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BRE Client Report

Evidence Gathering - Compensation and TPI Heating Controls

Prepared for:	**Department for Business, Energy and Industrial Strategy**
Date:	**September 2017**
Report Number:	**1178/06/2016 (ETS Framework - Lot 18) Issue: 3**

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Executive Summary

The overall aim of this study was to collect, analyse and synthesise available evidence on weather compensation, load compensation and Time Proportional and Integral (TPI) heating controls, as applied to domestic boilers (fuelled by gas, oil and LPG).

This report provides a technical description of each of the three types of advanced temperature controls, identifies the mechanisms by which they improve the energy efficiency of heating systems and identifies other benefits and disadvantages associated with their use. It outlines the current state-of-the-art for the technologies, the availability of products and current and future product cost trajectories. It identifies barriers to deployment and highlights gaps in the evidence base for each heating control technology.

Research Methods: The research comprised a literature search, online information searches and feedback from a range of stakeholders. The stakeholders included manufacturers of boilers and controls, installers of heating systems and other organisations with an interest in or knowledge of heating controls. Information was collected from stakeholders using an online questionnaire and follow-up telephone interviews.

Evidence for Energy Savings: Five sources of test evidence relating to energy savings were identified for TPI control along with one for weather compensation and one for load compensation control. The evidence sources were evaluated based on the extent to which the test conditions were representative of heating systems and operating conditions that are typical for UK housing. This exercise demonstrated that there is a lack of evidence regarding the energy savings that these controls are likely to achieve in practice.

Factors Affecting Energy Savings: Key factors affecting the energy efficiency improvements that are achieved with advanced controls were identified. These include the annual heat demand in the dwelling, the temperature of water circulating in the system, the heating schedule and the presence of other energy saving features. The way in which users interact with controls, for example by frequently changing settings, was also identified as having a significant impact on the energy saving potential. When assessing the credibility of test results, one key factor is the existing or counterfactual controls against which any savings are measured.

Market and Cost of Advanced Energy Saving Controls: It was established that weather and load compensation and TPI controls are readily available in the UK and that current costs (including installation) attract price premiums of approximately £200, £100 and £65, respectively.

Industry stakeholders anticipate that the purchase price of temperature controllers with compensation capability will fall over the next five years, but that the purchase price of weather sensors and TPI controllers are more likely to stay the same.

Reliable information on the current market share for each type of control is not available; rough estimates based on stakeholder responses suggest that the current market shares are around 12% for TPI control, and around 2% for both weather and load compensation.

Available evidence suggests that TPI controls can be used with almost all new and existing boilers. Although some sources identify concerns regarding the inbuilt controls in a modulating boiler conflicting with TPI control, no definitive proof was provided.

Technical Constraints: There are a number of technical restrictions with compensation controls. In the UK they are invariably used with modulating boilers which therefore need to be compatible with compensation control and able to differentiate between heat demands for space heating or hot water. The majority of gas and LPG boilers currently being installed can fulfil these criteria. However, only a portion of existing heating installations are suitable for compensation controls.

Conventional weather compensation control requires an appropriately sited weather sensor to be connected to the boiler. In instances where there is no appropriate place to put the weather sensor, control systems that are connected to the internet can access local online weather data instead.

Barriers and Technical Advances: Barriers to wider uptake of advanced temperature controls were identified and evaluated based primarily on stakeholder views. Lack of both consumer and installer awareness were cited most frequently as a main barrier, particularly by (more knowledgeable) installers. Lack of technical skills to install and commission advanced controls was identified as a main barrier by 80% (n=13) of installers, with a much smaller proportion of other respondents citing this. Performance benefits not being widely recognised was identified as one the main barriers by 61% of respondents. Lack of compatibility and cost barriers were cited as main barriers by less than a quarter of respondents.

Technical advances identified included the emergence of scaled down versions of commercial building management systems, multi-zone load controls, smart controls which possess self-learning capabilities and occupancy sensors.

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1 Introduction

1.1 Background

The main function of domestic heating controls is to ensure that desirable internal temperatures are maintained within the home, but they also have the potential to reduce energy use. Heating controls can achieve energy savings in two ways:

- Increasing energy efficiency of the heat generator, or
- Reducing the amount of heat that is wasted.

The amount of heat that is wasted can be reduced by switching the heating off when it is not required, making sure that the desired internal temperatures are not exceeded (avoiding overheating) and reducing heat losses in pipework.

This study, undertaken for the Department for Business, Energy and Industrial Strategy (BEIS), follows on from a 2016 scoping study on heating controls[1]. That study undertook an evidence review of academic, industry and policy evidence sources to identify UK publications relating to the cost-effectiveness, energy savings and usability associated with controls. The review identified a lack of robust evidence regarding the cost effectiveness and usability of a number of heating controls including compensation and (Time Proportional and Integral) TPI controls.

Room thermostats, programmer/timers and Thermostatic Radiator Valves (TRVs) are standard heating controls which have a high market penetration, and are generally required to meet energy related building regulations. Other control types are classed as advanced heating controls and possess functionalities such as remote control, automation, learning algorithms and zonal control.

This current study focusses on three types of advanced heating controls which are described as automatic, in that they do not rely on additional user intervention. They are weather compensation, load compensation and TPI control.

More details on the operation and control characteristics of these types of controls are provided in Section 2.

[1] Lomas,K, Haines,V and Beizaee,A (2016) *Heating Controls Scoping Review Project*, Loughborough University for DECC, April 2016

1.2 Objectives

The overall aim of this study is to collect, analyse and synthesise evidence relating to weather compensation, load compensation and TPI heating controls, as applied to domestic boilers (fuelled by gas, oil and LPG)

As set out in the project brief, the specific research objectives of this study are:

- To provide an outline of the current state-of-the-art for each technology.
- To review key product types available and the maximum potential UK market for each type of control.
- To outline current product costs and future consumer cost trajectories.
- To identify and assess the technical requirements and best practice methods that influence in-situ performance.
- To identify technical, market, regulatory and consumer barriers to deployment.
- To identify evidence gaps and make recommendations for filling them.

2 Types of Temperature Control for Heating Systems

Heating controls perform a number of functions within wet central heating systems. These include:

- Temperature control (to maintain a comfortable internal environment),
- Safety controls,
- Timers and programmers (to avoid heat being provided when it is not needed), and
- Controls to ensure that the heating system is operated efficiently.

Some of these functions can overlap and in some instances they may conflict. This is particularly relevant in the case of temperature control for comfort and controls that increase system efficiency. When considering the energy efficiency of controls it is important that they, and the alternatives against which they are being compared, provide internal temperatures which meet the needs of the occupants.

This section describes the operation and control characteristics of different types of temperature control, focussing on the three advanced heating controls that are the subject of this study. It also identifies the energy efficiency and comfort benefits that advanced controls can offer over standard heating controls.

The basic element of all types of temperature control for wet central heating systems fed by boilers are a temperature sensor, a controller and the boiler itself. The sensor measures the temperature and transmits this information to the controller. The controller generates an output signal based on this information, which is sent to the boiler which acts on it. For most heating systems the temperature sensor(s) will be located in a room thermostat, and/or outside (in the case of weather compensation). The controller may be located within a room thermostat or within the boiler.

2.1 Standard Temperature Controls

The simplest form of temperature control is an **on/off controller.** This switches the boiler off when a temperature sensor reaches a set point (upper limit) and on again when it falls below a lower limit. With these controls there needs to be a difference between the upper and lower limits to prevent the boiler from continuously cycling on and off and causing excessive wear on heating system components. However, this differential results in a certain amount of temperature swing around the set point. The typical inherent temperature swing in this kind of room thermostat is of the order of around 3°C for mechanical thermostats. The control characteristics of a standard on/off controller are shown in Figure 1.

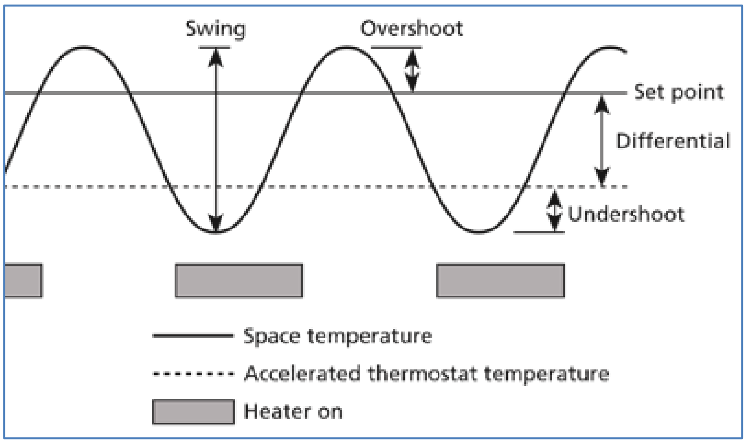

Figure 1: Operation of an on/off thermostatic controller[2]

The majority of thermostats that are currently on the market are **electronic** and react more quickly to temperature change compared to mechanical ones, with typical temperature swings of around 1-1.5°C.

The temperature sensor and control unit can be either hard wired or communicate wirelessly via radio frequency signals.

In the UK, heating systems are usually controlled by a single room thermostat. This means that the temperature achieved in other parts of the building will be dependent on the heat emitters in each room being sized to match heat requirement in that room. In

[2] Butcher, KJ (Editor) (2009). *Building Control Systems, CIBSE Guide H,* Chartered Institute of Building Services Engineers, London, UK

spaces where the heat emitters are oversized compared to the reference room, TRVs can be used to reduce the heat output in other rooms.

2.2 Advanced Temperature Control

Advanced temperature controllers have the ability to automatically (without user intervention) provide more accurate temperature control and achieve energy efficiency improvements compared to standard temperature controls.

The three types of advanced heating control that are the subject of this study are:

- Weather compensation control
- Load compensation control, and
- Time proportional and integral (TPI) control

These are all types of proportional control as they are able to vary the heat output from the system based on the heat demand.

A technical description of these controls and of their associated advantages and disadvantages is provided in the remainder of this section.

2.3 Compensation Controls

Compensation control is a type of proportional control which estimates the heat demand based on measured temperature and limits the flow water temperature to the heating system accordingly. Whilst weather compensation uses external temperature to determine the heat demand, load compensation uses internal room temperature.

Compensation control involves the controller sending a signal to the boiler based on the temperature measured by the temperature sensor. The boiler then interprets this signal and modulates its heat output in response. The majority of boilers installed in the homes in the UK have this capability. However, it is also possible to use compensation control with on/off condensing boilers.

Additional energy savings for compensation control over standard temperature controllers arise from having a lower water return temperature for the system when heat demand is lower. Whilst all boilers operate more efficiently when the return temperature is lower, this is particularly important for condensing boilers which are also more likely to operate in condensing mode and therefore achieve their maximum efficiency.

The relationship between boiler efficiency and return temperature for condensing boilers is shown in Figure 2.

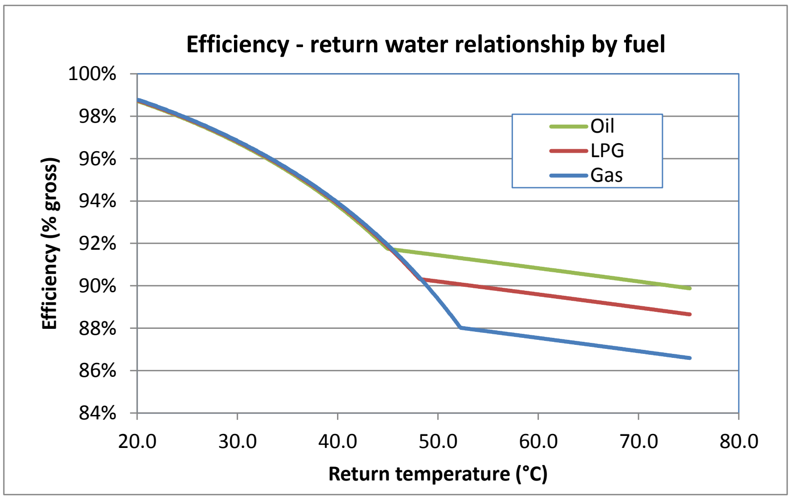

Figure 2: Theoretical relationship between boiler efficiency and return water temperature by fuel type[3]

This shows that at higher return temperatures, the boiler efficiency is lower. The gradient change occurs when the return temperature falls below the point where the boiler is able to operate in condensing mode and it is below this point that the energy efficiency improvement becomes more substantial. The diagram shows that gas boilers start to operate in condensing mode below around 55°C, whilst LPG (Liquid Petroleum Gas) and oil boilers operate in condensing mode below about 48°C and 45°C, respectively.

In addition to improving energy efficiency, lower water supply temperatures will tend to avoid the high temperature swings that can occur with standard temperature controls and so achieve greater comfort. They can also result in reduced pipework heat losses, which will contribute to the overall seasonal heating system efficiency.

There is no evidence that compensation controls have any additional maintenance requirements compared to a more basic temperature control system. However, controls with compensation capabilities are more often incorporated within more sophisticated programmable controllers which may have a greater propensity for failure due to the additional complexity; for example, touch screen user interfaces are likely to be less robust than a mechanical dial.

2.3.1 Weather Compensation Control

Weather compensation uses the external temperature to determine the heat demand in the building. This generally requires an external weather sensor. A key issue is the availability of a suitable place to site the external temperature sensor and the

[3] BRE (2016). *Consultation Paper – CONSP:02 SAP Seasonal Efficiency Calculation for Condensing Boilers*. SAP Supporting Document, Issue 1

associated wiring which will need to penetrate the building envelope. The temperature sensor needs to be installed in a position where it avoids direct sunlight, away from windows, doors and other ventilation outlets and also from gutters and balconies and ideally around 2 – 2.5 m above ground level.One alternative is to use wireless connections, but radio frequency communication will not be as reliable as a hard wired connection.

There are weather compensation controls that use online weather data to supply external temperature information. However, the online weather data will not be as accurate as having a (correctly sited) weather sensor because the temperature at the nearest weather station may not be updated frequently and/or it may be some distance away from the building. This possibly accounts for the fact that most controls that use online weather data use weather compensation in combination with load compensation.

The simplest form of weather compensation control uses a single curve to define the relationship between the boiler flow temperatures and the outdoor air temperature. Here the slope and shape of the curve are fixed but it is possible to shift the curve so that the boiler achieves the preferred internal temperature. More advanced controls use a range of heating curves that can be selected to match the thermal characteristics of the building. Figure 3 shows a simplified example of a weather compensation control curve.

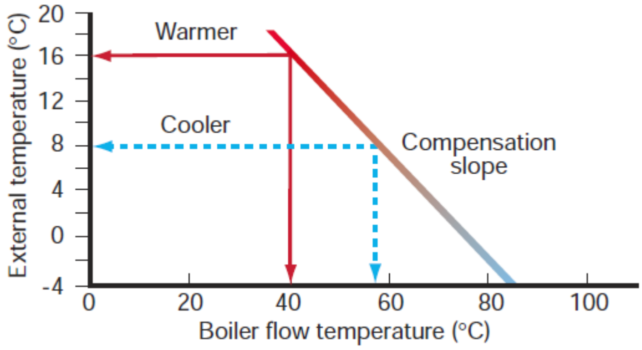

Figure 3: Simplified weather compensation control curve [4]

The most basic type of weather compensation control is an open loop system where there is no feedback between the temperature sensor and the internal room temperature. Here the weather compensation sensor is connected directly to the boiler. The control must be "tuned" to ensure that the desired internal temperature is achieved. This is done by adjusting the compensation curve during the commissioning stage.

[4] Housing Energy Efficiency Best Practice Programme (2001). *Good Practice Guide 302 Controls for Domestic Heating and Hot Water –Guidance for Specifiers and Installers*, September 2001

In the UK, weather compensation is commonly used in conjunction with a timer and a room thermostat. These identify when there is a need for heat, whilst the weather sensor, in effect, determines the amount of heat needed and controls the amount of heat produced. The presence of a timer will tend to reduce the energy efficiency improvement achieved from weather compensation by preventing the heating system from operating for a longer period at a lower flow temperature at periods of high heat demand. However, the timer and thermostat can save energy by ensuring that heat is only provided when it is needed.

A more effective option (compared to a timer and thermostat) is to use weather compensation control in conjunction with load compensation (see Section 2.5). These controls work together to determine whether there is a demand for heat and the amount of heat required.

No definitive data on the lifetime of compensation controls was identified in the literature. However, the stakeholder survey showed that the expected typical lifetime of weather sensors and compensation controllers will be of the order of 11-15 years.

2.3.2 Load Compensation Control

The control principles of load compensation are similar to those of weather compensation except that instead of using the external temperature to determine the heat demand, an internal sensor is used to measure the temperature inside the building.

Unlike weather compensation control, load compensation does not require extensive tuning and is able to react to changes in the heat demand in both the short term (for example to increased heat gains from higher occupancy/equipment usage) and longer term (for example improvements to the thermal performance of the building envelope).

2.4 Advantages and Risks Associated with Compensation Control

Compensation controls that are set up correctly should be able to provide accurate temperature control whilst improving the energy efficiency of the heating system. Some of the key additional advantages associated with load and weather compensation control are provided below.

- Load compensation automatically adjusts to changes to the building fabric such as installing insulation, and to variations in seasonal solar gains or shading due to foliage.
- Load compensation controls respond quickly to changes in heat demand. This makes load compensation suitable for heating systems that are used intermittently and/or where there are variable internal heat gains.
- Weather compensation control can limit heating losses in situations where the load is temporarily increased (for example when windows are opened).

Weather compensation control when used on its own also has some notable disadvantages.

- Weather compensation control needs to be tuned to match the heat demand in the building.
- Because weather compensation control results in lower water temperature circulating in the system, for intermittent heating schedules during milder weather it can take longer to reach the desired space temperature.

The latter problem can be overcome by using weather compensation control in combination with internal temperature sensors (load compensation) to ensure the internal temperature is used to increase the water temperature sufficiently on milder days to reduce the time required to reach set point temperature.

2.5 Time Proportional and Integral (TPI) Control

Time Proportional and Integral (TPI) control reduces the temperature swing about the set point (desired internal temperature). It uses algorithms which calculate the expected heat demand based on the measurement of how long the system has taken previously to achieve the set point. TPI control only operates once internal temperature gets within around 1^{o}C of the set point temperature.

For the purpose of this study, TPI control is defined as a device, or feature within a device, which maintains the temperature inside the building by cycling the boiler on and off in a ratio that is proportional to the difference between the required and measured temperatures inside the building.

TPI controllers switch the boiler on or off at different times using digital technology to match the boiler firing to the load on the system. The time proportion aspect of the control varies the on/off times within a constant cycle period. For example, in a 10 minute cycle period, if there is a call for 40% output from the boiler, in response it will switch on for 4 minutes and off for 6 minutes. The “integral” aspect of the control measures the difference between the internal temperature and the set point and adjusts the ratio of on:off time accordingly (less on time as the set temperature is approached). This results in a more stable control with minimal offset. Figure 4 shows the operational characteristic of TPI control.

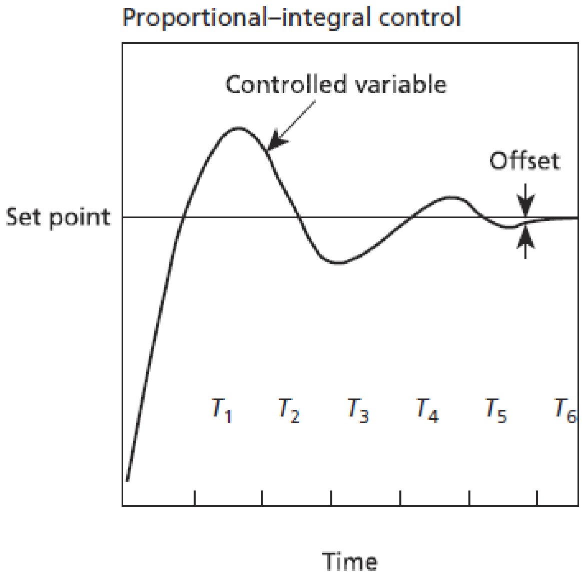

***Figure 4: Operational characteristic of TPI temperature control*[5]**

There is no evidence that TPI controls have any additional maintenance requirements compared to a standard temperature controller.

No definitive data on the lifetime of TPI controls was identified. However, the stakeholder survey showed that the expected typical lifetime will be of the order of 5-15 years.

2.6 Advantages and Risks Associated with TPI Control

TPI control provides a more stable internal temperature and therefore provides greater comfort levels compared to standard thermostatic controls.

