Department of Energy & Climate Change

How heating controls affect domestic energy demand:

A Rapid Evidence Assessment

January 2014 – Final Report

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Credits

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How heating controls affect domestic energy demand: A Rapid Evidence Assessment

Final Report

Prepared by *the*RTK ltd

January 2014

Contents

Executive summary

This report provides findings from the Rapid Evidence Assessment (REA) of how heating controls affect domestic energy demand that *the*RTK Ltd delivered to the Department of Energy and Climate Change (DECC).

DECC commissioned this review with the aim of synthesising existing research evidence on how domestic heating controls affect energy demand. The objective was for the review to contribute to the Smarter Heating Control Research Programme, aimed at establishing the extent to which the introduction of smarter heating controls is likely to save energy. The review was also intended to provide evidence with which to inform a subsequent design of a possible field trial that could detect any energy reductions associated with improving control technologies.

To that end, DECC set out five detailed research questions for the REA:

1. What heating controls are installed and how do these vary across different properties and households?
2. When, why and how are new heating controls installed?
3. How do people use their heating at present?
4. What can be learnt from previous evaluations of whether heating controls affect energy demand?
5. What are the evidence gaps that should be filled?

Methodology

The review followed a Rapid Evidence Assessment methodology in accordance with the guidance provided by DECC. Papers and reports were collected using a systematic search of relevant academic literature databases, a targeted search of the grey literature[1] and requests for suggestions from relevant stakeholders. Database search terms were chosen systematically and agreed upon in discussion with DECC. The quality of evidence was assessed by examining the methods used, judging their robustness and the strength of conclusions drawn from them. Initial searches of key databases uncovered a total of 1,684 abstracts. Detailed screening of these papers using a DECC data extraction template resulted in the selection of 14 peer reviewed research papers. An additional 6 reports from the available grey literature were selected.

To supplement findings from the Rapid Evidence Assessment, the review team undertook secondary data analysis using the 2011 Energy Follow-Up Survey (EFUS) of over 2600 households. Analysis is based on the interview sample with most of the findings weighted to the national level, using a weighting factor specific to the interview sample. These results of EFUS data are therefore representative of the English housing stock, with a population of 21.9 million

[1] Grey literature is broadly defined as including everything except peer-reviewed books and journals. More information can be found in the methodology section of this report and the Appendices.

households. The review also explored use of the Homes Energy Efficiency Database (HEED) containing details of over 13 million households, however due to methodological issues it was not possible to use this data extensively within this Rapid Evidence Assessment.

Key Findings

1. Little research has been undertaken in this domain and much of what is available comes from small scale case studies, most of which were not conducted in the UK.

2. Research from the UK and US has largely failed to provide a consistent body of evidence as far as the capacity of improved heating control technology to contribute to energy savings is concerned.

3. The most recent survey data on heating controls comes from the Energy Follow-Up Survey (EFUS). The data, weighted to be nationally representative, shows that 90% of households (19,700 thousand out of 21,900 thousand households of the English housing stock) have central heating. Of this group with central heating, 98% of households have primary heating controls that include one of the following: an overall on/off switch, a boiler thermostat and a central timer.

4. Analysis of EFUS data shows that 49% of households with central heating (9,600 thousand households out of 19,700 thousand) report having a full set of central heating controls defined as a thermostatic radiator valves (TRVs), a central timer, and room thermostats. This figure has been rising over recent years, but is uneven across demographic groups.

5. Further analysis of EFUS data found that households living in private rented accommodation are significantly less likely to have a full set of heating controls than households living under other forms of tenure. One person households are less likely to have TRVs fitted, and less likely to have a full set of heating controls.

6. Consumers typically replace their central heating controls when they replace their boilers. Installation rates of modern, fuel efficient boilers currently stands at around 5% of households each year.

7. Evidence indicates that installers, rather than domestic consumers, frequently make decisions about which central heating controls to install and where to install them.

