noted in the phase 2 tests, the Class V thermostat delivered higher energy savings in the ‘Winter’ tests compared to the Class VI thermostat, but also maintained a slightly lower living room temperature that could account for some of the savings. What is interesting in the tests was that the Class V and Class VI tests utilised the same control device as this is capable of being set up to use different control algorithms, with the difference for Class VI being that it will also take account of data from the outside temperature sensor connected into the boiler. Hence, in both tests the thermostat temperature sensor, its location and setpoint were the same so the reason for the different results needs to be looked at more deeply.

Class	Gas savings (kWh)		Mean living room temp (°C)		Time to reach setpoint (h:mm)		Mean living room temp after setpoint reached (°C)	
	Winter	Spring	Winter	Spring	Winter	Spring	Winter	Spring
V	8%	7%	20.3	20.8	1:39	1:04	21.0	21.4
VI	2%	7%	21.2	21.0	1:38	1:03	22.2	21.6

Table 3: Comparative Winter tests of Class V and Class VI controls against a baseline Class I test in phase 2

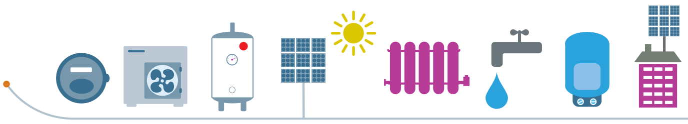
The comparative tests shown in table 3 for Class V and Class VI show that the Spring tests were very similar. In the Winter tests both control types got the room up to setpoint temperature in the same time, and once that setpoint was reached the Class V control accurately maintained the setpoint while the Class VI control experienced a slight overheating.

One of the aspects to be considered with this is the actual sequence of tests as shown in Table 4 below.

Test	1	2	3	4	5	6	7	8	9
Winter (4.2°C)	VI	V	IV	I	I				
Spring (8.9°C)						I	IV	V	VI

Table 4: Sequence of tests in order of completion. (Note: Class IV tests 3 and 7 included in section 6 of this report. Test 4 was aborted due to set up issues)

The Direct Modulating room thermostats used in these tests, in common with most controls of this type, contain an element of self-learning regarding how the building responds thermally. This allows the control to accurately manage the boiler modulation to provide close control of room temperature. As mentioned above, the Class V and Class VI control in the test was provided by the same physical room thermostat and therefore the device will have been learning about the thermal characteristics of the building in the first test period, which as seen in Table 4 was the Class VI Winter test. Had there been the opportunity to run this test again it is expected that the room temperature maintained would also have been close to 21oC, given that this is the same temperature sensor seeking to maintain the same setpoint, and that the Spring tests



provided similar results. Given the flow and return characteristics of the system are similar we are confident that either form of Directly Modulating room thermostat (i.e. load compensation or weather compensation) will produce similar savings.

From the perspective of the phase 2 tests we will take the lower (Class VI) energy savings as the figure for Directly Modulating room thermostats added to an optimised system. This is both to favour a conservative figure, but also to fit into the test approach which was to make comparisons with the living room maintained at the same average temperature[8].

4.3 Poor boiler modulation in the Spring tests

One of the issues found in both phases of the tests was that the boiler was unable to fully modulate in the Spring tests when the heat load of the Energy House was very small. This can be seen in Figure 10, which shows the phase 2 tests for the Class VI control.

The flow temperatures for the Spring tests show that, rather than running continuously at a low flow temperature, the boiler is reverting to an on/off mode of operation although it is still modulating to reduce the flow temperature. This clearly shows that the boiler is unable to modulate down far enough to match the lower heat load of the building in the Spring tests, which are at typical outside temperatures for the UK in April. Although we do not have direct data from the tests to make a comparison, it is theoretically expected that further energy savings would be possible if the boiler was able to modulate down to a lower temperature rather than revert to on/off mode.

Currently, 80% of boilers sold are combination boilers[9], which means that they provide instantaneous hot water as well as heating. These boilers will be sized for the hot water load required, which is usually much higher than the heating load of the building. In addition to this, there is known to be a problem with boilers being regularly oversized in UK homes[10] rather than sized to the heating load. Even with a correctly sized boiler, and as explained in section 1.2.2, the boiler will be required to mainly operate at a 'part load' rather than its full design load.