Furthermore, a more stable temperature may allow the user to reduce the set point temperature as the swing below the set point (under-heating) is smaller. This could potentially lead to substantial energy savings as even a small decrease in the average room temperature will lead to a substantial reduction in the heat demand and hence the energy consumption. Although this may result in additional energy savings, it will not increase the seasonal energy efficiency of the heating system.

A key risk for TPI controls is associated with the additional wear and tear on the boiler in particular arising from the increased cycling on and off. Therefore, it is important that the cycle time should be set to avoid any potential wear problems. Noise from the boiler constantly firing up can also be problematic.

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[5] Butcher, KJ (Editor) (2009). *Building Control Systems, CIBSE Guide H*, Chartered Institute of Building Services Engineers, London, UK

No studies were identified that explicitly prove that boilers in heating systems with TPI controls wear out quicker than those without. However, it is acknowledged that the typical lifetime of boilers is determined in part by the number of firing cycles.

A TPI controller will work with any type of boiler and there are no additional installation requirements for TPI controls compared to a more basic thermostatic control.

3 Research Methodology

To gain the most comprehensive understanding of the three types of advanced temperature controls, information was sought from a variety of different sources. These included a literature search, internet searches and feedback from stakeholders.

3.1 Desktop Research and Literature Search

Literature searches were carried out to identify research reports and technical papers relating to the energy savings and other benefits and disadvantages associated with TPI and compensation controls and the control principles by which they operate. The search started with existing documents that the project team was already familiar with and following up relevant references cited in each document in a daisy chain fashion. This was supplemented by carrying out internet searches to identify additional material, concentrating effort on topics where information was scarce or lacking depth. A similar search process was used to identify relevant legislation and standards relating to the controls and information concerning the market for temperature controls.

Information was also obtained from the websites of manufacturers of temperature controls and boilers who supply the UK market, and also from online retailers, in order to identify information on product availability, cost, specification and installation guidance. These sources were used to supplement the information gathered from stakeholders.

All information sources were reviewed based on their relevance and the year of publication and their independence and impartiality were taken into account when evaluating the evidence.

In addition to referencing specific data sources within the body of the report, a bibliography of the documents identified is provided in Appendix A.

3.2 Stakeholder Evidence

A list of stakeholders was identified and agreed with BEIS and initial contact was made via telephone to ascertain their willingness to contribute to the study. They were chosen to represent all those involved in the supply chain and the stakeholder groups contacted included manufacturers of boilers and controls, installers, trade associations, consumer organisations, professional bodies and other organisations with relevant knowledge.

Nearly all of those contacted expressed a willingness to provide information, but expressed a preference for information requests to be provided in a written format rather than by participating in a telephone interview. At this stage the stakeholders were also asked whether they knew any other individuals or organisations that might be able to contribute to the study and where appropriate these were contacted also.

An online questionnaire was compiled by BRE specialist social researchers with experience of carrying out surveys of building professionals. The questionnaire included a mix of closed and open questions designed to collect opinions and to identify additional evidence sources for this study. The questionnaire also collected information relating to the name and role of the organisations of the respondents and the context of their experience and knowledge of each of the three types of controls.

In all, 100 responses were received to the online questionnaire. However, once the data were cleaned and submissions from duplicate respondents and incomplete submissions were removed, 48 responses remained. The stakeholder analysis presented in this report is based on the 48 complete unique responses.

When evaluating numerical information such as cost, installation times and sales volumes, a few values that seemed to be extreme or unrealistic and at odds with the distribution of values provided by other respondents were screened from further analysis. However, it was only necessary to screen out values in a few instances.

The questionnaire respondents comprised 16 manufactures of boilers or controls (40%), 19 installers (33%) and 13 other respondents (27%). Responses from manufacturers included a significant number of key players in the UK market.

The majority of installers who responded to the survey were members of Ecotechnicians, a not for profit self-regulating network of heating engineers in the UK with a particular interest in system efficiency. Members of this organisation are vetted and participate in continual professional development and are likely to represent more knowledgeable and well informed installers.

Other respondents comprised:

- Manufacturers of Other Heating System Components (4)
- Trade Associations (3)
- Professional Bodies (2)
- Consumer Organisation (1)
- Consultant (1)
- Energy Supplier (1)
- Retailer (1)

Follow up interviews were undertaken with around 15 respondents. These comprised a mix of requests for supporting evidence and clarification regarding responses to specific questions.

Although the number of responses received was good and sufficient to inform this report, the sample size was not considered large enough to warrant assessment of the statistical significance of the responses. However, in order to provide a detailed insight into the responses and to identify areas where there might be bias, the analysis looked at the responses for each of the three main respondent types.

A copy of the questionnaire is provided in Appendix B whilst Appendix C presents a complete analysis of the results of the survey. Key findings are quoted within the appropriate sections of the main report.

4 Legislation and Standards Relating to Heating Controls

This section outlines current legislation and existing standards that relate to heating controls.

4.1 Building Regulations

In England and Wales, Approved Documents L1A[6] and L1B[7] provide overall guidance on how to satisfy the energy performance provisions of Part L of the Building Regulations for new build and existing dwellings. These Approved Documents refer to a 'second tier' document - the Domestic Building Services Compliance Guide[8] - as a source of detailed guidance on means of complying with the requirements of Part L, including the minimum provisions for controls associated with the various heating, cooling, ventilation and hot water systems for both new and existing buildings. The Compliance Guide also indicates further control options that will improve energy efficiency beyond the minimum requirements of the Part L.

For gas and oil fired space and water heating systems the compliance guide specifies minimum standards for boiler efficiency, hot water storage and also for system preparation and commissioning. It also specifies boiler interlock, zoning and temperature control of the heating and hot water circuits.

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[6] Department for Communities and Local Government (2016). *Approved Document L1A: Conservation of Fuel and Power in New Dwellings, 2013 edition with 2016 amendments*

[7] Department for Communities and Local Government (2016). *Approved Document L1A: Conservation of Fuel and Power in New Dwellings, 2010 edition (incorporating 201, 2011, 2013 and 2016 amendments)*

[8] HM Government (2013). *Domestic Building Services Compliance Guide 2013 edition - for use in England (online version). Available from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/453968/domestic_building_services_compliance_guide.pdf. [Accessed November 2016]*

For new systems the recommended minimum controls for both gas and oil-fired wet central heating systems are that they should be fitted with an independent time controller and either, i) a room thermostat (which may be programmable) in the reference room (generally the main living area) with TRVs in all other rooms, or ii) individual networked radiator controls in each room on the circuit.[9]

For existing systems, components should, with some exceptions, meet the same standards as for new systems. The guide also encourages upgrading the rest of the system when emergency or planned replacements are being carried out.

The impact of heating controls is recognised within the Standard Assessment Procedure (SAP)[10] by applying specific percentage point improvements to the heating system efficiency depending on the type of controls. Currently additional percentage point increases are applied to enhanced[11] compensation controls compared to more basic controls[12], but any potential benefits from TPI controls are not currently recognised within SAP[13].

4.2 Relevant EU Directives

The Ecodesign Directive 2009/125/EC is a framework for establishing minimum performance requirements for energy-related products placed on the EU market. Currently there are no Commission Regulations (and none that are being developed) that relate specifically to heating controls for boiler systems. However, the Energy Labelling Directive 2010/30/EU, which complements Ecodesign by providing a framework for performance labelling of energy related products, does incorporate provision for taking account of the impact of various different classes of temperature controllers as part of an overall system energy label. This means that the efficiency improvement credited to the installed heating controls are taken into account in determining the seasonal energy efficiency of the heating system on the energy label.

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[9] Building Regulations have included a requirement for temperature controls for space heating in new dwellings since 1990.

[10] The Standard Assessment Procedure (SAP) is the methodology used by the Government to assess and compare the energy and environmental performance of dwellings. Its purpose is to provide accurate and reliable assessments of dwelling energy performances that are needed to underpin energy and environmental policy initiatives.

[11] The definition applied to advanced compensation controls is “A device, or feature within a device, which maintains the temperature inside the building by sensing and limiting the temperature of the water leaving the heater in relation to the temperatures measured outside the building. The temperature of the water leaving the heater may be adjusted by modulating the burner or by switching the boiler on and off”

[12] Basic room thermostats get a credit for reducing the internal temperature by 0.6^{o}C

[13] Shiret,A, Haydton,J and Young,B (2011). *Changes to the treatment of heating and hot water systems with boilers in SAP 2012, STP11/B09*, Technical Papers Supporting SAP 2012, 21st October 2011.

The various temperature control classes are defined in supplementary Commission communications regarding the energy labelling of space heaters[14] , which assign a percentage heating system energy saving to each control class. The definitions of these ErP (Energy related Products) control type can be summarised as follows:

Class I represents standard on/off temperature controller which would be sufficient to meet with Building Regulation requirements.

Class II and Class III are weather compensating controls, for modulating boilers and on/off boilers, respectively. These are not prevalent in the UK compared to other European countries as they do not include a room thermostat. The amount of heat supplied by these controls is determined solely by the external temperature sensor.

Class IV is a TPI temperature controller for use with an on/off boiler.

Class V is a load compensating controller.

Class VI is a weather compensation controller for use with modulating boilers with a room thermostat, whilst Class VII is a variant that uses time proportion control to facilitate control of the boiler output temperature by switching the boiler on or off rather than modulating the output.

Finally Class VIII is a more sophisticated form of load compensating controller where the boiler flow temperature is determined by the aggregated heat load determined from multiple room thermostats.

The recast Energy Performance of Buildings Directive (EPBD – 2010/31/EU)[15] requires that Member States should, "….set system requirements in respect of the overall energy performance, the proper installation, and the appropriate dimensioning, adjustment and control of the technical building systems which are installed in existing buildings. Member States may also apply these system requirements to new buildings." However, the effect of this aspect of the Directive on heating controls in the UK is unclear.

[14] Official Journal of the European Union (2013). *Commission 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.* L 239, 6.9.2013, p 1

[15] DIRECTIVE 2010/31/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 19 May 2010 on the energy performance of buildings (recast)

4.3 Installation Requirements

The Domestic Building Services Compliance Guide[16] also provides guidance on commissioning of boiler systems. This states that all equipment, including controls, should be commissioned in accordance with the manufacturers' instructions. It also states that the installer should explain fully to the user how to operate the system in an energy efficient manner. It cites the Benchmark Commissioning checklist as a way of showing that commissioning has been carried out successfully.

The Benchmark scheme is a nationally recognised member scheme that places the responsibilities on both manufacturers and installers to ensure best practice in installation, commissioning and servicing of domestic heating and hot water products. The scheme is managed and promoted by the Heating and Hot water Industry Council (HHIC) and currently only covers gas boiler systems. Failure to install and commission according to the manufacturer's instructions and complete the Benchmark Commissioning Checklist will invalidate the warranty for gas boiler installations (the Checklist is provided in Appendix D).

The Checklist requirements for controls are weak and only require installers to note the type of controls that are present. It identifies load/weather compensation, but does not specifically mention TPI control. Whilst it requires measurement of the flow and return temperature in heating mode, it does not specify the conditions under which the temperature is measured. The Checklist also includes a service record which recommends regular servicing (in accordance with manufacturer's instructions) and the use of manufacturer's specified spare parts when replacing controls.

4.4 Other Relevant Standards and Quality Marks

Around the world new legislation is promoting the use of energy efficient technologies. The European Standard EN 15232 ("Energy performance of buildings – Impact of Building Automation, Controls and Building Management") was compiled in conjunction with the Europe-wide implementation of the EPBD. The standard describes methods for evaluating the influence of building automation and technical building management on the energy consumption of buildings and is primarily aimed at commercial buildings with building management systems. However, the principle could potentially be applied to heating controls for domestic wet central heating systems.

The standard defines four efficiency classes - A to D - and a building equipped with building automation and control systems is assigned to one of these classes. The standard makes provision for estimating the potential savings for thermal and electrical

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[16] HM Government (2013). *Domestic Building Services Compliance Guide 2013 edition - for use in England (online version).* Available from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/453968/domestic_building_services_compliance_guide.pdf. [Accessed November 2016]

energy for each class based on the building type and building purpose. The values of the energy class C are used as the reference for comparing the efficiency of the other classes.

5 Energy Savings From Heating Controls

This section explains the difference between energy efficiency improvements and energy savings for heating systems. It identifies the factors that affect the energy efficiency improvements from advanced temperature controls. It also describes the main methods used to measure efficiency improvements and savings from heating controls and the benefits and disadvantages associated with each of them.

Sources of evidence for the energy savings achieved by each type of control (including responses from the stakeholder survey) are summarised and the associated merits and weaknesses are discussed. The results of modelling studies carried out in support of the SAP 2016 consultation[17] are also reviewed. Finally the evidence sources are summarised and evaluated.

5.1 Measuring Energy Savings and Energy Efficiency Improvements

For heating controls it is important to differentiate between energy efficiency improvements to the heating system and the energy savings which result from restricting the operating times and internal temperature of the building.

The energy efficiency of a heating system can vary considerably over the year and therefore the seasonal energy efficiency is the metric that is generally used. This is defined by the ratio of energy input into the boiler to heat output from the radiators over the course of a year.

This section is primarily concerned with improvements that controls make to the seasonal energy efficiency, but it also acknowledges the potential for controls to realise energy savings by controlling the timing and/or internal temperature more accurately.

The energy efficiency improvements and energy saving potential of heating controls can be measured in a number of ways:

[17] BRE (2016). *Consultation Paper – CONSP:02 SAP Seasonal Efficiency Calculation for Condensing Boilers.* SAP Supporting Document, Issue 1

- Full scale field trials in real houses are theoretically ideal, but difficult to realise because there are many different combinations of building type, heating system and heating schedules to consider which require extensive data collection and analysis. Such trials are therefore very expensive and rarely conducted.
- Using tests houses and environmental chambers (which may be a full scale domestic room) with actual or simulated outdoor climate conditions. These kinds of facilities are generally used by control manufacturers to test products. Such tests generally consider a small range of standard test conditions and will not necessarily reflect the full range of situations encountered across the housing stock.
- Computer modelling and simulation can also be employed. This has the advantage of allowing many different options to be considered. However, the accuracy of the results are crucially dependant on how accurately the computer model represents the heating system, the heat demands, the control systems and settings. It is more difficult to represent accurately the impact of user behaviour.

As heating controls facilitate an improvement in energy performance, a key issue for all types of energy performance measurement is the baseline against which the improvement is judged.

Advanced temperature controls that reduce the size of temperature swings compared to a more basic thermostat will tend to reduce the periods of under-heating. This may enable consumers to lower the temperature setting on the thermostat and still achieve comfort conditions. Given that a 1^{o}C reduction in the temperature setting can lead to an additional energy savings of around 10%, it is important that this aspect of energy savings from controls is not ignored. However, energy savings achieved through this mechanism are very hard to measure as they depend on the occupants' perceived level of comfort and their behavioural responses; both of these factors are highly variable.

5.2 Factors that Affect the Energy Efficiency Improvements from Temperature Control

One of the most important factors that influence the energy savings achieved by all three types of controls is the **base case** against which the savings are being compared. The base case that is probably most relevant for the UK housing stock is a heating system with a standard thermostat and TRVs, as this represents the minimum standards recommended to meet current Building Regulations for new build and is the most common situation in existing installations[18]. This would also be appropriate for upgrading existing heating controls.

[18] Palmer,J and Cooper,I (2013*). United Kingdom Housing Energy Fact File 2013.* Department of Energy & Climate Change

For all types of temperature control the energy efficiency savings will be dependent crucially on the **annual heat demand** for the building which is determined by:

- The building characteristics, including size and thermal properties of the building envelope
- The heating schedule (heating times and internal set points)
- Internal heat gains within the building, and
- The external temperature.

The energy efficiency and **operational parameters of the heating system** will also affect the energy savings that can be achieved. Key factors here include:

- The flow and return temperature
- The plant size ratio (the ratio of the maximum heat out of the system compared to the maximum design heat demand)
- The presence of timing controls
- The presence and accuracy of any existing temperature control
- The presence of other energy saving features such as optimum start/stop controls.

The way the controls are used by the consumer will also significantly affect the savings that controls can achieve. In particular, frequent changes to the temperature settings on thermostat and/or TRVs will significantly reduce the energy efficiency improvement achieved by advanced energy controls as they prevent the control from predicting the heat demand accurately.

5.2.1 Factors that Affect the Energy Efficiency Improvement from Advanced Temperature Controls

In addition to the factors identified for all types of temperature control, for compensation control the following factors will also determine the potential energy efficiency improvement:

- The extent to which the boiler can modulate (turn down) its heat output. This determines how low the return temperature can go and hence the scope for energy efficiency improvement. Most modern boilers are able to effectively modulate down to 30% of their maximum heat output or lower.
- In-built modulating control that will tend to lower the heat output (and hence lower the return temperature) when the return temperature gets high and be more energy efficient to start with.
- Use with other separate controls – weather compensation control results in lower energy efficiency when used with a separate timer (See Section 2.3.1 for explanation) and are not compatible with separate optimum start stop controls. However, weather compensation control integrated with a programmable thermostat with optimisation will tend to be more effective than with a separate

thermostat and optimum stop start functionality can be integrated within weather compensation controllers.

- Large changes in heat demand arising from intermittent heating patterns, short heating periods and high variations in occupant density will require higher flow temperatures to reach the set temperature and hence reduce energy efficiency improvements.
- The extent to which external temperature (weather) or internal heat load (load) determines the demand for heat.
    - This can be resolved by using controls that combine weather and load compensation (e.g. ErP Class VI control class).

As well as increasing the energy efficiency of the boiler, compensation controls may also lead to:

- less wear and tear on the boiler from reduced cycling
- lower pipe losses through unheated areas
- less noise from the boiler firing up.

5.2.2 Factors that Affect the Energy Efficiency Improvement from TPI Controls

As for compensation controls, the plant size ratio and how energy efficiently the heating system is already operating will affect the energy efficiency improvements that TPI control can achieve. However, the key factor that influences energy savings for TPI control is the proportion of time that the heating system is running in a steady state.

5.3 Recognition of Energy Efficiency Improvements in Energy Labelling and in SAP

This section identifies the energy savings that are credited to advanced temperature controls by Building Regulations, embodied in SAP, and under Energy Labelling requirements. (Details of the relevant legislation is provided in Section 4.)

The seasonal energy efficiency improvements allocated to the various ErP control classes (See Section 4.2 for further details) are summarised in Table 1.

Control Class Number	Control Type	Thermostat type	Modulation or on/off	Contribution to seasonal efficiency (percentage points)	Percentage point Improvement over Class I
I	Standard	Room Thermostat	on/off	1%	-
II	Weather compensation	No Thermostat	modulating	2%	1%
III	Weather compensation	No Thermostat	on/off	1.5%	0.5%
IV	TPI	Room Thermostat	on/off	2%	1%
V	Load compensation	Room Thermostat	modulating	3%	2%
VI	Weather compensation	Room Thermostat	modulating	4%	3%
VII	Weather compensation	Room Thermostat	on/off	3.5%	2.5%
VIII	Load Compensation	Multi-sensor Temperature Control	modulating	5%	4%

Table 1 – Ecodesign regulation (811/2013) temperature control class efficiency corrections

These allocate additional energy efficiency improvements compared to a standard room thermostat (Class I) of between 0.5% and 3% for weather compensation, 2% to 4% for load compensation and 1% for TPI control[19]. However, the technical origin of these values and hence reliability is not stated in any literature so their usefulness is questionable.

SAP currently allocates a 3% efficiency credit to condensing gas boilers' space heating efficiency for enhanced load compensators (load and weather compensation) and a 1.5% credit for oil or LPG boilers. SAP does not allocate any additional savings to TPI control over a basic on/off thermostat.

It is important to remember that both SAP and ErP are concerned with measuring the energy efficiency of the heating system i.e., the ratio of energy input to heat output. If a control enables the average temperature in the room to be achieved without compromising comfort this can lead to additional energy savings by reducing waste.

5.4 Modelled Energy Efficiency Improvements

Recent modelling work has been carried out on compensation control in support of the 2016 SAP Consultation[20]. This calculated the seasonal efficiency for a wet central

[19] Note that the ErP seasonal efficiency calculation method subtracts 3% from the base case if no control is present.

[20] BRE (2016). *Consultation Paper – CONSP:02 SAP Seasonal Efficiency Calculation for Condensing Boilers.* SAP Supporting Document, Issue 1.1

heating system fed by a boiler. It did so by estimating an hourly efficiency from the return water temperature and an efficiency-return water temperature curve. These vary on an hourly basis with reference to the space heating load, whereby the seasonal space heating efficiency is determined by the summation of the hourly heat energy requirements divided by the summation of the hourly fuel energy. Two situations were modelled as follows:

- Perfect weather and load compensator – the mean emitter temperature (and hence water return temperature) is that required to exactly match the dwelling heat losses after accounting for internal heat gains.
- No compensator – the return water temperature is taken as the design value throughout the heating season.