8. Findings from analysis of EFUS on how households heat their homes include:
    - 74% of households (12,200 thousand) with central heating used a timer to switch their heating system on and off, 15% switch their heating on and off manually, 10% switch their heating on and off by turning the thermostat up or down, and 1% by other means;
    - Of those with central heating reporting timed heating, 77% (9,400 thousand households) reportedly used two heated periods per day, and about 14% (1,800 thousand households) used one heated period, with only about 9% (just over a 1,000 thousand households) using more heated timed periods on an average weekday. Weekend periods were reportedly very similar;
    - The number of reported hours the central heating is on per day varies but the mean times were calculated to be 8 hours 15 minutes a day during the week, and 8 hours

39 minutes at weekends with some households having their heating on for substantially more than the average;

- In households where the heating was reportedly switched on and off only once, it was on for an average of 10 hours 24 minutes on a weekday, and 10 hours 51 minutes on a weekend day and in homes reportedly turning their systems on and off twice a day, the average weekday on time was 6 hours 45 minutes, compared with 7 hours 14 minutes on a weekend day.
- Around half of households providing data on boost heating reportedly used 4 hours or less with 10% using just one and 20% just two hours a week but with a number of households using many more hours, some up to a maximum of 98 hours per week.
- Heating ‘density’ plots for weekdays show that for single periods most heating is on from around 7.00am to 10.00pm, while for two periods there were fairly distinct peaks around 6am to 9am and 4.00pm to 10.00pm. Weekend periods were found to be very similar though it was found that heating comes on slightly later on weekend mornings.

9. Some studies, mainly from the US, have found usability issues with currently available domestic heating controls.

10. Evidence suggests domestic consumer use of heating controls is often driven by a desire to achieve thermal comfort rather than a wish to save energy.

Gaps in the existing evidence base

1. To date, very few UK studies have rigorously evaluated the overall effect of providing households with technologically improved heating controls in terms of energy saved.

2. The field lacks good national data on central heating demand temperatures and durations.

3. Insufficient evidence exists about the role of consumer behaviour in potential relationships between energy savings and improved control technologies.

4. Only limited empirical evidence exists with regard to when, why and how new domestic heating controls are installed.

5. Several aspects of improved heating control usability remain to be investigated.

1. Introduction

1.1 Background

Domestic energy use accounts for 29% of UK energy consumption with space heating responsible for 66% of domestic energy consumption and water heating for an additional 17%[2]. Carbon budgets commit the UK to reduce overall CO2 emissions by at least 80% by 2050. Improving heating controls is seen as one potential way to reduce emissions. However, little is known about what heating controls are installed; when why or how this installation takes place; how people use their heating system at present; or what impacts heating controls might have on energy demand.

1.2 Aims and objectives of the review

DECC commissioned this Rapid Evidence Assessment (REA) with the aim of synthesising existing evidence on how domestic heating controls affect energy demand. Consistent with standard Rapid Evidence Assessment methods[3], it pulls together evidence from peer-reviewed academic publications and commercial reports. A key role is to provide evidence with which to inform the design of a trial that could detect any energy reductions associated with improving control technologies against a background of considerable variation in energy use across different households.

The objective was for the REA to contribute effectively to a wider programme of work aimed at establishing the extent to which the introduction of smarter heating controls is likely to save energy. To that end, DECC set out five detailed research questions for the review:

1. What heating controls are installed and how do these vary across different properties and households?
2. When, why and how are new heating controls installed?
3. How do people use their heating at present?
4. What can be learnt from previous evaluations of whether heating controls affect energy demand?
5. What are the evidence gaps that should be filled?

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[2] DECC Energy Consumption in the UK (2013), Chapter 3: Domestic energy consumption in the UK between 1970 and 2012. Available at https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/65954/chapter_3_domestic_factsheet.pdf. (27/01/2014).

[3] Rapid Evidence Assessment Toolkit. Available at http://www.civilservice.gov.uk/networks/gsr/resources-and-guidance/rapid-evidence-assessment (27/01/2014).

1.3 Key characteristics of domestic heating systems

This short section describes the essential elements of domestic heating system controls. It has been included to help with interpretation of the evidence the report discusses in later sections.