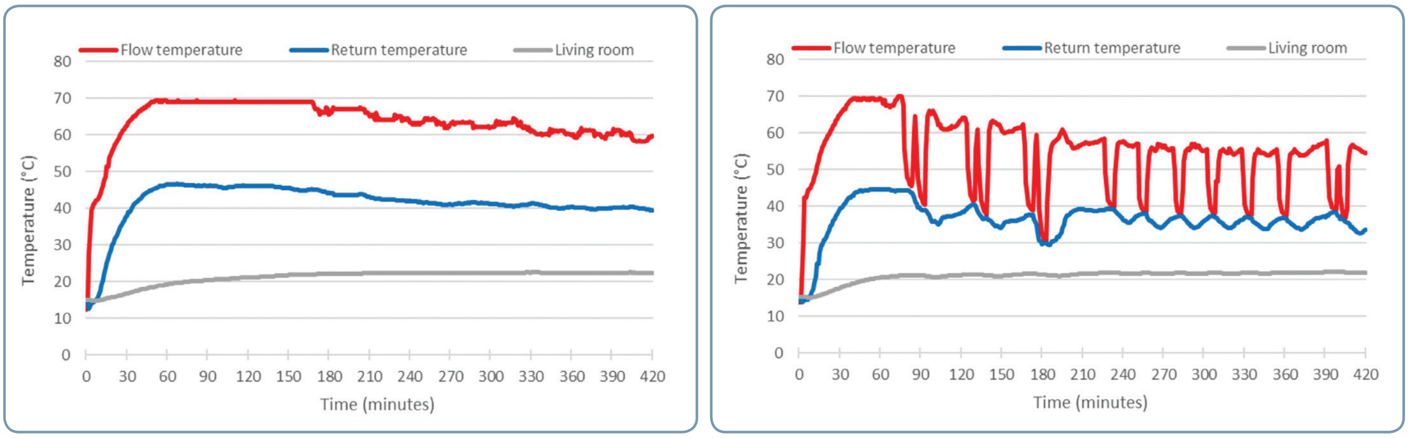


Figure 10: Flow (red) and return (blue) temperatures for the Phase 2 tests of the Class VI control for both Winter (left) and Spring (right)

---

[8] It should be noted that the European standard for Control Accuracy (EN15500) compares the performance by taking the lowest room temperature in the control cycle (hysteresis) rather than the average. Hence, under that Standard the 8% saving in the Winter tests would be the valid measurement.

[9] Data from 2020 industry statistics of boiler sales, source EUA.

[10] Effect of boiler oversizing on efficiency: a dynamic simulation study. George Bennett, UCL, Cliff Elwell, UCL (2020)

The degree to which a boiler can modulate to reduce its output is known as the 'modulation' ratio (or 'turndown' ratio.) For example, a boiler with a maximum heat output of 24 kW and a minimum heat output of 6 kW would be said to have a modulation ration of 4:1.

A technically realistic maximum modulation ratio is 10:1. However, a review of around 60 domestic central heating boilers sold by one of the main merchants at the end of 2020 showed that the average modulation ratio of those boilers was 5:1, and that this information was quite difficult to find for all boilers.

Using the average minimum heat output of these boilers against a review of the heat load of typical UK houses allows us to assess how often boilers are likely to be able to operate in their modulation mode without reverting to on/off. Table 5 shows this analysis for a range of typical house types and their part heat loads for the typical temperature in each month[11]. It is then assumed that the terraced and semi-detached houses would have a 24 kW combination boiler and the detached houses a 32 kW combination boiler, both sized for the hot water load and with an average minimum heat output of 4.9 kW and 6.5 kW respectively based on average modulation ratios. The cells highlighted in light green are the only months where you would expect the boiler to fully modulate at average outside temperatures[12].

		Oct	Nov	Dec	Jan	Feb	Mar	Apr
Pre-mid 60s	**Terrace**	2.90	3.98	4.88	4.85	4.66	4.17	3.43
Mid 60s–1991	**Terrace**	1.99	2.74	3.35	3.33	3.20	2.86	2.35
Post 1991	**Terrace**	1.75	2.40	2.94	2.92	2.81	2.51	2.06
Pre-mid 60s	**Semi**	4.30	5.90	7.23	7.19	6.91	6.18	5.08
Mid 60s–1991	**Semi**	2.51	3.45	4.22	4.20	4.03	3.61	2.97
Post 1991	**Semi**	1.84	2.52	3.08	3.07	2.95	2.64	2.17
Pre-mid 60s	**Detached**	6.38	8.76	10.72	10.66	10.25	9.16	7.53
Mid 60s–1991	**Detached**	4.04	5.54	6.79	6.75	6.49	5.80	4.77
Post 1991	**Detached**	3.66	5.02	6.15	6.11	5.88	5.26	4.32