The seasonal space heating efficiency was calculated for a range of different design flow and return temperatures for different fuels (natural gas, oil and LPG) and for modulating and on/off boilers. The calculated savings for each type of control were calculated based on a percentage of the difference between a boiler operating with a thermostatic room control and with idealised compensation control.

To provide a realistic estimate of the energy efficiency improvement that weather and load compensation are expected to achieve in practice, a percentage of the idealised compensation savings is taken.

Table 2, reproduces a table from the SAP 2016 consultation paper for for gas boilers which shows the estimated energy efficiency improvement for each type of compensation controls.

Control Class Number	Control Type	Modulation	Design Flow/Return Temperature			
			80/60 or 70/60	55/47.1	45/38.6	35/30
II	Weather compensation	modulating	0.7%	3.4%	6.1%	8.0%
III	Weather compensation	on/off	0.9%	3.5%	6.0%	7.7%
V	Load Compensation	modulating	0.7%	3.4%	6.1%	8.0%
VI	Weather compensation	modulating	1.8%	5%	6.9%	8.4%
VII	Weather compensation	on/off	2.3%	5.4%	7.2%	8.7%
VIII	Load Compensation	modulating	0.7%	3.4%	6.1%	8.0%

Table 2: Calculated percentage energy efficiency improvements for different types of compensation controls over a standard room thermostat for gas boilers[21]

As well as providing estimates of the energy efficiency improvements that can (theoretically) be achieved by compensation controls, the report also provides an indication of the range of energy savings that are likely to be achieved for different types of heating systems and operating conditions.

The extent to which the calculated energy efficiency improvements reflect the actual savings depends on how accurately the heating system, including controls, is modelled. Whilst hourly modelling is generally acknowledged as being appropriate for calculating the seasonal efficiency of heating systems, it may be that hourly time steps are not sufficiently detailed to capture the dynamics of control systems so as to provide a guide to the marginal impact of controls.

[21] BRE (2016). *Consultation Paper – CONSP:02 SAP Seasonal Efficiency Calculation for Condensing Boilers.* SAP Supporting Document, Issue 1.1

The heating schedules and occupancy patterns used in SAP have been developed to reflect typical heat demands in buildings so these calculated values should provide a reasonable basis for estimating energy savings in the absence of detailed monitoring data.

Detailed dynamic modelling of controls is undertaken by universities and other research institutions, but no reports of energy efficiency improvements and energy savings arising from advanced energy savings temperature controls from modelling were identified for this study. Work commissioned by BRE[22] in support of Defra's MTP (Market Transformation Programme) developed a capability to dynamically model heating systems to assess the energy savings potential of different types of controls for a range of representative housing types and heating schedules. However, funding for the MTP programme ceased before this work was completed. The modelling work was undertaken by the University of Strathclyde and since MTP funding ceased the research team have been working in collaboration with two major control manufacturers to validate the model[23]. The modelling capability includes both compensation and TPI control.

5.5 Evidence of Energy Savings from Weather Compensation Controls

Only one primary source of data on energy savings from weather compensation control was identified. This was a confidential test carried out at the Salford University's test house facility for Viessmann[24]. The test compared the performance of a heating system with a modulating gas boiler, mechanical room thermostat and TRVs to that of an identical heating system whose thermostat included weather compensation capability. More details on the test conditions and discussion of the results is provided in Appendix E and evidence is evaluated in Section 5.8.

Secondary data sources, mostly from manufacturers' literature, typically quote savings of between 10% and 40%. Respondents to the stakeholder survey were asked what they thought would be a typical percentage of annual energy savings that they would expect from weather compensation. The results are summarised in Figure 5.

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[22] Cockcroft,J, Samuel,A, and Tuohy,P (2007). Development of a Methodology for the Evaluation of Domestic Heating Controls, Phase 2 of a DEFRA Market Transformation Programme Project, Final Report. Energy Systems Research Unit, University of Strathcyde.

[23] Cockcroft,J Kennedy,D, O'Hara,M, Samuel,A, Strachan,P and Tuohy,P (2009). *Development and Validation of Detailed Building, Plant and Controller Modelling to Demonstrate Interactive Behaviour of System Components*. Energy Systems Research Unit, University of Strathecylde, Honeywell Control Systems and Danfoss Randal Ltd, Building Simulation 2009, 11th International IBPSA Conference, July 2009.

[24] Viessmann (2014). *Confidential Technical Report*. University of Salford, November 2014

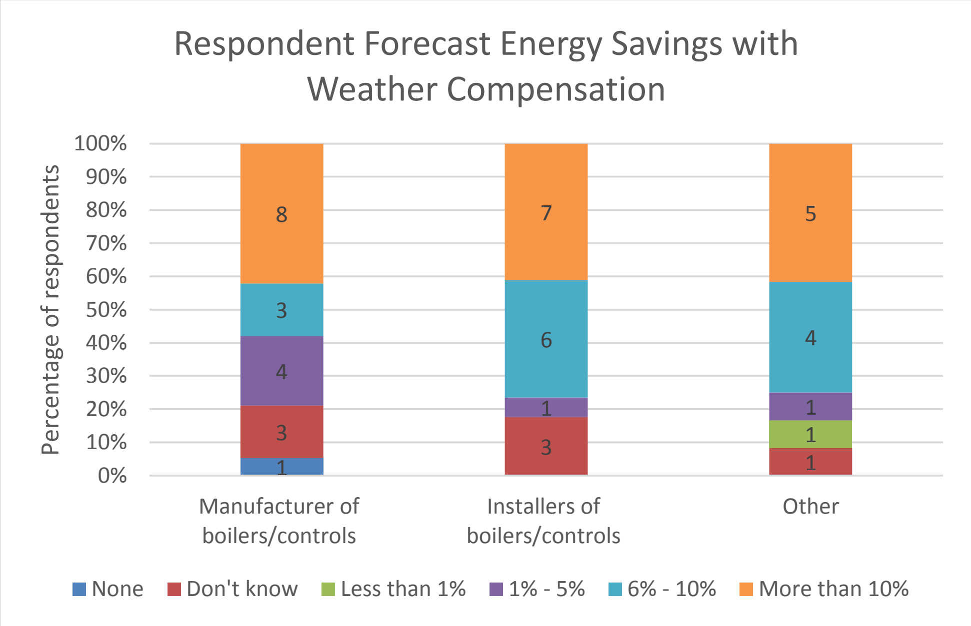

Figure 5: Percentage forecast energy savings from weather compensation by respondent type and number of respondents

Only one of the respondents expected weather compensation control to achieve no savings, whilst 15% (n=7) either said they didn't know or didn't select a saving percentage. Of the 83% (n=40) that did identify a typical percentage energy saving, 50% (n=20) selected greater than 10% saving, whilst a further 33% (n=13) selected savings of between 5% and 10% energy saving as being typical. The proportion of respondents expecting savings of >10% is similar across all respondent groupings. However, it is noticeable that a higher proportion of manufacturers (among the small example) expect lower energy savings to be typical compared to the other respondent groups.

Overall the high proportion of respondents claiming high energy savings for these controls would seem to reflect the values that are typically quoted in manufacturers' literature.

5.6 Evidence of Energy Savings from Load Compensation

One primary source of evidence on energy savings from load compensation control was identified. The test conditions and the findings of this study are discussed and analysed in this section along with the expected energy savings reported by the stakeholders.

This paper[25] presents the results of tests carried out in an environmental chamber on a heating system with a modulating gas boiler. The test conditions were to heat the test chamber for 12 hours with an external temperature of $10^{o}C$ and an internal temperature of $20^{o}C$.

More details on the test conditions and discussion of the results is provided in Appendix E and evidence is evaluated in Section 5.8.

Another study by Staffordshire University[26] reports field measurements for a type of on/off load control. This control operates by reducing the time that the boiler fires when the difference between the supply and return temperature is small and the return temperature rises above a certain level. Trials were carried out at a number of different premises, where the heating system was run with and without the control mechanism in a 24hr cycle over a period of around 30 days. However, the study only measured the difference in the proportion of time that the boiler was firing which does not directly relate to the energy savings. Therefore, this evidence source was not evaluated.

Respondents to the stakeholder survey were asked what they thought would be a typical percentage of annual energy savings that they would expect from load compensation. The results are very similar to those for weather compensation and are summarised in Figure 6.

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[25] O'Hara,M (2009). *Reducing the Carbon Footprint of Existing Domestic Heating: A Non-Disruptive Approach,* Danfoss Randall Limited, EEDAL 2009, 16-18 June 2009

[26] Hanstock,M (2013). *TEC Boiler Controls Test Methodology Evaluation.* Faculty of Computing, Engineering and Science, Electronic Design Centre

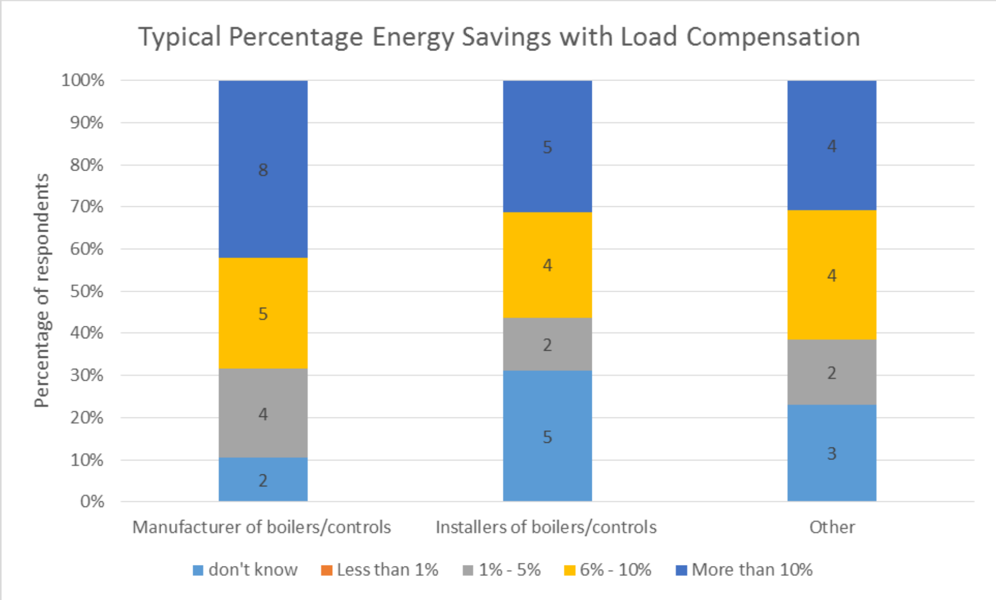

Figure 6: Percentage forecast energy savings from load compensation control by respondent type and number of respondents

5.7 Evidence of Energy Savings from TPI Control

Several test studies and one field trial were identified that reported measured energy savings for TPI controls. The test conditions and the findings of these studies are discussed and analysed in this section and the expected energy savings reported by the stakeholders are presented.

5.7.1 TPI Control Evidence: University of Salford Test House Studies

A technical report on energy savings carried out in a test house[27] showed that a TPI thermostatic control achieved energy savings of 33% compared to a "no thermostat" base case. This was measured over a 24 hour period with a typical "twice a day" heating schedule (06:30-09:00 and 15:30-23:00) with an external temperature of 5^{o}C and an internal set temperature of 21^{o}C. The test also reported an additional ~21% of energy savings where TRVs were installed in addition to the TPI thermostatic control.

The results of two other tests carried out at this facility were provided by stakeholders on an in-confidence basis. Neither looked at energy consumption compared to a base case without TPI control, however, they are of interest for temperature controls in general. One showed that decreasing the temperature on a TPI rather than switching

[27] BEAMA (2014). *Technical Report – Energy Savings from the Addition of a TPI Room Thermostat and TRVs to a Domestic Heating System*, University of Salford, June 2014

the heating system off can reduce energy consumption[28]. A further test showed that TRVs in combination with a TPI room thermostat can reduce energy consumption where the heat demand in other rooms is lower than in the reference room[29].

5.7.2 TPI Control Evidence: O'Hara/Danfoss EEDAL 2009

Another paper[30] presents the results of tests carried out in an environmental chamber on a heating system with a modulating gas boiler. The test conditions are the same as those used for the load compensation test which is reported in the same paper. This reported that the electronic on/off control achieved a ~2% energy saving compared to the mechanical control, and that in TPI mode (with 6 on-off cycles per hour) achieved an energy saving of ~10.35% over the mechanical on-off control and ~8.25% over the electronic on/off control.

5.7.3 TPI Control Evidence: EST TPI Control Field Trial

A report for the Energy Saving Trust[31] trialled the use of TPI controls in around 50 homes. Monitoring data was collected at 5 minute intervals for around a year both before and after TPI controls were fitted and the data extensively analysed. The report identified that whilst there were periods where TPI control was effective, they accounted for only a small proportion of the total operating time. Although on average a small reduction in energy consumption with TPI controls was observed for the sample (the average seasonal energy efficiency across the sample was 82.86% pre TPI control and 83.21% post TPI control), the difference was not statistically significant. The report also identified that whilst there might be a slight increase in electricity consumption with TPI control it was not statistically significant.

Respondents to the stakeholder survey were asked what they thought would be a typical percentage of annual energy savings that they would expect from TPI control. The results are summarised in Figure 7.

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[28] BEAMA (2014). *Technical Report – Energy Savings from the Addition of a TPI Room Thermostat and TRVs to a Domestic Heating System*, University of Salford, June 2014.

[29] BEAMA (2016). *Confidential Technical Report.* University of Salford, April 2016.

[30] O'Hara,M (2009) Danfoss Randall Limited, *Reducing the Carbon Footprint of Existing Domestic Heating: A Non-Disruptive Approach*, EEDAL 2009 16-18 June 2009.

[31] Gastec, AECOM and EA technology (2010). *Final Report: In-Situ Monitoring of Efficiencies of Condensing Boilers – TPI Control Project Extension*. September 2010.

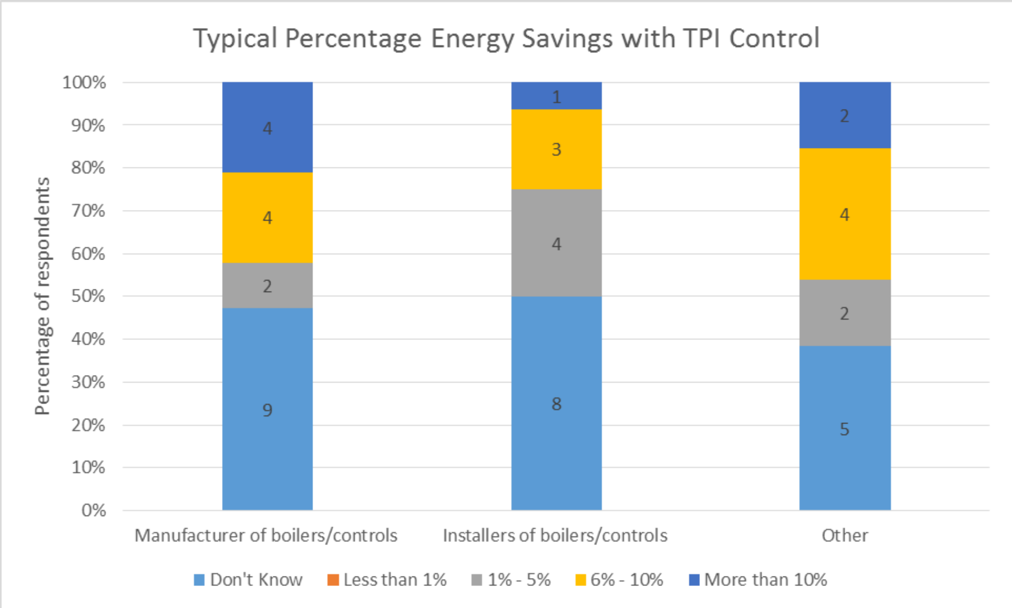

Figure 7: Percentage forecast energy savings from TPI control by respondent type and number of respondents

It is noticeable that a greater proportion of stakeholders have answered "don't know" compared to compensation controls and that this proportion is high even amongst manufacturers. Of those respondents who provided a value, the majority have identified savings of 6%-10% as being typical.

5.8 Evaluation of Evidence for Energy Savings

This section summarises the sources of evidence for energy savings by source type, evaluates them against a number of criteria and assesses how likely the reported savings are to be representative of what can be achieved in the UK housing stock.

In order to assess the validity of the reported savings an evaluation exercise was undertaken which examined the extent to which the test conditions reflected UK heating systems and operating conditions and other aspects that might affect the energy savings reported.

The evidence sources were evaluated against the following criteria:

- Base case heating system - A modulating boiler where the temperature is controlled using an electronic room thermostat with or without TRVs in all other rooms is taken as a representative base case.
- The heating schedule – A schedule with two heating periods, a shorter heating period in the morning and longer heating period in the evening is taken to be representative of heating schedules in the UK.
- Internal Temperatures – A set point of 20°C in the living room (and 18°C in the rest of the house, where appropriate) is taken to be a representative heating schedule for the UK.

- Whether the study takes into account the effects of occupant behaviour that impacts on heating demand.

For each evidence source, the extent to which the test conditions are representative of heating systems in the UK were assessed as being typical, plausible or unrepresentative. The results of this analysis are presented in Table 3 with plausible and unrepresentative conditions highlighted in orange and red, respectively (see key below).

	Unrepresentative
	Plausible

An overall assessment of the extent to which the measured energy savings are likely to reflect typical energy savings for heating systems in the UK is based on the assessment for each criteria.

Control type	Study	Energy savings reported	Base case	Internal temperature achieved	Heating schedule	Occupant behaviour
Weather Compensation – Test House	Viessmann (2014)	15% to 45%	room thermostat and TRVs	$21^{o}C$ - Internal temperature not reached with weather compensation	long twice a day schedule	No
Load Compensation – Environmental Chamber	O'Hara (2009)	10%/14%	room thermostat	$20^{o}C$	steady state	No
TPI – Test House	BEAMA (2014)	33%	no thermostat	$21^{o}C$ but significant overheating in base case	long twice a day schedule	No
TPI – Test House	TACMA (2014)	Shows additional savings with longer heating periods	room thermostat and TRVs	$21^{o}C$	long twice a day schedule	No
TPI – Test House	BEAMA (2016)	Shows TPI room thermostat with TRVs can save more energy than TPI alone when heat demand in other rooms is lower.	room thermostat and TRVs	$24^{o}C$	steady state	No
TPI – Field Trial	Gastec (2010)	0-0.5%	Various	Actual - but variations over monitoring period	Actual - but variations over monitoring period	Yes
TPI – Environmental Chamber	O'Hara (2007)/ BEAMA (2009)	10%/14%	room thermostat	$20^{o}C$	steady state	No

Table 3: Evaluation of Evidence Sources against Test Criteria (Key on previous page)

Aside from the BEAMA 2014 test house, the base case for all the other studies are considered plausible.

The internal temperature set point of 24^{o}C used in the BEAMA test study is at the upper end of those typically observed in the UK housing stock and so is deemed to be plausible. Although the internal temperature point for the weather compensation (Veissmann 2014) and TPI (BEAMA 2014) studies is appropriate, there are significant differences in the temperatures achieved with and without the energy saving controls. For the weather compensation study the average internal temperature achieved is significantly lower than the set point temperature and because the TPI study uses a base case with no thermostat, the internal temperature for the base case is considerably higher than the set point temperature. Therefore, the savings reported by these two evidence sources are considered unrepresentative.

Steady state heating schedules are not representative of typical UK heating patterns, and are a likely to overstate the savings achieved by TPI control which only saves energy once the internal temperature set point is reached.

Aside from the TPI field trial which is based on actual heating demands, all the other studies have looked at steady state heat demands. These don’t take account of the changes in internal gains from other energy use within the home, from varying solar gains and from occupant behaviour including moving around the house opening and shutting doors and windows, drying washing on heat emitters, etc. Therefore, the savings reported by the other test house and environmental chamber studies are likely to represent the maximum potential savings that could be achieved in an actual home under the same circumstances.

Although the results of the test houses and environmental chambers are credible in themselves, as these studies have been undertaken or commissioned by control manufacturers, they are potentially less likely to select test conditions where energy savings are minimal. Therefore, these studies are more likely to represent the upper range of energy savings achieved in practice under the same conditions.

The TPI field trial is the only evidence source that is based on actual measurement and the results are inconclusive for reasons discussed in Section 5.7.3.