1.3.1 Gas and oil boilers

Gas and oil boilers are similar in many respects, in terms of technical specifications, efficiencies and permutations. The vast majority of boilers in the UK are gas fired and of these, most take natural gas off the grid[4]. Three main factors distinguish boilers: mounting and location, whether they are condensing, and whether they heat hot water directly (combination or 'combi' boilers[5]) or indirectly. The terms 'regular', 'standard' and 'conventional' in relation to boilers is now ambiguous and best avoided; before condensing boilers appeared, they meant a boiler which was not a combination boiler. When condensing boilers came onto the market it could also mean non-condensing. Now that all new boilers are condensing, the terms are likely to refer to non-combination boilers.

Modern boilers are usually mounted on a wall with a balanced flue[6] direct to the outside. Older boilers are often floor mounted and take combustion air from the room.

Back boilers (which are no longer produced) are located in a fireplace behind a gas fire, and have low efficiencies; large numbers were installed in the 1980s because they were simple and reliable[7].

Condensing boilers use a second heat exchanger to recover latent heat from the hot flue gases before they are exhausted through the flue. That is, they turn the water vapour produced by burning the gas, into liquid water which releases heat. National Energy Efficiency Data (NEED)[8] has shown that this increases the overall efficiency of the appliance to produce gas savings of up to 13 percentage points in a three bedroomed semi-detached house[9]. The 2006 Building Regulations, Part L1[10], introduced minimum efficiency standards for domestic boilers of 86% for gas and 85% for oil. Since the maximum efficiency of non-condensing boilers is only around 82%[11], the legislation in effect mandated condensing boilers, and so all new boilers are condensing.

Non-combination boilers heat a piped circuit which feeds radiators (or a warm air system), and a coil which heats up water in a hot water cylinder. These circuits can be controlled separately.

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[4] Off-grid gas boilers use Liquid Petroleum Gas (LPG) stored in a tank but are otherwise very similar to natural gas boilers.
[5] Subsequently referred to as combi boilers
[6] This means that combustion air is taken from the outside rather than from the room.
[7] Many of these still exist, however estimates of the approximate percentage was beyond the scope of this REA.
[8] National Energy Efficiency Data (NEED) links energy consumption data to household attribute data and data on energy efficiency measures in place. It calculated the energy savings from various energy efficiency measures in place in homes by comparing energy consumption before and after installation of a measure relative to changes in consumption observed in homes that did not receive measures. As opposed to theoretical savings from energy efficiency measures, the figures derived from NEED represent actual energy savings achieved.
[9] DECC (2012). Energy Efficiency Statistical Summary. Department of Energy and Climate Change, London. p. 23. Available at - https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/65598/6918-energy-efficiency-strategy-statistical-summary.pdf (27/01/2014).
[10] Office of Deputy Prime Minister. L1A Conservation of fuel and power in new dwellings. Available at - http://www.planningportal.gov.uk/uploads/br/BR_PDF_ADL1A_2006.pdf (27/01/2014).
[11] Information about boiler efficiencies is provided in the Product Characteristic Database File (PCDF). Available at - http://www.boilers.org.uk/ (27/01/2014).

Combination boilers (so called because they combine space and water heating in one unit) heat domestic hot water directly on demand. The boiler is plumbed into the cold mains supply entering the property, and when a hot tap is turned on, the fall in pressure in the hot water pipes triggers the boiler to fire and heat the water as it passes through a heat exchanger. Since the boiler can only heat up a certain amount of water at once, the hot water flow is usually slower than from a hot water cylinder. Some combination boilers contain small stores (buffer tanks) of hot water to supply a limited amount of hot water at a higher flow rate. Electric showers are also commonly installed with these systems. Because there are no 'standing losses' from the hot water cylinder and reduced pipework, combination boilers typically deliver hot water with an overall greater efficiency than non-combination boilers.