Table 5: Average heat loads in UK house types through the heating season. Green cells indicate the potential for average boilers to be able to operate under full modulation control

Our tests show that energy savings will still result from the application of Direct Modulating room thermostats even when the boiler is not able to fully modulate. However, these figures indicate that even better savings could be possible in homes if boilers with higher modulation ratios are selected and correct boiler sizing is encouraged.

4.4 Impact on occupant comfort

The effect of direct modulating control of the boiler is also seen in the degree to which the heating system provides close control of the room temperature inside the house. This can be seen in Figure 11, which shows the phase 1 tests for the Class V control compared to the Class I baseline.

---

[11] Average monthly heat loads calculated from SAP assessment of design heat load of typical house types (BRE)

[12] With the increase of fabric energy efficiency measures in existing homes the heat load will be further reduced and the potential for full modulation even less likely than these figures suggest.

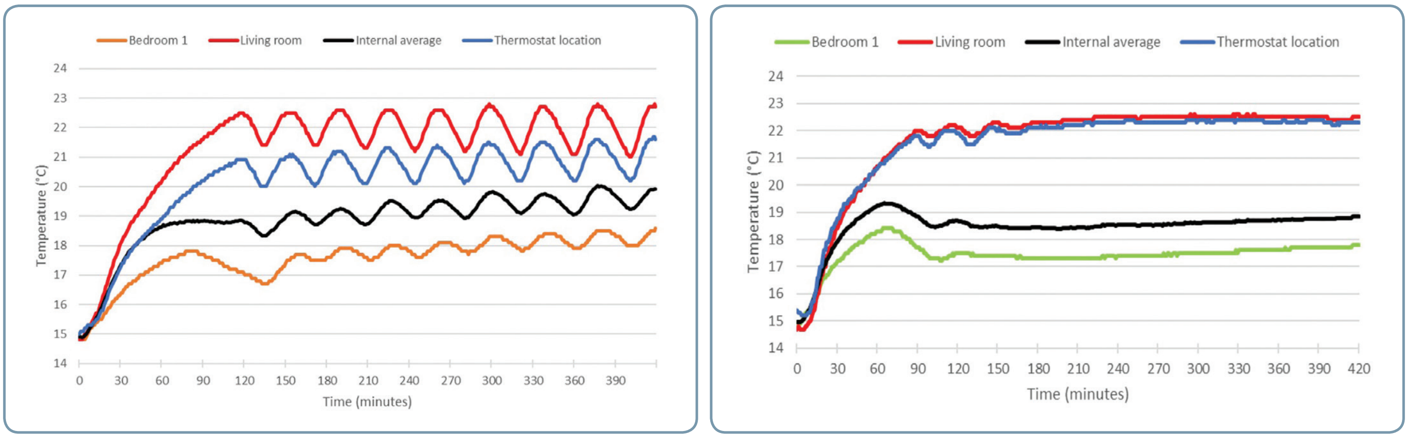


Figure 11: Room temperatures for the Phase 1 tests of the Class I (left) and Class V (right) control for Winter. Living room temperature is in red

The Class 1 control used in the test was of a modern type but even so, the temperature in the living room varies consistently by at least 1 degree and there was a significant difference between the temperature at the centre of the room (in red) and the temperature measured at the thermostat location (in blue.) Temperatures in other rooms in the house also show this variation as, despite being controlled by TRVs, they are still impacted by the on/off cycle of the boiler. This impact would be even more extreme with some Class 1 thermostats, particularly older ones in existing homes.

By contrast, the Class V control maintains a smooth temperature profile throughout the house which should provide much greater occupant satisfaction with the comfort provided by the heating system.

In addition, BS EN 15500 defines control accuracy as the deviation between the setpoint and the lowest temperature maintained, where the poorer the control accuracy, the more likely the user is to adjust the room setpoint upwards as a result of poor comfort. In our tests we have used the average temperature delivered by the Class 1 thermostat as the comparative baseline but this could well under-estimate energy savings as the control accuracy definition implies that we should compare against the lowest point of the temperature variance delivered by the Class 1 control.