The main conclusion of this study is that there is a lack of evidence on the energy savings that compensation and TPI controls are likely to achieve in practice.

Further details and discussion of the individual studies is provided in Appendix E.

6 Market for Advanced Temperature Controls

This section considers evidence regarding the availability of compensation and TPI control in the UK market and the supply chain. It draws on information provided in manufacturers' literature, analysis of the SAP Product Characteristics Database (PCDB) and from stakeholders. It also identifies the importance of communication protocols and presents options for existing protocols based on responses to the stakeholder questionnaire.

6.1 Availability of Advanced Temperature Controls

Weather compensation, load compensation and TPI controllers are readily available in the UK and are frequently identified by their ErP control class (See Section 4.2 for further information) in sales literature and product descriptions.

An analysis of the SAP Product Characteristics Database (PCDB)[32] was undertaken to provide an overview of the types of the heating controls that are currently on the market[33].

Whilst this database will not necessarily cover all products that are installed in UK homes, it would be expected to cover the majority of models that are available and hence provide a useful snapshot of the types that are currently on the market. As the database also identifies the year in which products first entered the market and when they become obsolete, it is able to provide a view of how the range of products available has changed in recent years.

Heating controls data has only been entered into the product database from 2012 and it is clear that it does not cover all control units on the market as known units from some major manufacturers do not currently feature. Nevertheless, this data should provide a good indication of the range of compensating controls that are available on the UK market.

The database currently contains details of 38 compensating control units from 10 manufacturers and of these 29 (76%) are for gas boilers, 7 (18%) for LPG boilers and 2 (5%) are for oil boilers. Aside from the two oil boiler controls, which are for on-off boilers, the remainder are for modulating boilers. Twelve (32%) of the controls use manufacturer specific eBUS communication protocols, 10 (26%) use the OpenTherm communication protocol, whilst the remainder (42%) use other manufacturer specific protocols. All of the models are identified as being incompatible with separate

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[32] Product Characteristics Database (2016) [Online] Available From: http://ncm-pcdb.org.uk [Accessed September 2016]

[33] The Product Characteristics Database exists to help SAP assessors find the correctly calculated seasonal efficiency and other characteristics for energy using products. It holds data on a variety of different types of products in separate tables and includes a category "Boilers, fired by gas, LPG or oil" that incorporates characteristics that relate to heating controls and identifies boilers that are compatible with different types of controls.

optimisation controls, however, this feature can be used with compensation controls provided it is incorporated into a single control unit.

It is not clear why more control manufacturers have not submitted information for inclusion in the PCDB, given that it is not possible to claim the additional efficiency savings for the heating system (eg. for Energy Performance Certificates (EPCs) and Building Regulation compliance) without it.

The PCDB also identifies boilers that are compatible with compensation controls and the type of communication protocol that they use.

The supply chain for all temperature controls, including advanced temperature controls for domestic heating systems, is strongly related to the boiler market.

The majority of boilers that are currently sold already have intelligent communication protocols (either manufacturer specific "closed" protocols or (less frequently) OpenTherm (which allows any OpenTherm controls to be fitted). These communication protocols enable the boiler to receive and respond to signals from the controller by reducing the heat output. Industry stakeholders report that around 70% of combi-boilers are fitted with a plug-in controller. This may come from the manufacturer as standard, or more commonly be fitted by the installer as an optional extra. These plug-in controllers range from a simple mechanical time clock, or a more complex programmer, to programmable room thermostats with load compensation. The volume of third party plug-in sales is growing. Product searches and industry stakeholders indicate that there is a small but growing number of internet-enabled thermostats, some of which offer combination load and weather compensation or programmable room thermostats incorporating TPI).

For new build dwellings the choice of heating system is typically determined by the builder. Builders will tend toward specifying the cheapest option available that meets with minimum performance standards as energy running cost will have little impact on the selling price.

For existing homes, available evidence indicates that the choice of boiler and controls is generally determined by installer's recommendations[34]. It is also the case that manufacturers provide training on installing their specific controls and sometimes offer incentives to installers to use their controls. Installers also instruct consumers in the use of the controls and set them up initially based on the consumer's lifestyle and preferences.

[34] Wade,F, Shipworth,M and Hitchings,R (2016). *How Installers Select and Explain Domestic Heating Controls, Building Research and Information.*

6.2 Potential Market for Advanced Temperature Control

This section presents evidence relating to the potential market for advanced temperature controls. It considers the UK market for the installation of new boilers and the retrofit, replacement and upgrade markets in existing heating systems.

6.2.1 New Boiler Installations

The potential market for advanced boiler controls in the UK is primarily driven by the number of new heating systems installed, therefore boiler sales is key indicator of potential market size. Data on the number of gas and LPG boiler sales in the UK is collected on a monthly basis by the Heating and Hot Water Industry Council (HHIC). In addition to this there are estimated to be an additional 5% of oil boilers installed[35]. Annual sales for domestic boilers in the UK are currently estimated to be 1.6 million, of which around 1.2 million are combi-boilers (system and regular boilers are not generally suitable for compensation control as it is not possible to differentiate between the space heating and hot water demand). The estimated stock of domestic boilers in the UK is around 23 million[36] which implies an average lifetime of 15 years. This is slightly lower than the 20 years implied by the English Housing Survey that reports each year some 5% of homes with wet central heating systems replace their boilers.

In the UK, compensation controls are generally used with modulating boilers. However, the HHIC data does not distinguish between modulating and on/off boilers, nor does it provide any indication as to whether the boilers contain, or have the communication facilities to work with, compensating controls.

In order to provide an indication of the boilers that are most suitable for compensation control, analysis of the boiler models in the SAP PCDB[37] was undertaken. This lists the vast majority[38]of boilers currently on the market and the year in which they were first manufactured. Table 4 shows the number of boilers currently on the market broken down by their modulating capability and fuel type.

[35] Based on the proportion on the proportion of existing gas and oil boilers for the *English House Condition Survey Energy Report* (DCLG 2014), on the assumption that nearly all existing oil boilers are installed in areas which do not have access to grid supply gas.

[36] Department for Communities and Local Government (2014). *English House Condition Survey Energy Report.*

[37] Product Characteristics Database (2016) [Online] Available From: http://ncm-pcdb.org.uk [Accessed September 2016]

[38] Unless boilers are listed in the PCDB default seasonal efficiency values are assumed in SAP so all but the oldest/least efficient boilers are likely to be included.

Number of boilers	LPG	Natural Gas	Oil	All
Modulating	744	1646	7	2397
On-off	49	263	1099	1411
Unknown	0	0	1	1
Total	793	1909	1107	3809

Table 4: Boiler models broken down by modulating/on-off status and fuel type (Source: Analysis of PCDB data)

This shows that 99% of oil-fired boilers registered on the database are non-modulating boilers, whilst 86% and 94% of natural gas and LPG-fired boilers, respectively, are able to modulate their heat output.

Figure 8 shows how the proportion of models on the market which are modulating combi- boilers has increased since 1988.

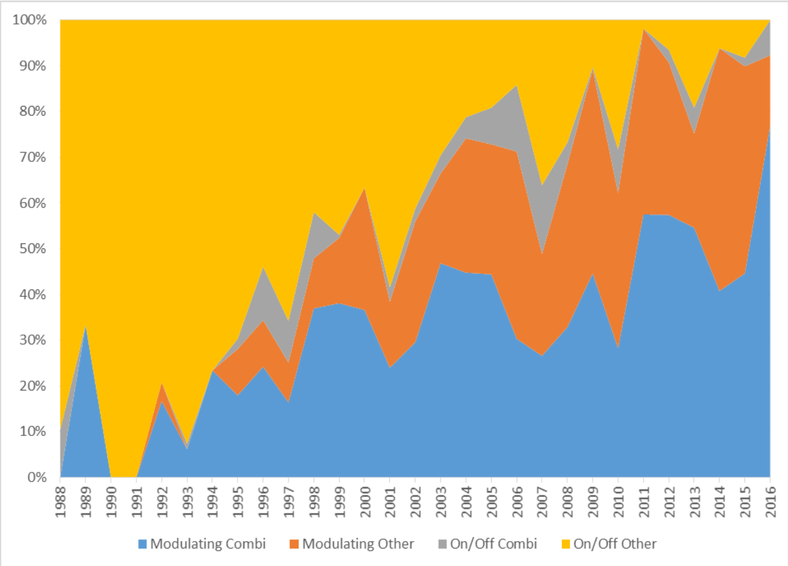

Figure 8: Boilers included in the PCDB by their first year of manufacture broken down by boiler type and modulation capability

Figure 9 shows the number of boilers entering the market that are compatible with advanced energy efficiency controls based on analysis of data held in the PCDB. Compatibility is determined by the ability of the boiler's internal control electronics to communicate with external controls.

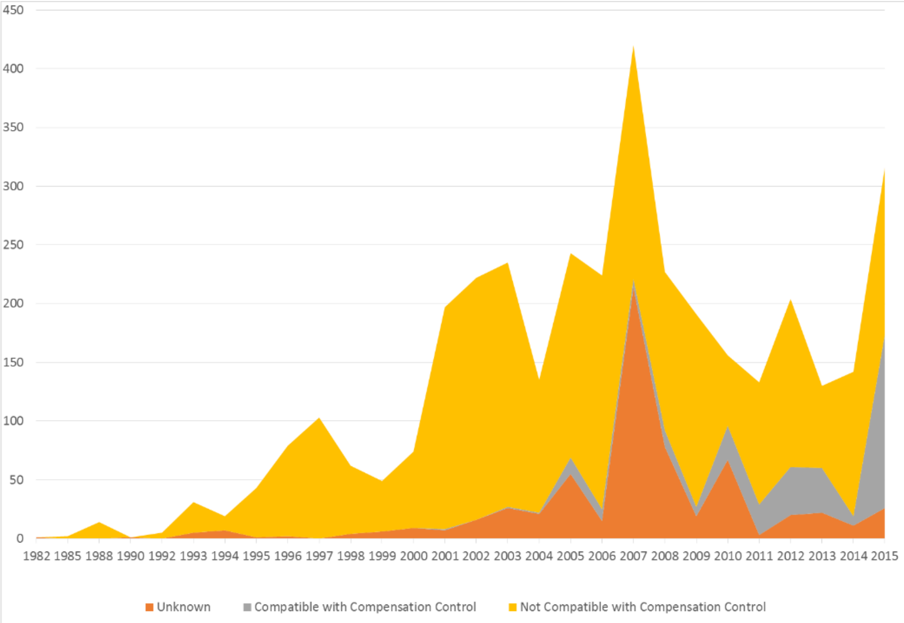

Figure 9: Number of boiler models entering the market by control compatibility status and year of market entry

This shows that that the number of boilers compatible with advanced controls has increased substantially since they first appeared in around 2000. Around half of all new models entering the market in 2015 are compatible with compensation controls and the number is increasing fast. Stakeholder interviews confirmed that the majority of boilers coming onto the UK market are compatible with advanced controls.

6.2.2 Installations in Existing Heating Systems

The potential market for advanced controls in existing heating systems comprises retrofit, replacement and upgrade segments. This section identifies evidence relating to the potential size of each of these market segments.

The potential retrofit market will be primarily comprised of the 15% of homes with gas central heating that currently have no room thermostat[39], those where the existing control has broken, and instances where consumers choose to upgrade their room thermostat/heating controls.

The Approved Documents supporting Building Regulations have, since the 1990s, specified that heating systems should be fitted with a room thermostat and TRVs.

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[39] The English House Condition Survey Report published in 2014 indicates that 15% of homes with gas central heating currently have no room thermostat https://www.gov.uk/government/statistics/english-housing-survey-2014-energy-report

However, the 2014 English House Condition Survey Energy Report[40] shows that for homes with gas and oil central heating, only 85% had at least one room thermostat and concluded that 21% of homes with a boiler-driven heating system would benefit from upgrading heating controls. Assuming a 15 year replacement cycle for boilers it is reasonable to assume that the proportion of homes that have no room thermostat will have reduced significantly over two years. As they are likely to be older systems it is probable that only a small proportion of these systems will be suitable for compensating heating controls.

Although the product lifetimes for controls (from the stakeholder survey) are of a similar order to the typical lifetime of a boiler, there will be instances where controls require replacement before the boiler - and this may happen more frequently with more sophisticated controls as there is more to go wrong (for example touch screen user interfaces and embedded software).

The results of the stakeholder questionnaire indicate that the majority of respondents think that there is a significant potential market for retrofitting all three types of control: 80%, 84% and 89%, for weather compensation, load compensation and TPI controls, respectively.

The relative size of the retrofit market is expected to be considerably smaller than the new installation (new build and replacement heating systems) market, although the savings potential is likely to be higher, particularly where they replace no or very old controls.

There will also be a potential market for consumers who chose to upgrade their heating controls. The Homes Energy Efficiency Database (HEED) database[41] does include some data on heating controls upgrades. However, the reported number of homes upgrading is small (31,419 out of a total stock of over 13 million), and the nature of upgrades is not recorded.

6.3 Current Market Share of Advanced Temperature Controls

No definitive evidence on the current market share of each of the three types of controls was identified. However, information provided by stakeholders would suggest that the current market shares are around 12% for TPI control, and around 2% for both weather and load compensation.

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[40] Department for Communities and Local Government (2014). *English House Condition Survey Energy Report, 2014*

[41] Energy Savings Trust (2016) [Online] HEED database. Available From http://www.energysavingtrust.org.uk/scotland/businesses-organisations/data-services/heed [Accessed September 2016]

7 Cost of Advanced Temperature Controls

This section summarises evidence obtained regarding the cost of advanced temperature controls. In addition to the initial purchase price, other lifetime costs associated with installation, commissioning and maintenance have been identified for each type of control. The data that is presented here is obtained primarily from information provided by respondents to the stakeholder survey. This was supported by information on product costs obtained by sampling popular online prices from trade and consumer retailers. More details and discussion of the cost data is provided in Appendix G.

7.1 Additional Cost of Weather Compensation, Load Compensation and TPI Controls

This section summarises the additional costs (inclusive of VAT) associated with each type of advanced temperature controls and an indication of the typical annual percentage savings that would be required for each control to repay the cost within its lifetime.

The additional costs are based on the stakeholder survey results (typical = 50th percentile, high = 75th percentile and low = 25th percentile) which were cross-checked against prices found on popular online wholesale and retail websites. Installer costs were estimated based on the typical additional installation time provided by stakeholders and an assumed hourly rate of £30 for installers.

Tables 5, 6 and 7 summarise the additional costs associated with weather compensation, load compensation and TPI control, respectively. These costs are based on the stakeholder survey results (typical = 50th percentile, high = 75th percentile and low = 25th percentile) and installer costs based on an hourly rate of £30.

Weather Compensation	Additional Cost (£)		
	Typical	High	Low
Control unit	£100	£150	£75
External temperature sensor	£50	£113	£30
Total hardware cost	£150	£263	£105
Installation	£51	£75	£30
Total Installation	£201	£338	£135

Table 5: Summary of the additional costs associated with installing a weather compensation control (stakeholder responses)

Load Compensation	Additional Cost (£)		
	Typical	High	Low
Control unit	£85	£115	£63
Installation	£23	£30	£15
Total	£108	£145	£78

Table 6: Summary of the additional costs associated with installing load compensation control

TPI controls	Additional Cost (£)		
	Typical	High	Low
Control unit	£50	£55	£30
Installation	£15	£19	£19
Total Installation	£65	£74	£49

Table 7: Summary of the additional costs associated with installing a TPI control

The total additional installation cost for weather compensation is higher than the additional (installed) cost of £120 (including VAT) quoted by the Ecodesign boiler study[42]. However, this may relate to installing weather compensation without a thermostat[43], which is common in North European countries and could account for this difference.

The cost of TPI control is broadly in line with an additional installation cost of £50 including VAT quoted by the Ecodesign boiler study[44].

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[42] Preparatory study on Eco-design of Boilers, Task 6 Report (Final) Rene Kemna, Martjin van Elburg, William Li and Rob van Holsteijn, September 2007 – 1.50 €/£

[43] The costs shown in Table 5 include the cost of a thermostat.

[44] Preparatory study on Eco-design of Boilers, Task 6 Report (Final) Rene Kemna, Martjin van Elburg, William Li and Rob van Holsteijn, September 2007

Table 8 shows the estimated annual percentage energy savings each type of advanced temperature control would need to achieve in order to payback the additional installation cost within their lifetime. The annual percentage savings required are based on a typical annual space heating cost of £551[45] and are shown for 10 year and a 15 year product life. The breakeven percentage energy savings were calculated as the additional installation cost divided by the product lifetime, to give the annualized additional cost divided by the annual space heating cost.

Control Type	Additional Cost (£)	Breakeven Energy Saving	
		15 Year Lifetime	10 Year Lifetime
Weather Compensation	200	2.4%	3.6%
Load Compensation	110	1.3%	2.0%
TPI Controls	65	0.8%	1.2%

Table 8: Typical additional installation cost for advanced temperature controls and the percentage energy savings required to payback within a 10 and 15 year lifetime

7.2 Future Cost of Advanced Temperature Controls

This section considers the underlying factors that are expected to affect the future cost of compensation and TPI controls. It also reports stakeholders' views on how they expect the purchase price of compensation and TPI controls to change over the next 5 years.

7.2.1 Future Weather Sensor Costs

The purchase price of a weather sensor is already relatively low at around £50 and they are available from a number of manufacturers. The technology is well established and temperature sensors are widely used in commercial and industrial applications. Technological intervention is therefore unlikely to lead to a significant reduction in the cost of external temperature sensors. This view is reflected in the responses from the stakeholder survey to the question "What do you expect to happen to the cost of a weather sensor over the next 5 years?" as summarised in Figure 10.

[45] Based on the average annual gas bill of £714 from Quarterly Energy Prices (BEIS 2016) and the proportion of energy used for space heating and hot water in the UK from the United Kingdom Housing Energy Fact File (Palmer 2013)

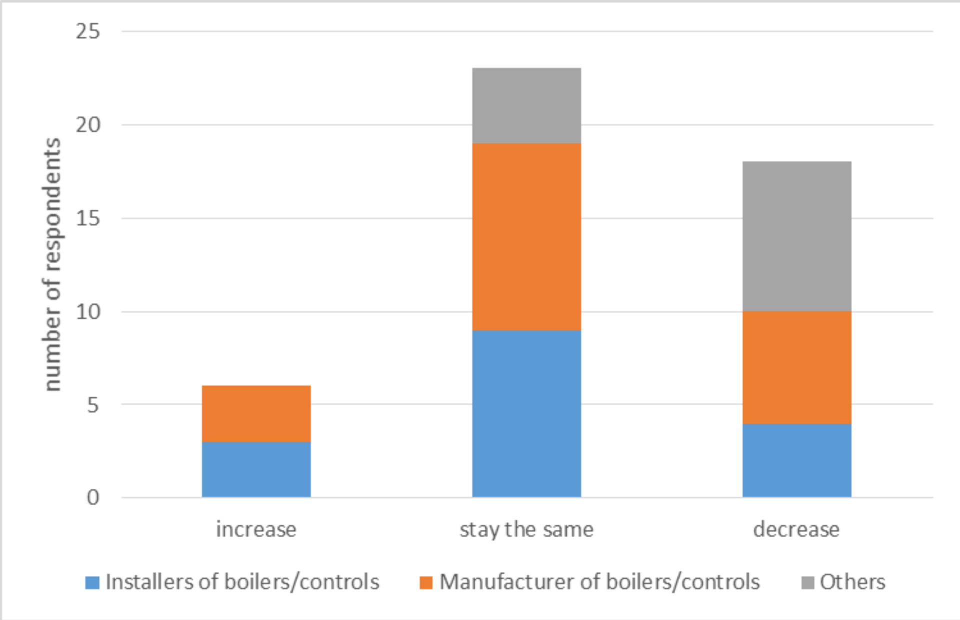

Figure 10: Respondent expectations on the future purchase price of a weather sensor

This shows that 48% of respondents (n=23) expected that the purchase price would stay the same, whilst 38% (n=18) expected it to decrease and only 13% (n=6) expected it to increase.

However, the use of internet-enabled controls that use online weather data can eliminate the requirement for, and hence the cost of a weather sensor altogether. Product price searches indicate that the cost of weather compensation controllers with this facility tend to be more expensive that those without. In addition, some control units (generally those with remote control capability) also charge monthly or annual service fees. Given the variety of product features and payment models available it was not possible to ascertain a typical cost associated with the use of online weather data.