Apart from the basic feature of condensing, modern boilers have various efficiency improvements over older boilers. These include electronic ignition which dispenses with a pilot light, a fan to improve combustion, and modulation. An older non-modulating boiler operates with a fixed output. Thus to deliver a load which is say 30% load of its output, it will cycle on and off every few minutes, being on 30% of the time. A modulating boiler will deliver a continuous output of 30% of its maximum output. Modern boilers are however much more complex than older boilers and may not be so reliable. Past research suggests that installers often recommend that householders keep their old, inefficient boiler for its reliability and to avoid the capital cost of a new one[12].

With regard to system efficiency, condensing boilers work best when they have low return temperatures. However it is believed that they are often being retrofitted to existing heating systems and controls that were designed to run hot to dissipate the high system temperatures generated by a conventional, non-condensing boiler[13].

Advanced controls are available that adjust system temperature to match the heating load and lower the return temperature. Fitting sensors that measure outside temperature is one such measure, a feature that is mandatory in Germany and available in the UK, though very rarely installed[14]. However research shows that both installers and consumers are often reluctant to embrace what they perceive to be new technology[15], despite assertions from the Building Services Research and Information Association that new technology smart communication devices are likely to be a 'mass market' in the future[16].

1.3.2 Domestic gas heating systems

Figure 1 shows a typical gas or oil central heating system, with hot water tank. Water from the boiler is pumped around two circuits: one circuit serving radiators, the other (the 'primary' hot water circuit) serving a coil inside a hot water cylinder. A three-port valve controls flow to each circuit, allowing, for example, the boiler to heat water in the summer without heating radiators.

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[12] Banks, N (2000). Socio-technical networks and the sad case of the condensing boiler. ACEEE Summer Study Proceedings 2000. ACEEE. Available at - http://www.eceee.org/library/conference_proceedings/ACEEE_buildings/2000/Panel_8/p8_1/paper (27/01/2014).

[13] Building Services Research and Information Association (BSRIA) (2009) Condensing boilers and domestic heating controls. Available at - http://www.bsria.co.uk/news/dom-controls/. (27/01/2014).

[14] Building Services Research and Information Association (BSRIA) (2009) Condensing boilers and domestic heating controls. Available at - http://www.bsria.co.uk/news/dom-controls/. (27/01/2014).

[15] Banks, N (2000). Socio-technical networks and the sad case of the condensing boiler. ACEEE Summer Study Proceedings 2000. ACEEE. Available at - http://www.eceee.org/library/conference_proceedings/ACEEE_buildings/2000/Panel_8/p8_1/paper (27/01/2014).

[16] Building Services Research and Information Association (BSRIA) (2009). Condensing boilers and domestic heating controls. Available at http://www.bsria.co.uk/news/dom-controls/. (27/01/2014).