SECTION B

The Benefits of Correct Selection, Set-Up and Commissioning of Central Heating Systems

5.

The importance of boiler and system commissioning

Part L of the Building Regulations, which covers energy conservation, requires that fixed building services (such as central heating systems) are *"commissioned by testing and adjustment as necessary to ensure that they use no more fuel and power than is reasonable in the circumstances."* Guidance on this currently requires that commissioning should be in accordance with manufacturer's instructions, and there is also reference to the 'Benchmark Commissioning Checklist' that can be used to show that work has been carried out satisfactorily. This checklist may also be a condition of the boiler warranty.

The scope of set-up and commissioning work carried out in the phase 2 tests, as described in section 2.3.1 followed the Benchmark Commissioning Checklist with additional adjustment of the modulation control settings on the boiler to suit the controls and the building it was fitted in. However, a key aspect of effectively setting up the system is to do so in the context of the calculated heat loss of the building and it is not believed that this is the case with most boiler replacements currently carried out in the UK.

It is not necessarily the case that all aspects of effective commissioning are carried out as common practice by the majority of heating installers. For example, the 2018 BEIS Boiler Plus consultation revealed that *"most installers do not have a common understanding of hydraulic balancing, with only 18% claiming to undertake it as a standard practice. As many as 44% of installers charge £50-£300 for the service, and it is not clear whether the remaining 38% are able to offer it."* However, while recognising that this expected practice is not currently enforced, the subsequent Boiler Plus requirements that were introduced stopped short of taking measures to increase the level of enforcement of hydraulic balancing.

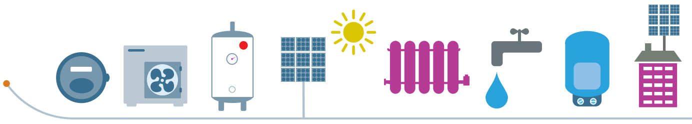
5.1 Impact of commissioning and set up on the phase 2 tests.

As discussed in section 3.2.1, the set-up and commissioning work done on the boiler for the Phase 2 tests was seen to improve the performance of the boiler under control of a Class I room thermostat. This was because the boiler was able to operate in condensing mode for the full 7-hour period under this control, whereas in the phase 1 tests this did not happen.

Unfortunately, it is not possible to directly compare the phase 1 and phase 2 tests to get an overall savings figure that includes both the impact of the commissioning and the additional effect of the Directly Modulating Room Thermostat, compared to the impact of the Directly Modulating Room Thermostat alone. This is because there were significant differences between the two tests as below:

- **There was a different heat transfer coefficient (HTC) in the Energy House for the two tests as the adjoining property was unheated in the first test. In effect, the first test was carried out in a detached house and the second in an end terraced house.**
- **There were slight differences between the average internal temperatures maintained during the two sets of tests.**
- **The phases of tests were carried out with different boilers, with a different heat output.**

While there is good evidence from these tests and elsewhere that fully commission and balancing the system will, in themselves, provide significant energy savings it was outside the scope of these tests to quantify those savings. However, it would be strongly recommended that more work is done to quantify these. This would support requests for better enforcement of the current requirements in the Building Regulations, and help consumers understand the need for this work to be done on their heating system.



Conclusions

- Thorough boiler commissioning and system balancing can be observed to have a significant beneficial impact on the operation of a heating system.
- This impact should result in reduced gas consumption, but we were unable to quantify this in these tests as a direct comparison could not be made between the phase 1 and phase 2 tests.
- While the measured savings of the Directly Modulating Room Thermostats in phase 2 are lower than in phase 1 due to the change in the baseline, we would expect the overall savings (commissioning plus controls) to be at least as large as the savings from the Directly Modulating Room Thermostats in the phase 1 tests.
- More work is needed to measure the potential energy savings from commissioning and system balancing.

SECTION C

The Role and Benefits of On/Off Load Compensating Room Thermostats

6.

Assessing the energy savings potential of on/off load compensating room thermostat

6.1 What is an On/Off Load Compensating Room Thermostat?

In addition to the Class V and Class VI room room thermostats described above, the Energy Labelling Regulations also include a Class IV room thermostat[13]. These devices are similar to a Class V control in that they use load compensation to measure the internal temperature to work out how far it is from the setpoint and will also learn from the building response over time to improve accuracy. However, rather than communicating with the boiler to directly modulate the flow temperature, the intelligence within a Class IV room thermostat uses an algorithm to calculate an efficient firing cycle for the boiler and uses an on/off signal to operate the boiler in accordance with the algorithm.