7.2.2 Future Costs of Compensation Control

The marginal additional purchase cost of a controller that includes compensation control is currently around £100 (See Section 7.3). However, as compensation controls are generally included in controllers that possess other advanced features, this probably represents an overestimate of the additional cost. The marginal cost of the compensation control itself is likely to be significantly less and the additional production costs associated with including additional logic within the printed circuit board of an advanced controller with multi-functionalities are likely to be modest. As the market for advanced controllers grows, the marginal cost of the compensation control functionality is expected to fall.

The views expressed by stakeholders appear to support this view. Figure 11 shows how the stakeholders expect the price of controls with compensation capability to change over the next 5 years.

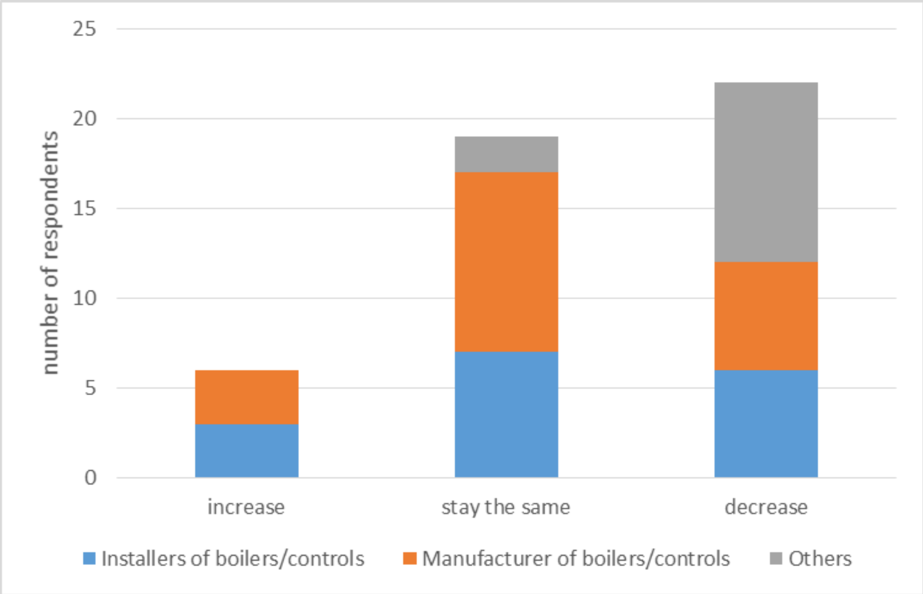

Figure 11: Respondent expectations on the future purchase price of a controller with compensation capability

This shows that 46% of respondents (n=22) are expecting the purchase price to decrease over the next 5 years, whilst 40% (n=19) expected it to stay the same and only 13% (n=6) expected it to increase.

7.2.3 Future Cost of TPI Control

Stakeholders were also asked how they expected the purchase price of TPI controls to change over the next 5 years. The results are summarised in Figure 12.

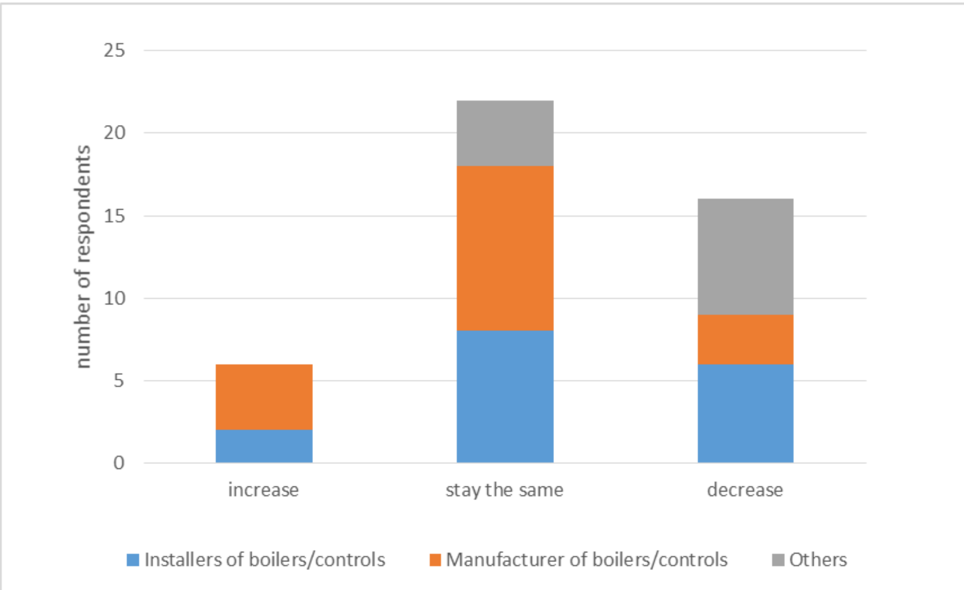

Figure 12: Respondent expectations on the future purchase price of TPI controls

7.3 Factors Expected to Influence the Future Price of Advanced Temperature Controls

To provide an understanding of the underlying reasons for the future price changes of advanced temperature controls, stakeholders were asked to select from a list the factors that they thought would most impact on these control technologies in the next 5 years. The factors offered, number of respondents and the percentage selecting each factor are shown in Table 9.

Response	Proportion	Respondants	%
Government legislation		39	85%
Increased consumer awareness		39	85%
Evidence of savings		37	80%
Increased installer awareness		33	72%
Cost/benefit information		32	70%
Good practice specification		31	67%
Technological improvements		27	59%
Availability of trained installers		25	54%
Economies of scale		23	50%
Increased competition		13	28%
Other (please specify)		2	4%

Table 9: Stakeholder survey results: Factors expected to influence the price of advanced temperature controls over the next 5 years

Government legislation and increased consumer awareness were cited as factors by 85% of respondents, with evidence of savings, increased installer awareness and cost benefit and good practice information cited by over two thirds of respondents.

These results suggests that most respondents think market pull factors rather than supply side improvements are most likely to influence the future price of advanced temperature controls.

8 Barriers to Increased Uptake of Advanced Temperature Controls

This section identifies barriers to the increased uptake of advanced temperature controls based on existing research reports, input from stakeholders and information gleaned from heating system installer and wider industry discussion fora.

8.1 Technical Barriers

Most of the barriers identified here have been discussed earlier in the report and this section summarises them and identifies potential solutions.

As the majority of boilers currently on the market are modulating combi-boilers, which are increasingly likely to be compensation control compatible, the technical barriers for compensation control in new installations of gas and LPG boilers are not considered to be significant. However, nearly all oil boilers on the market are on/off models.

Most UK installations of non-combi boilers use wiring configurations which generally do not separately identify space heating demand. Evidence from stakeholders and wider industry discussion fora indicate that it is usually possible for a knowledgeable installer to reconfigure the wiring and sensors to enable the boiler to separately identify a demand for space heating. However, the general consensus seems to be that it is either not possible or not worthwhile to reconfigure the wiring for existing heating systems.

Although a suitable place to site a weather sensor is a barrier for traditional weather compensation control, this can be overcome by systems that access local online weather data over the internet.

In instances where it is not feasible to connect the weather sensor to the heating system using wiring, models that use wireless radio frequencies to transmit information can be employed. The latter avoid the possibility of being incorrectly wired by installers, although it has the potential for communication problems caused by radio interference[46] and will require batteries to be replaced, ususally once a year. For all temperature controllers it is important that controls are correctly wired and the communication protocols used are compatible for the system to operate effectively.

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[46] This problem is caused by interference from other systems or devices using nearby frequency bands in an increasingly over-loaded radio spectrum. It can be overcome by designing controls with a satisfactory level of immunity to interference. Compliance with EU standards is not always sufficient to ensure that the transmitter-receiver pair will work correctly in the presence of other signals. However, products bearing the Radiomark symbol have been certified to meet this requirement (see website www.radiomark.org).

8.1.1 Communication Protocols

Boilers need to have intelligent communication protocols to enable the use of sophisticated heating controls. The protocols used have the ability to determine which controls can be used with particular boilers, and also what information can be exchanged. The protocol therefore has a significant impact on the effectiveness of the controls installed.

Compensation controls need to use the same communication protocol as the boiler in order to operate. Currently there are a number of different manufacturer-specific protocols and one open standard protocol, OpenTherm[47], used in the UK. Of the stakeholders who responded to a question on communication protocols (41), 16 were familiar with OpenTherm and between them they identified 23 other protocols, all of which are proprietary/manufacturer specific protocols. This means that the number of compensation control products that will work with a specific boiler is limited. If a common protocol were adopted in the UK this would potentially increase competition between control manufacturers.

The main advantages cited for OpenTherm by stakeholder respondents are that it is an internationally recognised open standard which is compatible with products from multiple manufacturers and a database of OpenTherm products is readily available. Disadvantages identified by respondents related in the main to difficulties associated with setup and limited functionality.

Of the other proprietary control protocols identified, the advantages quoted related to ease of setting up (plug and play) and additional functionality. The only disadvantage identified was that they were restrictive and locked into controls from a specific manufacturer.

Based on discussions posted on wider industry discussion fora, there is substantial anecdotal evidence of poor communication and conflicts between different types of controls and specific heating systems set ups. The TPI field trials also provide evidence of controls not working as they should and cited examples of heating systems cycling on and off based on the return temperature instead of the room temperature.

It is possible that enhancements to the current OpenTherm communication protocol could provide additional functionality which would encourage more manufactures to adopt this protocol and hence achieve wider interoperability between controls and boilers. The OpenTherm protocols allows manufacturers to build extra functionality into their controls and a Technical Commission of the OpenTherm Association monitors this and ensures that standardised functions are added to the Protocol.

[47] OpenTherm is widely adopted in the Netherlands and in Benelux countries.

8.2 Market Barriers

As with many energy efficiency improvements, split incentives will tend to restrict the uptake of advanced heating controls. For new build dwellings, the builder pays for heating system controls, while the consumer pays the energy bill - so the builder will tend to choose the option that incurs the lowest capital cost. For existing homes it is the installer who generally recommends heating controls whilst consumers pay the energy bill. As many installers are less familiar advanced heating controls, which can be more complicated to set up and commission and are more likely to result in call-backs[48] - and they do not benefit from the reduced energy bills - they will tend to stick with standard thermostats. Also, as installers are operating in a competitive market, there is a disincentive to include more expensive temperature controls when compiling quotes.

8.3 Technical Advances and Competition

Advanced temperature controls are effectively in competition with other types of energy efficiency measures and other energy saving controls. Although the mechanisms for saving energy may be different, the marginal savings achieved for a particular control mechanism will generally be lower when implemented with other control strategies. Optimization controls that are integrated with compensation control will lead to greater savings. However, controls that act to reduce the heating period will lead to lower energy efficiency improvement for both compensation and TPI control.

Multizone load controls (ErP Control Class VIII) include 3 or more room sensors that vary the flow temperature of the water leaving the boiler dependent upon the aggregated measured room temperature deviation from room sensor set points. They have the potential to match the flow temperature more closely to the heat demand of the whole house which will achieve greater energy efficiency improvement compared to a single room thermostat.

The growth of smart controls which have the ability to communicate over the internet has several implications when they are used in conjunction with advanced temperature controls.

They provide remote control capabilities via smart devices and can enable consumers to reduce the period of time when heat is not needed but is still provided by the system. This will tend to reduce the absolute savings and cost effectiveness of the controls under discussion. Furthermore, because increased use of remote controls will tend to lead to shorter heating periods, for TPI control this will decrease the proportion of the time spent at the set point temperature, and therefore decrease the seasonal energy efficiency improvements than can be achieved. For compensation controls, shorter

[48] Call backs were cited as being a particular issue with weather compensation controls because the radiators do not always feel hot when the heating is on in milder weather even though the room temperature is satisfactory.

heating periods will tend to increase the heat demand during the on period and this will reduce the potential impact of compensation controls.

However, smart controls which possess self-learning capabilities can be used to optimise the system to best meet the user's heat requirements in the most energy efficient manner. Smart controls could also be used in conjunction with advanced temperature controls to provide feedback to the user on how efficiently the heating system is operating under various conditions, making consumers more aware of the savings they make by "driving" their heating system more efficiently. Smart controls could also enable advanced temperature controls to be managed and monitored remotely by third parties for those who are less able to operate their own heating controls.

8.4 Other Barriers

Other barriers to the increase uptake of advanced temperature controls were identified as relating to cost, information, skill shortages, compatibility with other controls and recognition of performance benefits.

In order to assess the relative importance of these factors, stakeholders were asked to select (up to 5) main barriers to wider uptake of advanced temperature control. The results of this survey question are summarised in Figure 14.

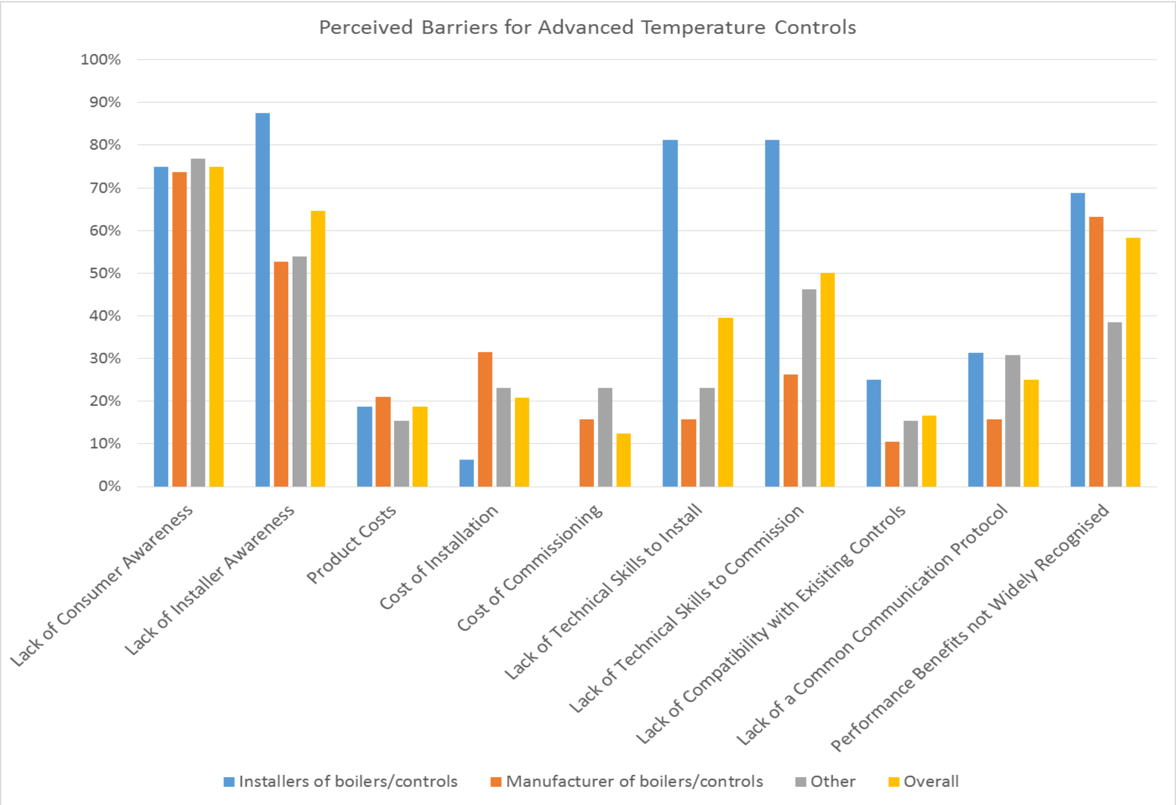

Figure 14: Stakeholder survey results: Perceived barriers for advanced controls (percentage of respondents)

Lack of both consumer and installer awareness were cited frequently with 79% (n=36) and 68% (n=31) of respondents, respectively, selecting these barriers. The proportion of installers highlighting lack of installer awareness is even higher than for other categories. To some extent this probably reflects the fact that the installers who responded to the survey are nearly all members of Ecoinstallers. This is effectively a self-selected group of individuals who have an interest in energy efficient heating systems and are likely to have more knowledge of advanced energy saving controls compared to the others.

Performance benefits not being widely recognised was identified as one of the main barriers by 61% of respondents (n=28), with manufacturers and installers tending to rate this more highly. This probably reflects the fact that in SAP no seasonal energy efficiency benefits are allocated to TPI control and that those allocated to advanced compensation controls are not viewed significant enough to promote wider uptake. This view is supported by the observation that a significant number of compensation controls are not currently included in the PCDB.

Lack of technical skills to install and commission advanced controls was identified as a main barrier by 80% (n=13) of installers, though by a much smaller proportion of other respondents. This view is borne out by the lack of accessible technical information identified during this project and noted discussions on internet fora seeking advice on specific installation and commissioning issues. Lack of compatibility with existing controls and the lack of a common communication protocol were identified as one the main barriers by 17% (n=8) and 26% (n=12) of respondents, respectively.

It is interesting to note that cost was not identified as a main barrier by most respondents. To some extent this probably reflects the view that most expect the price of advanced temperature controls to fall in the future.

8.5 Possible Actions for Increasing the Uptake of Advanced Temperature Controls

Table 10 suggests some possible actions aimed at consumers, installers, manufacturers that could potentially address the barriers identified for advanced temperature controls.

Supply Chain Participant Group	Possible Actions
Consumers	Greater awareness of advanced heating controls
	Guidance on selecting appropriate controls for different homes and lifestyles
	Guidance on how to operate energy efficiency heating controls to minimise energy use without compromising comfort
Installers	Independent information and training material regarding the capabilities and limitations of each type of controls
	Enhanced training on installation and commissioning of advanced controls
	More comprehensive commissioning procedures e.g., expansion of the Benchmark Checklist to include justification of choice of control, checks to confirm that the system is working as expected
Manufacturers	Requirements for greater transparency between boiler and control manufacturers regarding compatibility of individual boilers and controls – e.g., log additional data in the PCDB
	The development of a standard test protocol for heating controls that reflects the typical operating conditions in UK homes and would enable manufacturers to differentiate their products
	Development and adoption of an extended (compared to the current OpenTherm protocol) communication protocol standard

Table 10: Possible actions overcoming barriers to the wider uptake of advanced temperature controls for supply chain participant groups

There are a number of actions that could be undertaken to encourage the uptake of advanced temperature controls. These include:

- Research to provide an improved understanding of actual heat demands and heating system performance.
- Research to undertake independent monitoring studies and tests on the actual performance of energy controls.
- The development of a robust test procedure for measuring the energy savings from heating controls.
- Undertaking more detailed studies to enhance the methodology for modelling the performance of controls (e.g. consider the use of dynamic modelling with shorter time steps) to better inform policy making and the energy efficiency improvements credited to them in SAP.
- Including a requirement to install advanced heating controls (where cost effective/appropriate) to comply with Building Regulations. For example, a

requirement for ErP Class V or above for compensation-compatible modulating boilers.
- The provision of information to users on the additional energy savings that can arise from more accurate temperature control. For example, the development of Good Practice Guidance.

9 Gap Analysis

A number of research questions were posed at the start of this study and this section identifies areas where there gaps in the evidence base were identified. A full list of the questions and a summary of the response of this study is provided in Appendix G.

The key information gap identified is a lack of evidence regarding the seasonal energy efficiency improvements that each type of control can realise. A better understanding of the energy savings that advanced temperature controls can achieve in practice would be beneficial in informing the development of policies to promote wider uptake.

Other areas where evidence is lacking include:

- How advanced energy savings controls interact with other heating system controls, in particular to ascertain whether TPI controls conflict with inbuilt modulating controls in boilers.
- The extent to which the presence of other control functionalities and settings influence the energy efficiency improvements achieved.
- Whether the increased switching that occurs with TPI control can lead to increased wear and tear on the boiler and to quantify any impacts in terms of increased maintenance cost and reduced lifetime.
- The extent to which more stable temperature controls enable consumers to turn down the thermostat without reducing comfort. These savings could potentially be significant compared to energy efficiency improvements.

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Appendix B Stakeholder Questionnaire

Introduction

This questionnaire is part of a research project BRE is carrying out on behalf of the Department for Business, Energy and Industrial Strategy, (BEIS), formerly DECC, to gather evidence about three types of heating (boiler) controls for gas, oil and LPG boilers. The study will provide information about these types of controls to underpin future energy efficiency policy.

The three types of control technologies we are interested in are:

- Weather compensation
- Load compensation and
- TPI (Time Proportional Integral) controls

We are inviting selected stakeholders to share their experiences and opinions about these controls and would be very grateful if you could take the time to complete this short questionnaire. There will also be an opportunity to discuss your responses in more detail if you wish.

Please be assured that any information you give in the questionnaire or any follow up call will be treated in the strictest confidence by the research team and all your responses will be reported as anonymous data.