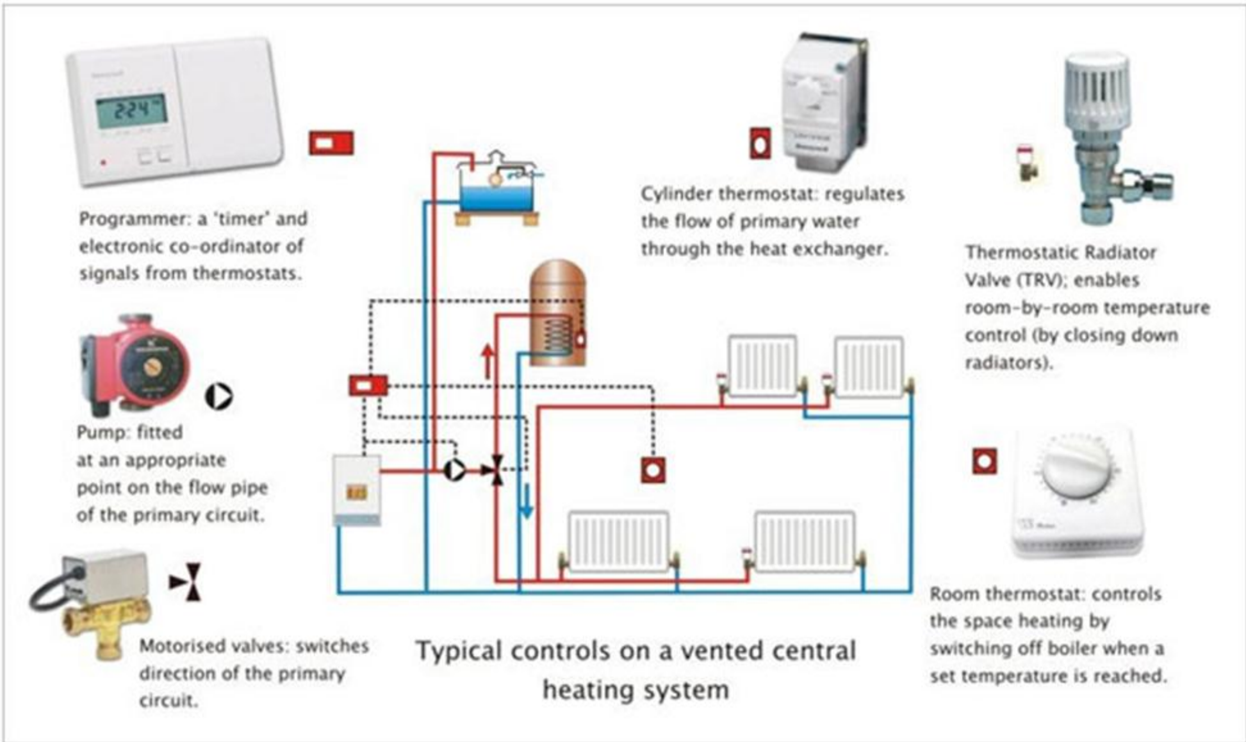

Figure 1. Typical domestic heating system and components.

Source: Southern Counties Heating and Plumbing[17].

Most systems with hot water tanks also have an electric immersion heater that can heat water independently of the boiler system. Immersion heaters are usually installed as a backup. However, some homes with gas heating systems use electric immersion heating for hot water during the summer.

In recent years, the use of combination or 'combi' boilers has become more common; in 2011 they accounted for 40% of domestic boilers in the UK[18]. Combi boilers heat water directly in the boiler on demand, thus dispensing with the need for a hot water cylinder. They can be more efficient, particularly for low usage, as there are no standing losses from a tank and the primary circuit. However, flow rates are typically poorer than from a tank because water has to be heated as it is used.

1.3.3 Domestic heating controls

Householders typically only interact with three types of control:

1. the room thermostat;

2. the programmer – sets on/off times of heating; hot water may be on the same or a separate time schedule; and

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[17] Available at www.sc-hp.co.uk (27/01/2014).

[18] DECC (2012). Energy Efficiency Statistical Summary. Department of Energy and Climate Change, London. p. 32 Available at - https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/65598/6918-energy-efficiency-strategy-statistical-summary.pdf (27/01/2014).

3. thermostatic radiator valves (TRVs)

Figures 2 to 7 show examples of these three types of commonly used domestic heating controls and other aspects of the heating system.

Figure 2. Typical room thermostat with light indicating when heating is on.

Figure 3. Typical central heating timer.

Typical central heating timers allow consumers to set times for the heating system. This model has the same schedule for heating and hot water. Each can be timed, permanently on or permanently off, independently.

Figure 4. Left: Manual on/off radiator valve. Right: Thermostatic radiator valve (TRV).

Figure 5. Boiler return temperature thermostat

Figure 6. Frost thermostat linked to boiler[19].

Although most homes now have most of the controls shown above, the degree of control can vary considerably depending on the age of the system.

A typical level of flexibility offered by a room thermostat, programmer and TRVs would be two or three periods per day for heating and hot water (either with the same times or different time schedules), with the option of different schedules for weekdays and weekends. Usually heating and hot water can also be set to permanently 'on', permanently 'off'. When timed, some systems allow the heating or hot water control to be 'advanced' to the next 'on' or 'off' state, e.g. to turn

[19] A frost thermostat linked to a boiler turns the boiler on in very low temperatures to prevent damage from water freezing in the boiler or pipes.

on heating early. Some controllers also have a boost setting for an additional one, two or more hours.