6.2 Tests to establish the Energy Savings from Directly Modulating Room Thermostats

As part of the test programme described in section 2, the energy saving performance of a Class IV on/off load compensating room thermostat was also assessed. The test results are below.

6.1.1 Phase 1 results – Impact of an On/Off Load Compensating Room Thermostat

Class	Control type	Gas savings (kWh)		Mean living room temperature (°C)	
		Winter	Spring	Winter	Spring
I	**On/off room thermostat**	**-**	**-**	**21.3**	**21.9**
IV	**On/off load compensating room thermostat**	**11%**	**9%**	**21.7**	**21.9**

Table 6: Comparison of Class IV control against baseline Class I test in phase 1

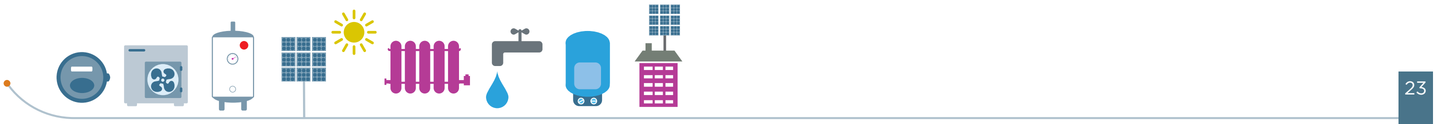
Conclusions

- The Class IV thermostat delivered significant energy savings compared to the Class 1 on/off room thermostat while maintaining similar mean living room temperatures.
- The Class IV thermostat showed an estimated heating energy saving over the course of the heating season as **10%**[14]. This compared well to the seasonal saving of 12% estimated for the Class V thermostat.

---

[13] Class IV is currently described in the regulation as a "TPI room thermostat, for use with on/off output heaters." However, 'TPI' is only one form of a range of devices performing a similar function. In recognition of this, the European Commission review of this regulation that is currently underway is proposing that this shall be changed to "a generic load compensating control using proportional on/off control. This would include TPI controls that currently fall under class IV but not exclude other similar control devices that use different algorithms." The review also proposes that any classes that reference the boiler (e.g. "for use with on/off output heaters") should be changed to refer to the form of control (e.g. "weather compensating control, on/off".) The test results in this report confirm that a Class IV thermostat will work effectively with a modulating boiler.

[14] Estimated using the process as laid out in section 3.1.1.



6.2 Analysis of the Class IV test results

Graphs of the flow and return temperatures in the heating system when the boiler is being controlled by the Class IV thermostat (see Figure 11) show how the control algorithm works to keep the return temperature low and also, through limiting the firing periods, reduces the maximum flow temperatures. It does not directly modulate the boiler.