To begin the survey please click on the **Next >** button below. Until you click the **Submit** button at the end of the form, you can to return to an earlier question by clicking the **< Back** button if you want to change an answer.

Definitions

For the purpose of this study we are adopting the following definitions.

The definitions may be viewed in a separate window at any point in the survey, by clicking on the 'Definition' link at the bottom of the page.

Weather compensation - A device, or feature within a device, which maintains the temperature inside the building by sensing and limiting the temperature of the water leaving the heater in relation to the temperatures measured outside the building. The temperature of the water leaving the heater may be adjusted by modulating the burner or by switching the boiler on and off.

This control type is equivalent to the Ecodesign regulation (811/2013) [1] temperature control Class II (for modulating heat generators) and Class III (for on/off heat generators) and Classes VI and VII, respectively, which include an additional room temperature sensor.

Load compensation – A device, or feature within a device, which maintains the temperature inside the building by sensing and limiting the temperature of the water leaving the heater in relation to the heat demand inside the building.

This control type is equivalent to the Ecodesign regulation (811/2013) temperature control Class V (for modulating boilers).

Note that for both weather and load compensation controls the requirement to limit the flow temperature means that devices measuring only return temperature will not satisfy this definition.

TPI (Time Proportional Integral) controls – A device, or feature within a device, which maintains the temperature inside the building switching the current supplied to the boiler on or off in order to adjust the temperature of the water leaving the heater in manner that is proportional to the level of heat demand. The "integral" aspect of this type of control provides a more stable room temperature and reduces overheating.

[1] Commission communication in the framework of the implementation of Commission Regulation (EU) No 813/2013 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to Ecodesign requirements for space heaters and combination heaters and of 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, OJ (2014/C page 207/02), 3.7.2014.

Section A: About you and your organisation

A1. Organisation name

A2. Which of the following best describes the role of your organisation?

Manufacturer of boilers/controls
Installers of boilers/controls
Academic research
Trade association
Professional body
Consumer organisation
Other (*please specify*)

A3. Please indicate which of the following types of heating (boiler) control technologies you are aware of and which you have had experience of. (*Mark all that apply*)

	Aware of	Experience of
Weather compensation		
Load compensation		
TPI (Time Proportional and Integral)		

FILTER: Answer **If**
A3. Please indicate which of the following types of heating (boiler) control technologies you are aware of and which you have had experience of.
Weather compensation - Experience of **Is Selected**
Or Load compensation - Experience of **Is Selected**
Or TPI (Time Proportional and Integral) - Experience of **Is Selected**

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A4. In what context have you worked with the individual heating (boiler) controls? (*Mark all that apply*)

	Weather compensation	Load compensation	TPI (Time Proportional and Integral)
Design and manufacturer			
Supplier (if this is different from above)			
Installation			
Specification			
Operation of a system using the control			
Maintenance of a system using the control			
Sales and marketing			
Research and development			
Other (*please specify*)			

Section B: Potential for savings

B1. In your opinion, does the use of these control technologies result in energy savings?

Weather compensation	
Load compensation	
TPI (Time Proportional and Integral)	

FILTER: Answer **If**
B1. To your knowledge, does the use of these controls result in energy savings?
Weather compensation - Yes **Is Selected**
Or Load compensation - Yes **Is Selected**
Or TPI (Time Proportional and Integral) - Yes **Is Selected**

B1a. Please give an indication of the typical annual energy savings you would expect these types of control technologies to achieve.

	Less than 1%	1% - 5%	6% - 10%	More than 10%
Weather compensation				
Load compensation				
TPI (Time Proportional and Integral)				

B2. If you are aware of any monitoring or modelling studies that provide evidence of energy savings for any of these types of control technologies please provide details below.

Please indicate which of the technologies the evidence applies to, i.e. Weather compensation (W), Load compensation (L) or TPI.

Section C: Cost of purchasing and installation

C1. To your knowledge, is the purchase cost of a boiler that is compatible with these types of control technology generally higher than one without this facility?

Yes (*please provide an estimate of the typical additional purchase cost*)

No

Don't know

Outdoor Weather Sensors

C2. Does the installation of an outdoor weather sensor require any additional cost compared to a standard installation?

Yes (*please provide an estimate of the typical additional cost per installation*)

No

Don't know

C3. Does the installation of an outdoor weather sensor require additional time compared to a standard installation?

Yes (*please provide an estimate of the typical additional time per installation*)

No

Don't know

Weather Compensation Controllers

C4. Does the installation of a room thermostat with a weather compensation controller **cost more** compared to a standard system?

Yes (*please provide an estimate of the typical additional cost per installation*)

No

Don't know

C5. Does the installation of a room thermostat with a weather compensation controller take **additional time** compared to a standard system?

Yes (*please provide an estimate of the typical additional time per installation*)

No

Don't know

Load Compensation Controllers

C6. Does the installation of a room thermostat with a load compensation controller **cost more** compared to a standard system?

Yes (*please provide an estimate of the typical additional cost per installation*)

No

Don't know

C7. Does the installation of a room thermostat with a load compensation controller take **additional time** compared to a standard system?

Yes (*please provide an estimate of the typical additional time per installation*)

No

Don't know

TPI (Time Proportional and Integral) Controllers

C8. Does the installation of a room thermostat with a TPI controller **cost more** compared to a standard system?

Yes (*please provide an estimate of the typical additional cost per installation*)

No

Don't know

C9. Does the installation of a room thermostat with a TPI controller take **additional time** compared to a standard system?

Yes (*please provide an estimate of the typical additional time per installation*)

No

Don't know

C10. What do you expect to happen to the **purchase price** of these types of control technologies in the next 5 years?

Weather sensor

Weather compensation

Load compensation

TPI (Time Proportional and Integral)

C11. What do you expect to happen to the **installation cost** of these types of control technologies in the next 5 years?

Weather sensor
Weather compensation
Load compensation
TPI (Time Proportional and Integral)

C12. What factors do you think will have the most influence on the price of these control technologies in the future? (*Mark all that apply*)

Size of market
Economies of scale
Availability of trained installers
Government legislation
Good practice specification
Increased competition
Technological improvements
Other (*please specify*)

Section D: Technical issues

D1. What would you expect to be the typical lifetime for these types of control technologies?

Weather sensor	❍	❍	❍	❍	❍
Weather compensation	❍	❍	❍	❍	❍
Load compensation	❍	❍	❍	❍	❍
TPI (Time Proportional and Integral)	❍	❍	❍	❍	❍

D2. Please list the names of any communication protocols (used with these control technologies) that are you aware of/familiar with, e.g. OpenTherm?

Protocol 1	
Protocol 2	
Protocol 3	
Protocol 4	

Protocol 5	

FILTER: Answer **If**
D2. Please list the names of any communication protocols (used with these control technologies) that are you aware of/familiar with, e.g. OpenTherm?
Protocol 1 **Is Not Empty**
Or Protocol 2 **Is Not Empty**
Or Protocol 3 **Is Not Empty**
Or Protocol 4 **Is Not Empty**
Or Protocol 5 **Is Not Empty**

D3. What do you think are the **advantages** of these protocols?

Protocol 1	
Protocol 2	
Protocol 3	
Protocol 4	
Protocol 5	

FILTER: Answer **If**
D2. Please list the names of any communication protocols (used with these control technologies) that are you aware of/familiar with, e.g. OpenTherm?
Protocol 1 **Is Not Empty**
Or Protocol 2 **Is Not Empty**
Or Protocol 3 **Is Not Empty**
Or Protocol 4 **Is Not Empty**
Or Protocol 5 **Is Not Empty**

D4. What do you think are the **disadvantages** of these protocols?

Protocol 1	
Protocol 2	
Protocol 3	
Protocol 4	
Protocol 5	

Section E: Factors that influence performance

E1. Are any of these control technologies incompatible with any other types of heating control?

Yes (*please give details*)

No

Don't know

E2. Are there any circumstances where you have found these control technologies to result in either overheating and/or under heating)?

Yes (*please give details*)

No

Don't know

E3. Are you aware of any practical problems associated with **installing** these control technologies?

Yes (please give details)

No

Don't know

E4. Are you aware of any issues associated with **commissioning** these control technologies?

Yes (please give details)

No

Don't know

E5. Are you aware of any issues associated with **the operation** of these control technologies?

Yes (*please give details*)

No

Don't know

E6. Are there any other circumstances where you would expect these control technologies to be unsuitable?

Yes (*please give details*)

No

Don't know

Section F: Market potential of each type of control

F1. We are interested in the size of the current market for these types of control technologies. Please estimate the approximate number of units sold per annum nationally for each type of control technology in new boiler installations for domestic heating systems.

Leave box blank if you do not have this information.

Weather sensor	
Weather compensation	
Load compensation	
TPI (Time Proportional and Integral)	

F2. Do you think there is a significant market for retrofitting any of these types of control technologies?

Weather compensation	❍	❍	❍
Load compensation	❍	❍	❍
TPI (Time Proportional and Integral)	❍	❍	❍

FILTER: Answer **If**
F2. Do you think there is a significant market for retrofitting any of these types of control technologies?
Weather compensation - No **Is Selected**
Or Load compensation - No **Is Selected**
Or TPI (Time Proportional and Integral) - No **Is Selected**

F2a. What factors, do you believe, limit the retrofit market?

F3. Are you aware of any other technologies that can effectively do the same job as any of these types of control that are either on the market or in development?

On the market	❍	❍
In development	❍	❍

FILTER: Answer **If**
F3. Are you aware of any other technologies that can effectively do the same job as any of these types of control that are either on the market or in development?
On the market - Yes **Is Selected**

On the market: Please give details of the technologies.

FILTER: Answer **If**
F3. Are you aware of any other technologies that can effectively do the same job as any of these types of control that are either on the market or in development?
In Development - Yes **Is Selected**

Technologies in development: Please give details of technologies, including how close they are to market.

F4. Which of the following factors do you think will have most impact on the market for these control technologies in the next 5 years? (*Mark all that apply*)

- Economies of scale
- Availability of trained installers
- Government legislation
- Good practice specification
- Increased competition
- Technological improvements
- Increased installer awareness
- Evidence of savings
- Cost/benefit information
- Increased consumer awareness
- Other (*please specify*)

F5. What do you think are the main barriers to wider uptake of these types of control technologies? (*Choose up to 5*)

- Lack of consumer awareness
- Lack of installer awareness
- Product costs
- Cost of installation
- Costs of commissioning
- Lack of technical skills to install
- Lack of technical skills to commission
- Lack of a common communication protocol
- Performance improvement not adequately recognised e.g. in SAP
- Lack of compatibility with existing controls
- Other (*please specify*)

G: Finally

G1. If there any other issues associated with these types of control technologies that you would like to mention, please do so in the box below:

G2. If you know of any other organisations or individuals who you think may be able to provide additional information for this study, please provide their contact details below:

We would like to invite you to further discuss your experiences and knowledge of these type of controls in greater detail. If you are happy to be contacted by our researchers please tick the box.

Please provide your details below:

Name	
Telephone	
Email	

Thank you for your time. This is the end of the survey.
Please click on the Submit button below to send us your responses.

Appendix C Analysis of Stakeholder Responses

A1. Organisation name (answer required)

A2. Which of the following best describes the role of your organisation?

Answer	Bar	Response	%
Manufacturer of boilers/controls		19	39.58%
Installers of boilers/controls		16	33.33%
Academic research		0	0.00%
Trade association		1	2.08%
Professional body		1	2.08%
Consumer organisation		1	2.08%
Other (please specify)		10	20.83%
Total		48	100.00%

Other (please specify)

A3. Please indicate which of the following types of heating (boiler) control technologies you are aware of and which you have had experience of. *(Mark all that apply)*

Question	Aware of	Experience of	Response
Weather compensation	30	40	70
Load compensation	31	40	71
TPI (Time Proportional and Integral)	30	32	62

A4. In what context have you worked with the individual heating (boiler) controls? *(Mark all that apply)*

Question	Weather compensation	Load compensation	TPI (Time Proportional and Integral)	Response
Design and manufacturer	16	17	12	45
Supplier (if this is different from above)	10	11	7	28
Installation	29	27	22	78
Specification	25	25	17	67
Operation of a system using the control	30	27	23	80
Maintenance of a system using the control	27	27	20	74
Sales and marketing	25	23	18	66
Research and development	12	13	9	34
Other (please specify)	2	2	1	5

Other (please specify)

B1. In your opinion, does the use of these control technologies result in energy savings?

Question	Yes	No	Don't know/unsure	Response
Weather compensation	44	1	3	48
Load compensation	42	2	3	47
TPI (Time Proportional and Integral)	28	6	11	45

B1a. Please give an indication of the typical annual energy savings you would expect these types of control technologies to achieve.

Question	Less than 1%	1% - 5%	6% - 10%	More than 10%	Response
Weather compensation	1	6	13	20	40
Load compensation	-	8	13	17	38
TPI (Time Proportional and Integral)	-	8	11	7	26

B2. If you are aware of any monitoring or modelling studies that provide evidence of energy savings for any of these types of control technologies please provide details below.

Please indicate which of the technologies the evidence applies to, i.e. Weather compensation (W), Load compensation (L) or TPI.

C1. To your knowledge, is the purchase cost of a boiler that is compatible with these types of control technology generally higher than one without this facility?

Answer	Bar	Response	%
Yes (please provide an estimate of the typical additional purchase cost)		13	27.66%
No		28	59.57%
Don't know		6	12.77%
Total		47	100.00%

Yes (please provide an estimate of the typical additional purchase cost)

C2. Does the installation of an outdoor weather sensor require any additional cost compared to a standard installation?

Answer	Bar	Response	%
Yes (please provide an estimate of the typical additional cost per installation)		35	74.47%
No		9	19.15%
Don't know		3	6.38%
Total		47	100.00%

Yes (please provide an estimate of the typical additional cost per installation)

C3. Does the installation of an outdoor weather sensor require additional time compared to a standard installation?

Answer	Bar	Response	%
Yes (please provide an estimate of the typical additional time per installation)		34	73.91%
No		9	19.57%
Don't know		3	6.52%
Total		46	100.00%

Yes (please provide an estimate of the typical additional time per installation)

C4. Does the installation of a room thermostat with a weather compensation controller cost more compared to a standard system?

Answer	Bar	Response	%
Yes (please provide an estimate of the typical additional cost per installation)		27	57.45%
No		14	29.79%
Don't know		6	12.77%
Total		47	100.00%

Yes (please provide an estimate of the typical additional cost per installation)

C5. Does the installation of a room thermostat with a weather compensation controller take additional time compared to a standard system?

Answer	Bar	Response	%
Yes (please provide an estimate of the typical additional time per installation)		19	40.43%
No		24	51.06%
Don't know		4	8.51%
Total		47	100.00%

Yes (please provide an estimate of the typical additional time per installation)

C6. Does the installation of a room thermostat with a load compensation controller cost more compared to a standard system?

Answer	Bar	Response	%
Yes (please provide an estimate of the typical additional cost per installation)		24	51.06%
No		15	31.91%
Don't know		8	17.02%
Total		47	100.00%

Yes (please provide an estimate of the typical additional cost per installation)

C7. Does the installation of a room thermostat with a load compensation controller take additional time compared to a standard system?

Answer	Bar	Response	%
Yes (please provide an estimate of the typical additional time per installation)		11	23.40%
No		28	59.57%
Don't know		8	17.02%
Total		47	100.00%

Yes (please provide an estimate of the typical additional time per installation)

C8. Does the installation of a room thermostat with a TPI controller cost more compared to a standard system?

Answer	Bar	Response	%
Yes (please provide an estimate of the typical additional cost per installation)		17	36.17%
No		20	42.55%
Don't know		10	21.28%
Total		47	100.00%

Yes (please provide an estimate of the typical additional cost per installation)

C9. Does the installation of a room thermostat with a TPI controller take additional time compared to a standard system?

Answer	Bar	Response	%
Yes (please provide an estimate of the typical additional time per installation)		8	17.02%
No		30	63.83%
Don't know		9	19.15%
Total		47	100.00%

Yes (please provide an estimate of the typical additional time per installation)

C10. What do you expect to happen to the purchase price of these types of control technologies in the next 5 years?

Question	Increase	Stay the same	Reduce
Weather sensor	6	23	18
Weather compensation	6	19	22
Load compensation	4	20	22
TPI (Time Proportional and Integral)	6	22	16

C11. What do you expect to happen to the installation cost of these types of control technologies in the next 5 years?

Question	Increase	Stay the same	Reduce	Response
Weather sensor	14	22	10	46
Weather compensation	14	21	11	46
Load compensation	11	27	7	45
TPI (Time Proportional and Integral)	11	28	5	44

C12. What factors do you think will have the most influence on the price of these control technologies in the future? (*Mark all that apply*)

Answer	Bar	Response	%
Size of market		24	51.06%
Economies of scale		30	63.83%
Availability of trained installers		24	51.06%
Government legislation		31	65.96%
Good practice specification		28	59.57%
Increased competition		16	34.04%
Technological improvements		29	61.70%
Other (please specify)		9	19.15%
Total		191	100.00%

Other (please specify)

D1. What would you expect to be the typical lifetime for these types of control technologies?

Question	Less than 5 years	5 to 10 years	11 to 15 years	16 to 20 years	More than 20 years	Response
Weather sensor	-	15	16	13	3	47
Weather compensation	-	14	16	13	4	47
Load compensation	1	13	18	12	2	46
TPI (Time Proportional and Integral)	3	15	15	9	2	44

D2. Please list the names of any communication protocols (used with these control technologies) that are you aware of/familiar with, e.g. OpenTherm?

Row Labels	**Number of Respondents aware of/familiar with**
BACnet	3
Bdr bus	1
bridge bus net	3
Bus	3
Can bus	1
Ebus	16
IP	1
kbus	3
Kmbus	8
KNX	2
Lon	2
manufacturer specific	6
mbus	2
modbus	3
on/off	1
OpenTherm	31
Ramesis	1
RS485	1
thread	1
TPi	1

Row Labels	**Number of Respondents aware of/familiar with**
ubus	1
Wireless	3
z bus	1
z wave	1
Zigbee	4
Grand Total	100

D3. What do you think are the advantages and disadvantages of OpenTherm?

Advantages	**Disadvantages**
868MHz, simple command classes, robust mesh radio, good battery life, low cost	All the same.. no disadvantages
Ability to modulate the burner for accurate temp control, fault codes	Can be difficult to setup
Allows more competition and improvement	Don't know
Available to all OpenTherm controls	IPR was vested in a single source, now resolved with 3rd party technology suppliers
compatibility	Limited data set results in restricted boiler operation.
Control of the gas valve	Limited functionality
Cross appliance applications	Limited functionality
Cross manufacturer compatibility	Manipulation of the protocol to stop all controls being 100% compatible
Easy to install	Non
Efficiency	None
Increased efficiency	None except some unknowns about how OT interacts with an outdoor sensor

Advantages	**Disadvantages**
Increasingly standard across manufacturers	Not all aspects unlocked by boiler manufacturers
industry standard	Not as technologically partnered to the boiler
More control options	not enough functionality
numerous maximum devices	open access
Open for 3rd parties	wired
open protocol, wide compatibility with boilers,	All the same.. no disadvantages
Open standard	Can be difficult to setup
Open to all manufacturers	Don't know
There all the same	IPR was vested in a single source, now resolved with 3rd party technology suppliers
Universal	Limited data set results in restricted boiler operation.
Well established industry standard protocol	Limited functionality
Wide compatibility	Limited functionality

What do you think are the advantages and disadvantages of Ebus?

Advantages	Disadvantages
Ability to modulate the burner for accurate temperature control, fault codes	Don't know
Appliance specific	Exclusivity
Control of the gas valve	Locked to manufacturers
Dedicated communication with all components from a single manufacturer, complete interoperability.	Manufacturer specific therefore locked
Efficiency	Must be manufacturers controls
Extra features	None

None	None
None	Proprietory
plug and play	Restricted
Seamlessness	restrictive

What do you think are the advantages and disadvantages of kmBus?

Advantages	Disadvantages
Appliance specific	Exclusivity
Efficiency	Locked to manufacturers
Extra features	None
None	None
Proprietary manufacturer protocol facilitates greater system	Only KMBUS compatible products
Seamlessness	Restricted

What do you think are the advantages and disadvantages of Wireless/RF?

Advantages	Disadvantages
international standard, needs to get cheaper (look-alikes?)	interference in heavy commercial/industrial situations
large maximum amount of devices	Uses 2.4GHz, very crowded communication channel, signal propagation in typical UK home not as good as sub GHz band.
Well developed/understood, robust mesh, good battery life.	

E1. Are any of these control technologies incompatible with any other types of heating control?