Programmable thermostats are widely used in many parts of the world for both heating and cooling control, and many studies on domestic controls relate to these. Although available in the UK, few are at present installed. These devices combine the functions of the wall thermostat with a system timer. They allow different temperature values to be set for different time periods, for example a night 'set back' temperature of say 12°C to stop the building becoming too cold. This is not usually necessary in the UK due to a temperate climate, where the system is usually either on or off with a temperature separately set by the wall thermostat.

Figure 7. *Example* of a programmable thermostat.

The devices and controls shown in Figures 2-7 share common characteristics in that they each require action by the user to decide on and set a time or temperature control parameter via a physical adjustment. As a consequence, a body of research in this area has studied the effectiveness of this range of devices and controls in terms of consumer usability.

1.4 Smarter Heating Controls

The industry has recognised usability issues; as a result, two strands of new product are evident. The first can be characterised as retaining time and temperature setting as a manual activity using the controls described above, but improving their usability, i.e. making it easier to programme control settings. These can be described as ‘active’ smarter heating controls. So, for example products at this level of development might include deploying a hub unit that is connected to the household broadband internet service. The thermostat and time programmer are wirelessly linked to this hub via the internet to the vendor's servers. The user is then able to configure all their time and temperature settings from their home computer or tablet through an interface that includes prompts which aim to assist them in making consistent and efficient settings. Many suppliers also provide a smart mobile phone application to do the same job.

The second strand of product development sets out to automate some or all of the parameter setting process so that the task of adjusting times or temperatures is wholly or partly lifted from the user[20]. As a consequence, physical intervention by the user is needed less frequently to

[20] Boait P.J., & Rylatt R.M. (2010). A method for fully automatic operation of domestic heating. *Energy and Buildings*, 42 (1), p.11-16

maintain efficient settings, enabling the user interface to be further simplified[21]. Products in this strand of development typically aim to automate time setting by detecting occupancy and household activity using a variety of sensors. The system then uses the data collected to build a predictive model of occupancy patterns. Occupancy is then translated into heating times taking account of building thermal properties. Temperature setting can also be automated given knowledge such as the household demographics and the weather.

Based on evidence from this Rapid Evidence Assessment and the findings from other Smarter Heating Controls Research Programme reports including, Rubens, S., Knowles, J. (2013). *What people want from their heating controls: a qualitative study,* and Wall, S., (2013). *Usability testing of smarter heating controls*, a working definition of Smarter Heating Controls (SHCs) is being developed. At this time Smarter Heating Controls are seen as a group of technologies that, installed into a domestic heating system, seek to facilitate the centralised control of heating. Active Smarter Heating Controls typically provide consumers with greater control by enabling the local and remote control and management of temperature, time and zone. Passive systems are characterised by technologies that seek to control heating by learning about a consumer's heating behaviour or by delivering the same or similar amount of comfort by use of less energy.

[21] Peffer, T., Pritoni, M., Meier, A., Aragon, C. & Perry, D. (2011). How people use thermostats in homes: A review. *Buildings and Environment*, 46, p.2529–2541.

2. Methodology

This review of the existing evidence on how domestic heating controls affect energy demand has been conducted through a Rapid Evidence Assessment (REA) of peer-reviewed academic publications and other sources such as commercial reports, some of which were identified in interviews with key stakeholders. This REA follows guidelines developed by the Government Social Research Service[22]. It involves using a transparent and reproducible search to identify studies, and explicit and objective methods to select, extract, quality appraise and synthesise the evidence.

Details of the procedures used at each stage of the REA process can be found in *Appendix A – Details of the Rapid Evidence Assessment methodology*, a separate document to this report. Figure 8 summarises the procedure.