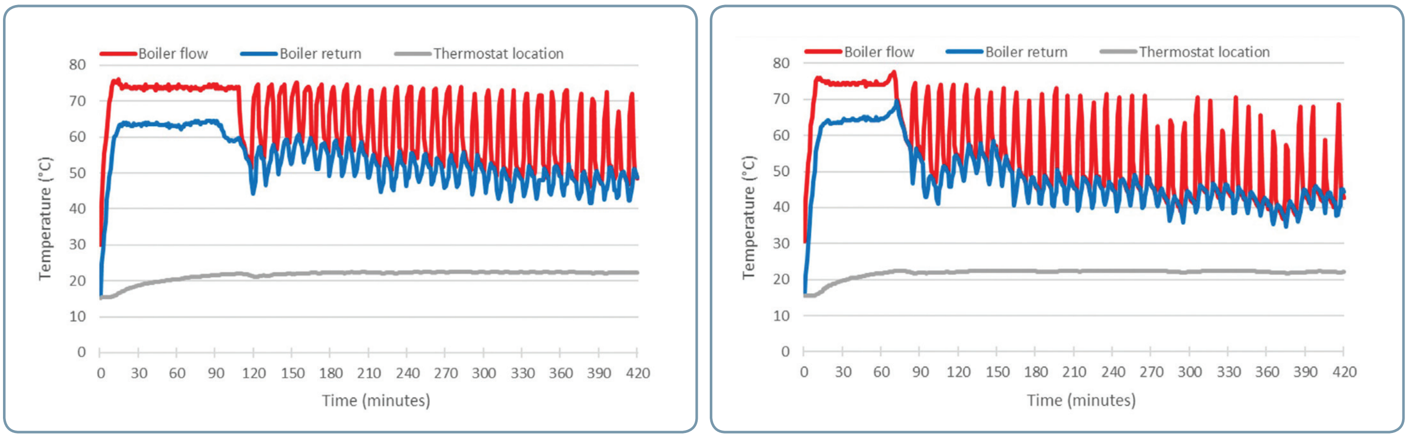


Figure 12: Graphs of Flow and return temperature for Class IV in Winter (left) and Spring (right) tests

One of the aspects of Class IV controls that has been raised as a concern is the frequent boiler cycling that can be observed in Figure 12 and the potential impact that this might have on the boiler lifetime. This concern was raised as an issue in the Boiler Plus policy review of 2017 leading to an exclusion of TPI controls (though not the broader category of on/off load compensation.) However, the BRE report commissioned for the study concluded that *"no studies were identified that explicitly prove that boilers in heating systems with TPI controls wear out quicker than those without[15]."* BEIS also made clear that TPI controls could be used in other applications which infers that any concerns were not substantial. Other research has also identified that boilers have an internal protection mechanism that will prevent problems: *"in the case of space heating operation, boilers normally include 'anti fastcycle' and pump overrun functions which limit the minimum time between burner starts. These functions mitigate undesirable control strategies from the heating system, which could lead to reduced component lifetime by exceeding components cyclic or thermal limits[16]."*

The closeness of the savings to the Class V tests are probably slightly exaggerated due to the fact that the Class V control in the Spring tests was also operating in a similar on/off load compensation mode due to the modulation limit of the boiler at low loads, as covered in section 4.4. However, this shows that the Class V savings could potentially be higher rather than that the Class IV savings are exaggerated in themselves.

It seems that there is a clear role for Class IV controls in situations where Directly Modulating Room Thermostats cannot be installed, either due to the absence of communications between

---

[15] BEIS Evidence Gathering report for Boiler Plus, BRE (2017)

[16] Space heating operation of combination boilers in the UK: the case for addressing real world boiler performance, Bennett, G., Elwell, C., & Oreszczyn, T. (2018)

boiler and control or some other reason. They could certainly be a minimum standard in place of Class I controls, recognising that they will offer significant savings for consumers in that respect, but without overshadowing the fact that Directly Modulating Room Thermostats would be the preferred option for the highest energy savings.

6.3 Impact on occupant comfort

The Class IV controls also delivered much more stable internal room temperatures, similar to the effect described for the direct modulating control in section 4.4. This can be seen in Figure 13, which shows the phase 2 Spring tests for the Class IV control compared to the Class I baseline.

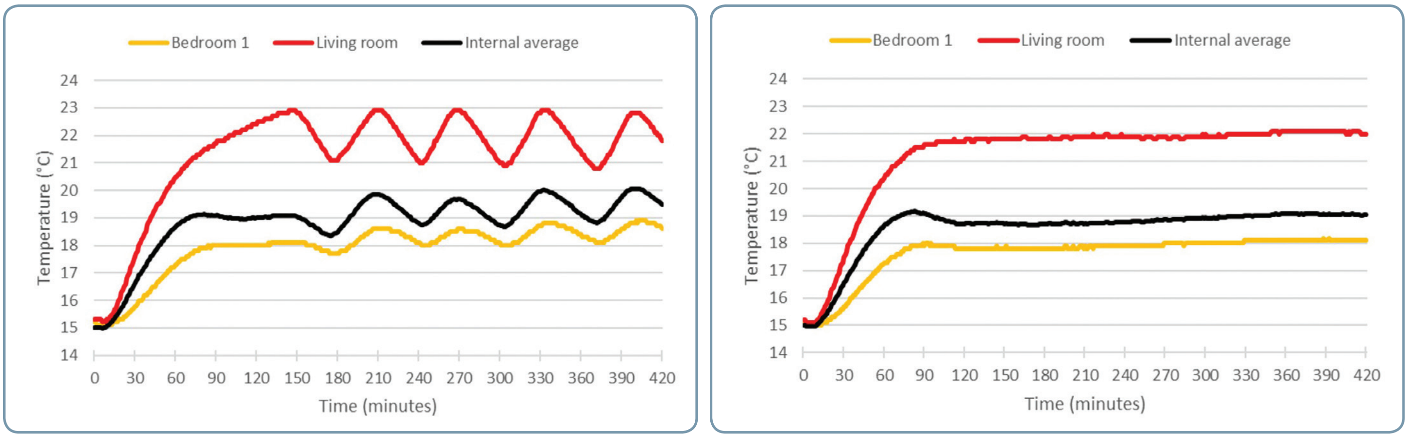


Figure 13: Room temperatures for the Phase 2 tests of the Class I (left) and Class IV (right) control for Spring. Living room temperature is in red