Answer	Bar	Response	%
Yes (please give details)		23	79.31%
No		6	20.69%
Total		29	100.00%

Yes (please give details)

E2. Are there any circumstances where you have found these control technologies to result in either overheating and/or underheating)?

Answer	Bar	Response	%
Yes (please give details)		14	36.84%
No		24	63.16%
Total		38	100.00%

Yes (please give details)

E3. Are you aware of any practical problems associated with installing these control technologies?

Answer	Bar	Response	%
Yes (please give details)		22	50.00%
No		22	50.00%
Total		44	100.00%

Yes (please give details)

E4. Are you aware of any issues associated with commissioning these control technologies?

Answer	Bar	Response	%
Yes (please give details)		19	44.19%
No		24	55.81%
Total		43	100.00%

Yes (please give details)

E5. Are you aware of any issues associated with the operation of these control technologies?

Answer	Bar	Response	%
Yes (please give details)		19	45.24%
No		23	54.76%
Total		42	100.00%

Yes (please give details)

E6. Are there any other circumstances where you would expect these control technologies to be unsuitable?

Answer	Bar	Response	%
Yes (please give details)		15	38.46%
No		24	61.54%
Total		39	100.00%

Yes (please give details)

F1. We are interested in the size of the current market for these types of control technologies. Please estimate the approximate number of units sold per annum nationally for each type of control technology in new boiler installations for domestic heating systems

Weather sensor	Weather compenstion	Load Compensation	TPI
10000	10000	1000	1000
0	10	0	0
30,000	30,000	>10k	125,000
80%	80%	60%	0
10000	25000	20000	20000
50,000	10,000	10	>500k
30	20	200,000	
100000	10000	50000	
100,000	100,000		

F2. Do you think there is a significant market for retrofitting any of these types of control technologies?

Question	Yes	No	Response
Weather compensation	33	8	41
Load compensation	32	6	38
TPI (Time Proportional and Integral)	31	4	35

F2a. What factors, do you believe, limit the retrofit market?

F3. Are you aware of any other technologies that can effectively do the same job as any of these types of control that are either on the market or in development?

Question	Yes	No	Response
On the market	14	28	42
In development	11	30	41

On the market and technologies in development: Please give details of technologies, including how close they are to market.

F4. Which of the following factors do you think will have most impact on the market for these control technologies in the next 5 years? (Mark all that apply)

Answer	Bar	Response	%
Economies of scale		23	50.00%
Availability of trained installers		25	54.35%
Government legislation		39	84.78%
Good practice specification		31	67.39%
Increased competition		13	28.26%
Technological improvements		27	58.70%
Increased installer awareness		33	71.74%
Evidence of savings		37	80.43%
Cost/benefit information		32	69.57%
Increased consumer awareness		39	84.78%
Other (please specify)		2	4.35%
Total		301	100.00%

Other (please specify)

F5. What do you think are the main barriers to wider uptake of these types of control technologies? (Choose up to 5)

Answer	Bar	Response	%
Lack of consumer awareness		36	78.26%
Lack of installer awareness		31	67.39%
Product costs		9	19.57%
Cost of installation		10	21.74%
Costs of commissioning		6	13.04%
Lack of technical skills to install		19	41.30%
Lack of technical skills to commission		24	52.17%
Lack of a common communication protocol		12	26.09%
Performance improvement not adequately recognised e.g. in SAP		28	60.87%
Lack of compatibility with existing controls		8	17.39%
Other (please specify)		7	15.22%
Total		190	100.00%

Other (please specify)

G1. If there any other issues associated with these types of control technologies that you would like to mention, please do so in the box below:

bre

Appendix D Benchmark Commissioning Checklist for Gas Boiler Systems

Benchmark Commissioning and Servicing Section

It is a requirement that the boiler is installed and commissioned to the manufacturers instructions and the data fields on the commissioning checklist completed in full.

To instigate the boiler guarantee the boiler needs to be registered with the manufacturer within one month of the installation.

To maintain the boiler guarantee it is essential that the boiler is serviced annually by a Gas Safe registered engineer who has been trained on the boiler installed. The service details should be recorded on the Benchmark Service Interval Record and left with the householder.

benchmark
COLLECTIVE MARK
THE MARK OF QUALITY FOR THE INSTALLATION, COMMISSIONING AND SERVICING OF DOMESTIC HEATING AND HOT WATER SYSTEMS

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GAS BOILER SYSTEM COMMISSIONING CHECKLIST

This Commissioning Checklist is to be completed in full by the competent person who commissioned the boiler as a means of demonstrating compliance with the appropriate Building Regulations and then handed to the customer to keep for future reference.

Failure to install and commission according to the manufacturer's instructions and complete this Benchmark Commissioning Checklist will invalidate the warranty. This does not affect the customer's statutory rights.

Customer name:	Telephone number:
Address:	
Boiler make and model:	
Boiler serial number:	
Commissioned by (PRINT NAME):	Gas Safe register number:
Company name:	Telephone number:
Company address:	
	Commissioning date:
To be completed by the customer on receipt of a Building Regulations Compliance Certificate*	
Building Regulations Notification Number (if applicable):	

CONTROLS (tick the appropriate boxes)				
Time and temperature control to heating	Room thermostat and programmer/timer		Programmable room thermostat	
	Load/weather compensation		Optimum start control	
Time and temperature control to hot water	Cylinder thermostat and programmer/timer		Combination Boiler	
Heating zone valves	Fitted		Not required	
Hot water zone valves	Fitted		Not required	
Thermostatic radiator valves	Fitted		Not required	
Automatic bypass to system	Fitted		Not required	
Boiler interlock			Provided	

ALL SYSTEMS				
The system has been flushed and cleaned in accordance with BS7593 and boiler manufacturer's instructions			Yes	
What system cleaner was used?				
What inhibitor was used?	Quantity			litres
Has a primary water system filter been installed?	Yes		No	

CENTRAL HEATING MODE measure and record:			
Gas rate	m³/hr	**OR**	ft³/hr
Burner operating pressure (if applicable)	mbar	**OR** Gas inlet pressure	mbar
Central heating flow temperature			°C
Central heating return temperature			°C

COMBINATION BOILERS ONLY				
Is the installation in a hard water area (above 200ppm)?	Yes		No	
If yes, and if required by the manufacturer, has a water scale reducer been fitted?	Yes		No	
What type of scale reducer has been fitted?				

DOMESTIC HOT WATER MODE Measure and Record:				
Gas rate	m³/hr	**OR**		ft³/hr
Burner operating pressure (at maximum rate)	mbar	**OR** Gas inlet pressure at maximum rate		mbar
Cold water inlet temperature				°C
Hot water has been checked at all outlets	Yes		Temperature	°C
Water flow rate				l/min

CONDENSING BOILERS ONLY		
The condensate drain has been installed in accordance with the manufacturer's instructions and/or BS5546/BS6798	Yes	

ALL INSTALLATIONS						
Record the following:	At max. rate:	CO	ppm	**AND**	CO/CO_2	Ratio
	At min. rate: (where possible)	CO	ppm	**AND**	CO/CO_2	Ratio
The heating and hot water system complies with the appropriate Building Regulations					Yes	
The boiler and associated products have been installed and commissioned in accordance with the manufacturer's instructions					Yes	
The operation of the boiler and system controls have been demonstrated to and understood by the customer					Yes	
The manufacturer's literature, including Benchmark Checklist and Service Record, has been explained and left with the customer					Yes	

Commissioning Engineer's Signature
Customer's Signature
(To confirm satisfactory demonstration and receipt of manufacturer's literature)

*All installations in England and Wales must be notified to Local Authority Building Control (LABC) either directly or through a Competent Persons Scheme. A Building Regulations Compliance Certificate will then be issued to the customer.

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SERVICE RECORD

It is recommended that your heating system is serviced regularly and that the appropriate Service Interval Record is completed.

Service Provider

Before completing the appropriate Service Record below, please ensure you have carried out the service as described in the manufacturer's instructions. Always use the manufacturer's specified spare part when replacing controls.

SERVICE 01					Date:
Engineer name:					
Company name:					
Telephone No:					
Gas safe register No:					
Record:	At max. rate:	CO	ppm	AND	CO_2 %
	At min. rate: (Where Possible)	CO	ppm	AND	CO_2 %
Comments:					
Signature					

SERVICE 02					Date:
Engineer name:					
Company name:					
Telephone No:					
Gas safe register No:					
Record:	At max. rate:	CO	ppm	AND	CO_2 %
	At min. rate: (Where Possible)	CO	ppm	AND	CO_2 %
Comments:					
Signature					

SERVICE 03					Date:
Engineer name:					
Company name:					
Telephone No:					
Gas safe register No:					
Record:	At max. rate:	CO	ppm	AND	CO_2 %
	At min. rate: (Where Possible)	CO	ppm	AND	CO_2 %
Comments:					
Signature					

SERVICE 04					Date:
Engineer name:					
Company name:					
Telephone No:					
Gas safe register No:					
Record:	At max. rate:	CO	ppm	AND	CO_2 %
	At min. rate: (Where Possible)	CO	ppm	AND	CO_2 %
Comments:					
Signature					

SERVICE 05					Date:
Engineer name:					
Company name:					
Telephone No:					
Gas safe register No:					
Record:	At max. rate:	CO	ppm	AND	CO_2 %
	At min. rate: (Where Possible)	CO	ppm	AND	CO_2 %
Comments:					
Signature					

SERVICE 06					Date:
Engineer name:					
Company name:					
Telephone No:					
Gas safe register No:					
Record:	At max. rate:	CO	ppm	AND	CO_2 %
	At min. rate: (Where Possible)	CO	ppm	AND	CO_2 %
Comments:					
Signature					

SERVICE 07					Date:
Engineer name:					
Company name:					
Telephone No:					
Gas safe register No:					
Record:	At max. rate:	CO	ppm	AND	CO_2 %
	At min. rate: (Where Possible)	CO	ppm	AND	CO_2 %
Comments:					
Signature					

SERVICE 08					Date:
Engineer name:					
Company name:					
Telephone No:					
Gas safe register No:					
Record:	At max. rate:	CO	ppm	AND	CO_2 %
	At min. rate: (Where Possible)	CO	ppm	AND	CO_2 %
Comments:					
Signature					

SERVICE 09					Date:
Engineer name:					
Company name:					
Telephone No:					
Gas safe register No:					
Record:	At max. rate:	CO	ppm	AND	CO_2 %
	At min. rate: (Where Possible)	CO	ppm	AND	CO_2 %
Comments:					
Signature					

SERVICE 10					Date:
Engineer name:					
Company name:					
Telephone No:					
Gas safe register No:					
Record:	At max. rate:	CO	ppm	AND	CO_2 %
	At min. rate: (Where Possible)	CO	ppm	AND	CO_2 %
Comments:					
Signature					

*All installations in England and Wales must be notified to Local Authority Building Control (LABC) either directly or through a Competent Persons Scheme. A Building Regulations Compliance Certificate will then be issued to the customer.

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Appendix E Further Details of Evidence for Energy Savings

Weather Compensation: University of Salford/Viessmann 2014

One day tests were carried out at 3 different external temperatures (3ºC, 8ºC and 12ºC), with the internal temperature set to 21ºC in the living room using the thermostat and to 18ºC elsewhere using TRVs. A twice daily schedule was applied with the heating on from 6:30 to 9:00 and then from 15:30 to 23:00.

The results of this test show large gas savings of 14%, 31% and 45% at external temperatures of 3ºC, 8ºC and 12ºC, respectively.

However, aside from issues regarding the extent to which steady state test conditions accurately reflect actual heat demands, there are two factors, in addition to weather compensation, that are expected to have contributed to the observed energy savings.

Firstly, the internal temperatures realised by the heating system with and without weather compensation are quite different. In all rooms the average, minimum and maximum temperatures recorded are significantly lower with weather compensation. In particular in the living room the set temperature of 21ºC is never reached and the maximum average temperature achieved is only 19.01ºC with an external temperature of 12ºC, and 18.65ºC with an external temperature of 3ºC. This will obviously have a significant influence on the energy savings.

The researchers report that failure to achieve the living room set point temperature was due to a “resolvable issues with set-up” and claim that the results show that weather compensation is better at preventing overheating. However, as the set temperature was not reached during the test the claimed savings are not justified by the test results.

A crude estimate of the savings that weather compensation might have achieved if the average internal temperatures achieved were the same for both test cases can be made based on the approximation that 1ºC reduction in the internal temperature will reduce energy consumption by around 10%. This crude adjustment gives revised gas savings for a thermostat with weather compensation control compared to one without of 4%, 13% and 29% at external temperatures of 3ºC, 8ºC and 12ºC, respectively.

Another potential factor is that the weather compensation control unit is assumed to include an electronic thermostat, whereas the comparison control is a mechanical thermostat. Tests in environmental chambers have shown that an electronic thermostat can achieve a 10-12% reduction in energy use compared to a mechanical model. It is therefore possible that a significant proportion of the savings observed in this study are attributable to this factor rather than weather compensation.

Although the base case and the heating schedule provide a reasonable reflection of typical UK heating systems, the test conditions will not reflect the variations in heat demand over the period and so will not reflect the dynamic reaction of the heating control to these changes.

When these factors are taken into account it is clear that the savings quoted will not reflect the typical savings that these controls are likely to achieve in domestic heating systems in the UK. However, they do demonstrate the expected finding that energy savings from weather compensation will be higher during milder weather.

Load Compensation Evidence: O'Hara/Danfoss EEDAL 2009

Test results were reported for the boiler operated with three types of control: a mechanical on/off thermostat, an electronic on/off thermostat, and a thermostat with load compensation (OpenTherm). This showed energy savings of 10.4% for the electronic control compared to mechanical on/off control. This saving is attributed primarily to the control electronics within the boiler modulating the flame with faster on/off signals from the electronic control. Using the load compensation facility of the modulating boiler demonstrated a 14.3% energy saving over the mechanical on/off control, but only a 3.4% energy saving over the electronic control.

Although the base case for this test is reasonable, and the average internal and external temperatures reflect typical average heat demand, a 12 hour steady state heating test does not reflect typical UK heating schedules, nor does it reflect the variations in heat demand over the period and so will not reflect the dynamic reaction of the heating control to these changes.

Evidence of Energy Savings from TPI Control

Several test studies and one field trial were identified that reported measured energy savings for TPI controls. The test conditions and the findings of these studies are discussed and analysed in this section and the expected energy savings reported by the stakeholders are presented.

TPI Control Evidence: University of Salford Test House Studies

A technical report on energy savings carried out in a test house showed that a TPI thermostatic control achieved energy savings of 33% compared to a “no thermostat” base case. This was measured over a 24 hour period with a typical “twice a day” heating schedule (06:30-09:00 and 15:30-23:00) with an external temperature of 5ºC and an internal set temperature of 21ºC. The test also showed an additional 20.82% of energy savings where TRVs were installed in addition to the TPI thermostatic control.

The ‘no controls’ base case is clearly not typical for the UK. However, in this study the maximum boiler output temperature was set to 82ºC which resulted in excess overheating for the base case with temperatures ranging between 20ºC to 37ºC during the heating period. This is clearly not representative of heating systems with no controls and occupiers would almost certainly turn down the boiler output temperature and reduce the heating period to achieve more acceptable internal temperatures.

Although the heating schedule provides a reasonable reflection of typical UK heating systems, the test conditions will not reflect the variations in heat demand over the period and so will not reflect the dynamic reaction of the heating control to these changes.

TPI Control Evidence: O'Hara/Danfoss EEDAL 2009

This paper presents the results of tests carried out in an environmental chamber on a heating system with a modulating gas boiler. The test conditions are the same as those used for the load compensation test which is reported in the same paper. This showed that the electronic on/off control achieved a 2.10% energy saving compared to the mechanical control, and that in TPI mode (with 6 on-off cycles per hour) achieved an energy saving of 10.35% over the mechanical on-off control and 8.25% over the electronic on/off control.

Although the base case for this test is reasonable, and the average internal and external temperatures reflect typical average heat demand, a 12 hour steady state heating pattern does not reflect typical UK heating schedules, nor does it reflect the variations in heat demand over the period and so will not reflect the dynamic reaction of the heating control to these changes. This is particularly important for TPI control as this feature only operates when the room temperature is close to the set point. In this test the heating will spend nearly all its time near the set point, a situation that is unlikely to be realised with the intermittent heating patterns that are common in the UK.

Whilst the average internal temperatures achieved with the TPI control are the same as those of the mechanical and electronic on/off controller, TPI control offers greater comfort as the temperature swing is significantly lower than for standard thermostats.

TPI Control Evidence: EST TPI Control Field Trial

A report for the Energy Saving Trust trialled the use of TPI controls in around 47 homes. Monitoring data was collected at 5 minute intervals for around a year both before and after TPI controls were fitted and the data extensively analysed. The report identified that whilst there were periods where TPI control was effective, they accounted for only a small proportion of the total operating time. Although on average a small reduction in energy consumption with TPI controls was observed for the sample (the average seasonal energy efficiency across the sample was 82.86% pre TPI control and 83.21% post TPI control), the difference was not statistically significant. The report also identified that whilst there might be a slight increase in electricity consumption with TPI control it was not statistically significant.

The report identified two prerequisites for effective TPI control to occur: the set point temperature must be reached and the boiler must be allowed to operate at the set point temperature for a significant amount of time. Analysis of the data revealed that sites were likely to be operating under these conditions for less than 9% of the time during the heating season; presumably this is mainly due to the intermittent heating schedules that are common in the UK.

Although the results of the field trial are inconclusive regarding the energy saving potential of TPI controls, they raise a number of issues on TPI control and on field studies of energy saving controls in general.

The most surprising observation of the study is that heating systems in the trial spent 91% of their time heating up to the set point temperature.

The report cites potential conflicts between the logic of TPI control and control embedded in the modulating boiler as a possible reason for not observing energy efficiency savings. The exact mechanism for this is not clear. It could be that the modulation effect interferes with the ability of the TPI control to determine the correct on/off ratio to use for the following time period. Alternatively it could be that the TPI control switching the boiler on and off more frequently means that the return temperature does not get high enough to trigger the inbuilt boiler control. No evidence of this conflict occurring was identified nor of the mechanism by which it operates. Whilst the report identifies instances of boilers cycling based on the return temperature, which could be an indication of this occurring, it does not indicate how frequently this happens.

It is worth noting that all but one of the properties in the field trial had a modulating boiler (which are more likely to have inbuilt logic for improving energy performance by modulating based on the return temperature). It would be interesting to know whether this reasoning lies behind the lack of an ErP control class for TPI control with a modulating boiler. This issue of compatibility between inbuilt boiler logic and TPI controls requires further investigation.

It is possible that some of the properties included in the field trial had energy saving or sophisticated programmable energy controls installed before the switch to TPI control. However, the "before TPI control" base cases were not taken into account in the analysis.

Homes being controlled by physically switching the thermostat and therefore preventing effective TPI control were also cited as a reason for not observing significant savings. In any future field trials changes within the buildings (fabric, internal heat gains) and changes made to control settings (in particular comfort taking by occupants) need to be measured so that analysis can take better account of the effect of these factors on energy consumption.

On potential implication of this field trial is that in order to realise savings TPI (and compensation controls) need to be combined with longer heating periods.

The EST TPI control field trial report did not undertake detailed analysis of room temperatures pre and post-TPI controls being fitted, but did comment that for most buildings the heat demands appeared to have changed considerably over the monitoring period.

The lack of statistically robust evidence of energy savings is not surprising given the relatively small sample size, the large number of variables and the fact that energy savings from controls involves the comparison of marginal energy efficiencies.

Appendix F Further Details on the Cost of Advanced Temperature Controls

Additional Cost of Compensation Control Compatible Boilers

Of the respondents to the stakeholder survey (Question C1), 58% (n=28) did not think that boilers with compensation control compatibility cost more than those without this facility, whilst 27% (n=13) thought they did cost more. Figure 15 provides a breakdown of the response by the main respondent groups.