Stage 1 Identify sources and develop search string	Electronic databases, websites and academic journals identified for REA. Search string developed and tested.
↓	
Stage 2 Conduct search	REA search conducted using search string within parameters specified (timeframe, limitations).
↓	
Stage 3 Remove duplicates and screening	Duplicate studies removed. Studies screened initially on abstract against exclusion/inclusion criteria to determine whether they are included in the REA.
↓	
Stage 4 Data extraction	Data extracted and recorded.
↓	

[22] Rapid Evidence Assessment Toolkit. Available at http://www.civilservice.gov.uk/networks/gsr/resources-and-guidance/rapid-evidence-assessment (27/01/2014).

Stage 5
Additional studies identified

Additional materials identified by topic experts, review team, web searches and citation chasing.

↓

Stage 6
Quality assessment

All studies included in the REA appraised using a quality assessment (QA) tool.

↓

Stage 7
Synthesis

Findings synthesized.

Figure 8. Summary of REA methodology.

2.1 Evidence selection method

This section sets out the methodology of how the evidence in this review was collected through the REA process and summarises the studies included. Details of the search criteria, inclusion and exclusion criteria, data abstraction strategy and critical appraisal strategy can be found in *Appendix A – Details of the Rapid Evidence Assessment methodology* which accompanies this report.

Papers and reports were collected using a systematic search of relevant academic literature databases, a targeted search of the grey literature and requests for suggestions from relevant stakeholders. Database search terms were chosen systematically and agreed upon in discussion with DECC. The quality of evidence was assessed by examining the methods used, judging their robustness and the strength of conclusions drawn from them.

Initial searches for the selection of peer reviewed research papers and reports of key databases uncovered a total of 1,684 abstracts. As shown in Figure 8, initial screening for relevance reduced that number to 219. A more detailed screening of that number led to a retrieval of 20 full research papers. A further six were excluded on reading the full text. All screening was completed using a DECC evaluation template (found in *Appendix B – DECC Data Extraction Template*) which developed criteria to select or exclude papers and was within the expected range of similar REAs conducted for DECC and other government departments.