Again, the Class 1 control used in the test was of a modern type but even so, the temperature in the living room varies by nearly 2 degrees. Temperatures in other rooms in the house also show this variation as, despite being controlled by TRVs, they are still impacted by the boiler cycling. By contrast, the Class IV control maintains a smooth temperature profile throughout the house which should provide much greater occupant satisfaction with the comfort provided by the heating system.

As mentioned previously, BS EN 15500 defines control accuracy as the deviation between the setpoint and the lowest temperature maintained, where the poorer the control accuracy, the more likely the user is to adjust the room setpoint upwards as a result of poor comfort. In our tests we have used the average temperature delivered by the Class I thermostat as the comparative baseline but this could well under-estimate energy savings as the control accuracy definition implies that we should compare against the lowest point of the temperature variance delivered by the Class I control.

SECTION D

Conclusions

7.

Conclusions

The conclusions from the tests were as below:

- Installing a Directly Modulating Room Thermostat (Class V or Class VI) as a direct replacement for a standard room thermostat (Class I) in a home heating system with a gas fired boiler can reduce the gas used for heating by 12% over the heating season.
- Installing an on/off room thermostat with load compensation (Class IV) as a direct replacement for a standard room thermostat (Class I) can reduce the gas used for heating by 10% over the heating season.

Based on the tests and the technology approach we can also draw the following conclusions:

- The Directly Modulating Room Thermostats (Class V or Class VI) visibly improved the operational performance of the boiler, ensuring that the boiler operated in condensing mode and modulated in response to part load conditions. There is a significant weight of evidence that these factors are highly desirable from an energy conservation perspective.
- All of the controls tested (Class IV, V and VI) delivered more stable control of room temperatures when compared to a standard room thermostat (Class I) and this should result in improved comfort for occupants.
- Thorough boiler commissioning and system balancing can be observed to have a significant beneficial impact on the operation of a heating system. This is expected to improve the baseline efficiency of the system, but all of the controls tested (Class IV, V and VI) will provide additional savings.
- The energy savings potential from Class IV, V and VI room thermostats is largely independent of consumer behaviour and will be delivered for most ranges of internal setpoint temperatures and system operating times.
- Directly Modulating Room Thermostats are a readily available technology in the form of a Class V load compensation room thermostat or a Class VI weather compensating room thermostat and the tests provide confidence that both approaches will deliver similar energy saving benefits.
- There is a clear role for Class IV controls in situations where Directly Modulating Room Thermostats cannot be installed, either due to the absence of communications between boiler and control or some other reason. However, Directly Modulating Room Thermostats would be the preferred option for the highest energy savings.
- Boilers with higher modulation ratios have the potential to deliver even better savings with these controls.

APPENDIX 1

Measurement of boiler efficiencies

Using the data collected in the tests it was possible to make a calculation of the boiler efficiency during the test period. Boiler efficiency was obtained by dividing the energy output of the boiler (measured by the heat meter) by the energy supplied to the boiler (obtained from metered gas use) over the test period. The efficiencies obtained are presented below.

There was no observed correlation between measured efficiency and control impacts. This may be due to the impact of the on/off control, given that boiler efficiencies are usually tested under steady state conditions. However, further analysis is needed on these before firm conclusions can be drawn.

Test phase	Class	Gas savings (kWh)		Boiler efficiency	
		Winter	Spring	Winter	Spring
1	I	-	-	88%	85%
	IV	11%	9%	84%	85%
	V	15%	9%	85%	86%
2	I	-	-	85%	86%
	IV	2%	6%	86%	86%
	V	8%	7%	86%	84%
	VI	2%	7%	86%	86%

Figure 14: Measurement of boiler efficiencies

Follow us on:

BEAMA Ltd

@BEAMAUK #NetZerobyDesign