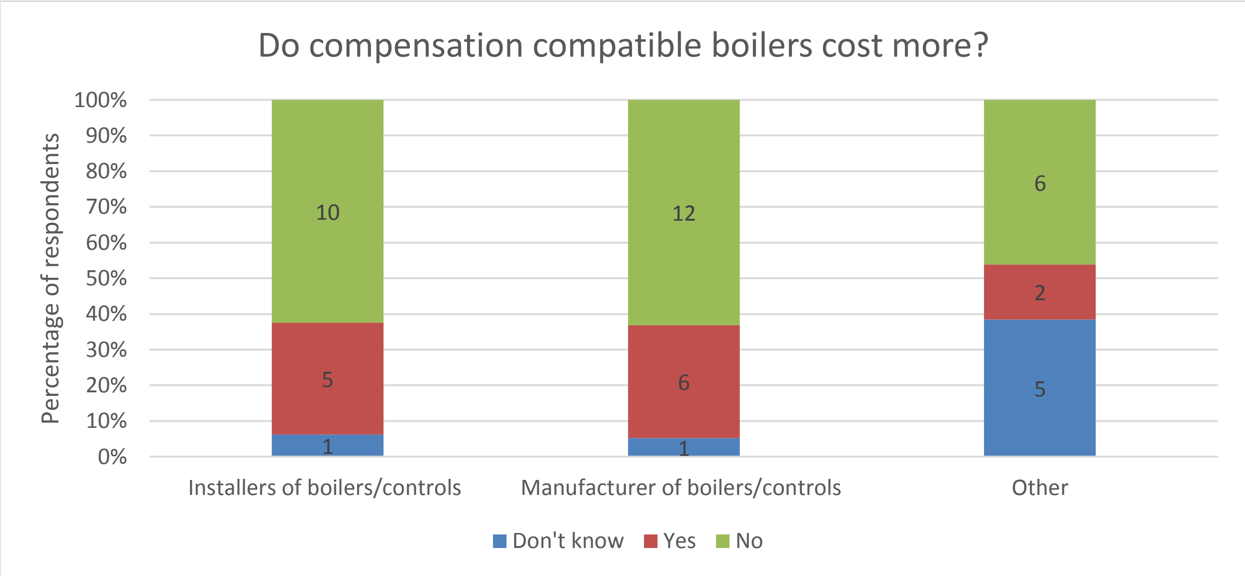

Figure 15: Stakeholder survey results: Do compensation compatible boilers cost more?

This shows that of the 15% (n=7) of respondents that selected 'don't know' or did not answer were from organisations other than installers or manufacturers. One respondent commented that the vast majority of boilers on the market allow for the retrospective connection of these controls. Of those that thought that compensation compatible boilers cost more, only 6 quoted a cost or cost range and these varied from £30-£300, with the majority around £100-£200.

Additional Cost for Weather Compensation Controls

This section provides evidence relating to the cost of installing a weather sensor and the additional cost of purchasing a control unit that includes weather compensation control capability.

Figure 16 shows the price bands that stakeholders selected when asked the price of a weather sensor.

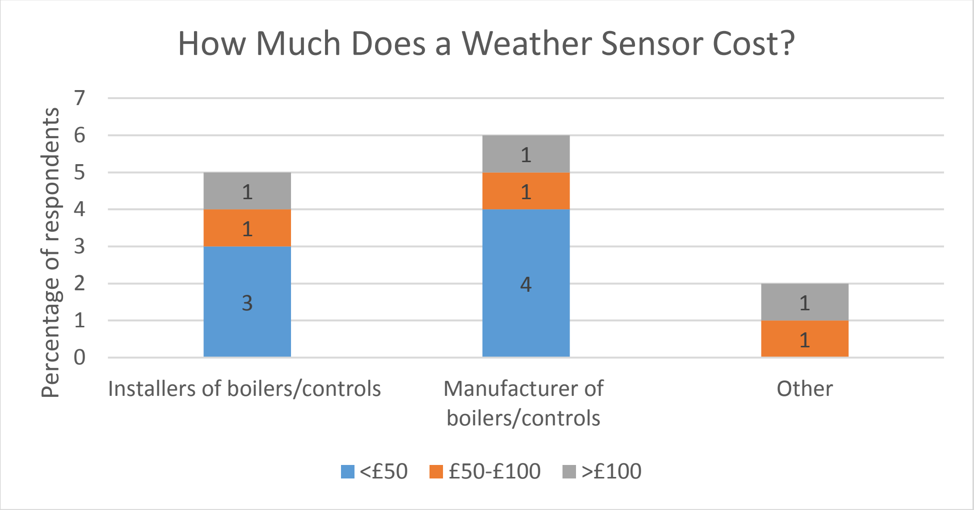

Figure 16: Stakeholder survey results: Typical cost of a weather sensor (£)

Only 13 stakeholders responded to this question and over half selected the price bracket <£50. The range of prices quoted by respondents were in good agreement with those found for online retailers.

In order to ascertain the additional cost of a control unit with weather compensation capability, stakeholders were first asked whether they expected controllers with this capability to cost more than those without. The responses to this question are summarised in Figure 17.

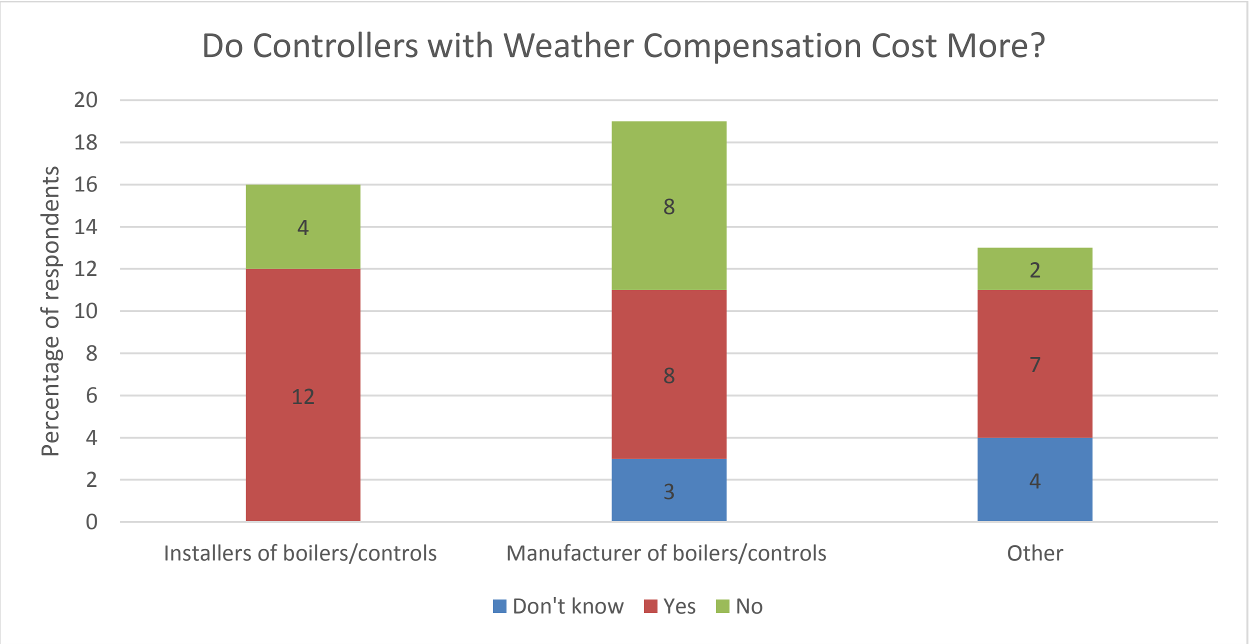

Figure 17: Stakeholder survey results: Do controllers with weather compensation capability cost more?

The majority of respondents indicated that they did expect controllers with weather compensation capability to cost more and that manufacturers were more likely to respond in the negative to this question[49].

Those stakeholders who indicated that they expected weather compensation capability to cost more (n=27) were then asked what they thought the additional cost would be. The responses to this question are shown in Figure 18.

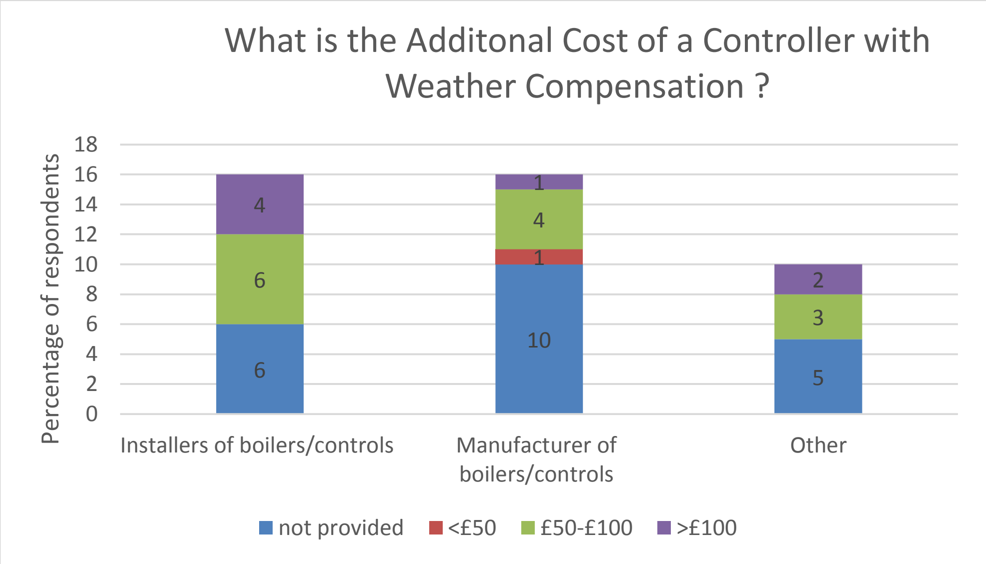

Figure 18: Stakeholder survey results: What is the additional cost of a controller with weather compensation capability?

Of those that provided a cost, 61% (n=13) selected values which fell within the range £50-£100.

It is important to realise that the additional cost of a controller with weather compensation functionality (compared to a standard model) may not be entirely down to the weather compensation aspect as these controllers frequently include additional functionalities, such as optimum start/stop and more programmable options, compared to a more basic controller.

Over half of the respondents to the stakeholder survey indicated that they would not expect controllers with weather compensation capabilities to take any longer to install than a standard control unit. Of the 40% of respondents (n=19) that thought it would take longer, estimates of the additional time taken ranged from 20 minutes to several

[49] Comments included indicate that some respondents provided a negative response to this question on the basis that weather compensation controls can be directly connected to the boiler.

hours. One of the respondents commented that additional time would be required to establish and check communication with the external sensor.

Cost of Load Compensation Control

For load compensation, 51% of respondents to the stakeholder survey expected a load compensation controller to cost more than a standard control unit, whilst 32% did not expect them to be any more expensive. Figure 19 summarises the responses of stakeholders and shows that the responses are similar for each of the main stakeholder groupings.

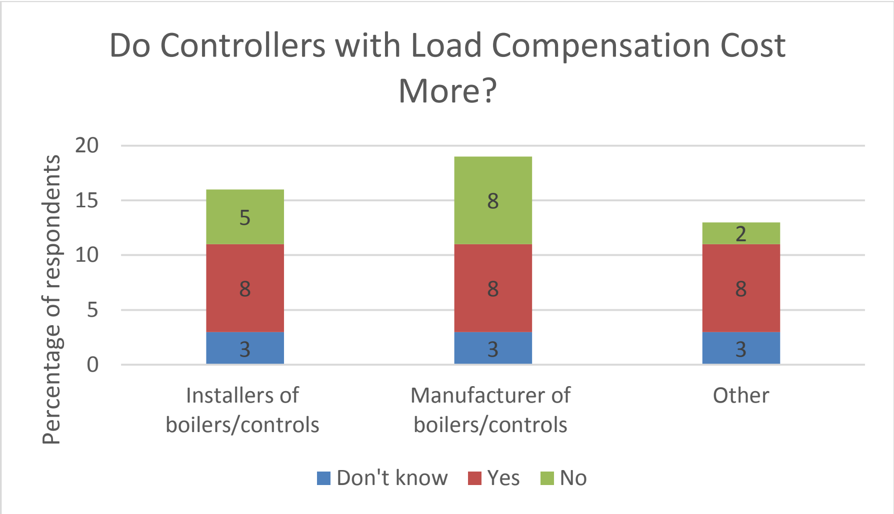

Figure 19: Stakeholder survey results: Do controls with load compensation capability cost more?

Of those who expected a load compensation controller to be more expensive, the typical additional cost reported was of the range £50-£100. The stakeholder responses to this question are summarised in Figure 20.

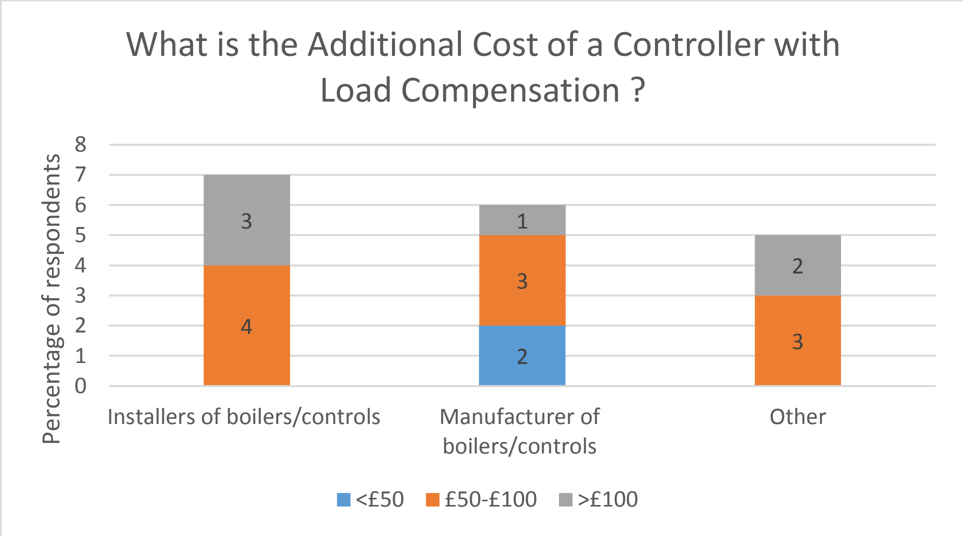

Figure 20: Stakeholder survey results: What is the additional cost of a controller with load compensation?

When asked about the additional time taken to install controls with load compensation, 60% of respondents thought it would require the same time as a standard system, whilst those who thought it would take longer estimated an additional 30-60 minutes.

Cost of TPI controls

Stakeholder responses to the questions regarding the additional cost of a TPI controller are shown in Figures 21 and 22.

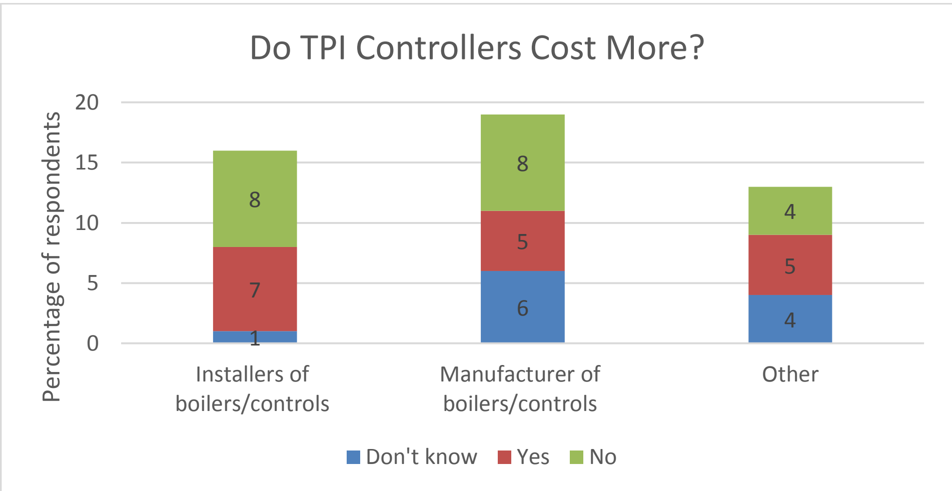

Figure 21: Stakeholder survey results: Do TPI controllers cost more?

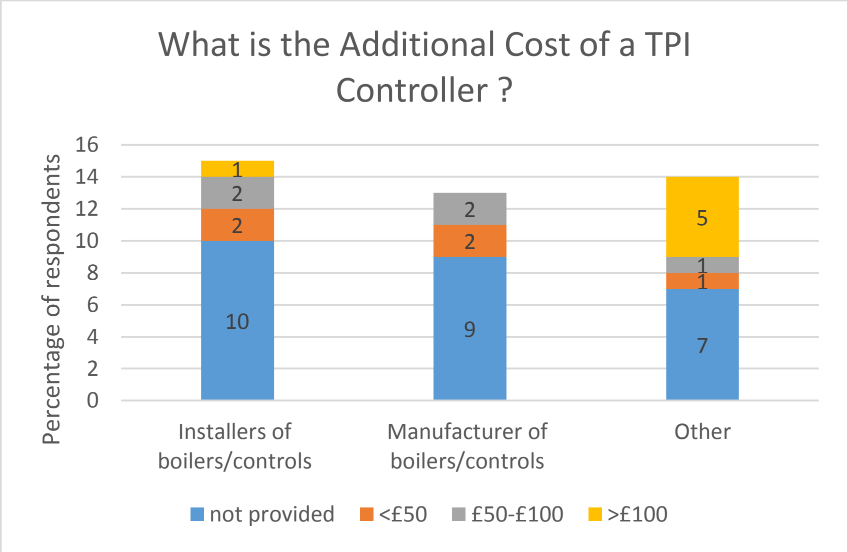

Figure 22: Stakeholder survey results: What is the additional cost of a TPI conroller?

Nearly half (43%) of stakeholders indicated that a room thermostat with TPI control would cost more than a standard unit and that the estimated the additional cost as being around £50. The range of additional costs attributed by the main stakeholder groups are similar.

The majority of respondents (64%) did not expect a TPI controller to take any longer to install than a standard unit, whilst those who did think it would take longer generally estimated an additional 30-60 minutes, with some respondents commenting that it would take longer to establish communication between the boiler and the thermostat.

Appendix G Research Questions and Evidence Identified

Research Question	Response
Advantages/Disadvantages of each technology?	Evidence provided
What is the expected in-situ performance (£, kWh and carbon) range (low/med/high) of each technology?	Inadequate evidence
What are the maintenance requirements and life expectancy of each technology?	Not significantly different to other temperature controls
What product types are available on the market in the UK (and in Europe if other products of note are available)?	All products widely available
What is the current market size?	The market for new installations is well defined and reasonable estimates are provided for existing heating systems
What is the potential market size for each technology?	Potential market share for new installations established, less certainty regarding existing heating systems
What technical standards govern each technology? Are there any gaps in standards?	Existing control standards only relate to accuracy with which temperature is measured. There are no standards that deal with the measurement of energy efficiency improvements.
How do these products differ from any similar forms of control deployed with renewable heat technologies (e.g. heat pump weather compensation)?	No significant differences identified
What/if any innovation is underway and how is this anticipated to impact the future market?	Information provided
What other technology options are available (or nearing commercialisation) to effectively reduce boiler flow temperatures?	None identified
What communication protocols are used by weather compensators?	Commonly used protocols identified and strengths and weakness discussed

Research Question	Response
What are the capital costs?	Information provided
What, if any, are the operating and maintenance costs?	No significant difference compared to standard controls
What are the opportunities for cost reductions under (i) low deployment, and (ii) high deployment scenarios -	Scope for cost reduction and factors that are expected to influence future purchase price identified. Cost reductions under high and low deployment scenarios not identified
What evidence is there of historic cost reductions from other related markets?	No evidence identified
What factors govern the effective design, installation and performance of each technology?	Heating system configurations and boiler type identified, - installation, commissioning addressed and factors that influence energy efficiency improvements identified
Under what circumstances would each technology deliver no/limited savings and what number of the UK housing stock fall within this category?	This will be determined by factors that govern energy performance and energy performance is highly uncertain
What are the risks associated with each technology (e.g. under/overheating, ease of installation, usability)? How are these risks addressed in practice?	Interactions with other controls - potential conflict of TPI control with modulation control inbuilt in boiler requires further investigation
What usability factors are relevant to each technology?	More related to type of interface rather than control technology
How does each technology interact with other forms of heating control and what is the expected impact of these interactions? How can these impacts be negated?	Interactions with other controls - potential conflict of TPI control with modulation control inbuilt in boiler requires further investigations
What technical barriers are there for the technology that prevents widespread deployment?	None for TPI - compatibility with existing heating systems an issue for compensation controls
Are these barriers likely to be solved through continued development or specific interventions?	As older heating systems get replaced the compatibility issue will gradually decline.
What specific installation challenges does the technology have?	Siting weather sensor and can involve complex wiring. Controls that can access internet weather data and RF connection can overcome these issues.

Research Question	Response
What set of skills would be required for installation and how do these compare with the current market of installers?	No additional skill set as such - Greater technical understanding and practical knowledge
What market barriers are there?	Barriers identified
What are the barrier costs or other indirect costs?	Not evaluated

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