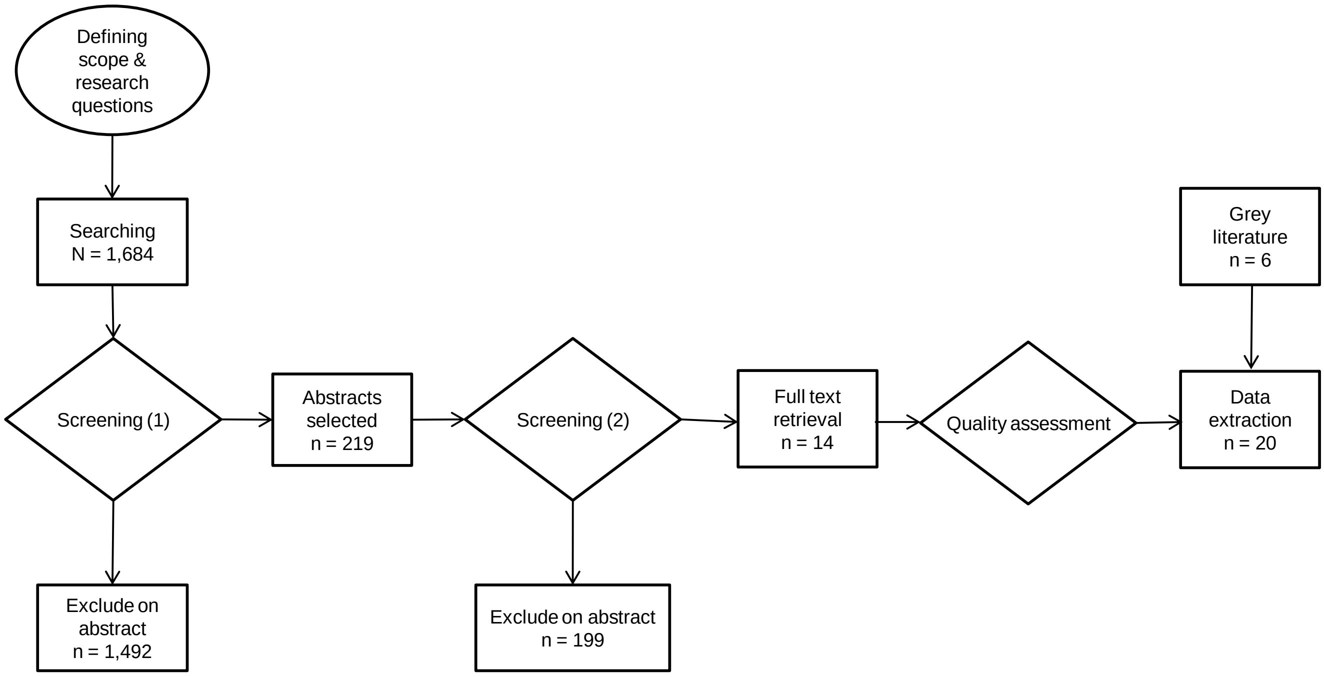

Figure 9. Rapid Evidence Assessment (REA) workflow: DECC evidence review of how heating controls affect domestic energy demand.

Reports from the grey literature were selected based on criteria agreed with by DECC. Grey literature is broadly defined as including everything except peer-reviewed books and journals. Grey literature is less likely to flow from the application of robust research methods and could be influenced by the interests of its authors. However, grey literature does serve to add context to the research questions and the research domain overall[23] and was therefore used within this REA. This process uncovered 44 papers from the grey literature, of which a total of 6 were selected for full data extraction. Inclusion of these papers were based on the criteria of whether they addressed the REA research questions and were recommended by sector or DECC experts[24].

In all the REA was successful in gathering 14 peer reviewed research papers and 6 reports from the available grey literature. The flow diagram below provides details of the numbers of studies identified at each stage of the REA process.

Consistent with standard REA practice, Table 1 summarises the relative strengths and weaknesses of each of the 20 papers identified in the review process. Where this review cites additional material, details of the research methods in the text have been included where they are available.

[23] Huffine, R. (2010). Value of Grey Literature to Scholarly Research in the Digital Age – National Library Coordinator presentation. Available at - http://cdn.elsevier.com/assets/pdf_file/0014/110543/2010RichardHuffine.pdf (27/01/2014); Benzies KM, Premji S, Hayden KA, Serrett K. (2006) State-of-the-evidence reviews: advantages and challenges of including grey literature. *Worldviews Evidence Based Nursing*. 3(2): p. 55-61.
[24] Details of the inclusion and exclusion process can be found in *Appendix A – Details of the Rapid Evidence Assessment methodology* which accompanies this report.

		1	2	3	4	5	6	7	8	
	Study methods	Is there a clear statement of the paper's aims?	Is the research reported in a peer reviewed journal?	Does the paper report a quantitative evaluation	Is the sampling and recruitment strategy rigorous and robust?	Are the methods of data collection rigorous and robust?	Was data analysis sufficiently robust?	Is the reporting good enough to enable results to be audited?	How relevant are the findings to this REA?	Country of study
BSRIA (2009)	Qualitative survey	Yes	No	No	Medium	n/a	n/a	n/a	2	UK
Boait & Rylatt (2010)	Single case observational study	Yes	Yes	Yes	Weak	Medium	Medium	n/a	1	UK
Combe et al, (2012)	RCT	Yes	Yes	Yes	Weak	Medium	Medium	n/a	2	UK
Consumer Focus (2012)	Review	Yes	No	No	n/a	n/a	n/a	n/a	2	UK
Crosbie & Baker (2010)	Qualitative interview study	Yes	Yes	No	Medium	Med/Wk	Weak	Med/Wk	2	UK
DECC/EST (2009)	Government report	Yes	No	No	Strong	Strong	Strong	Strong	2	UK
DECC/EEPH (2010)	Government report – market review	Yes	No	No	Strong	n/a	Medium	n/a	2	UK
Druckman et al (2011)	Discussion of household GHG related behaviours	Yes	Yes	No	n/a	n/a	n/a	n/a	1	UK
Gill et al (2010)	Survey and interview study	Yes	Yes	Yes	Weak	Medium	Medium	Medium	1	UK
Hong et al (2006)	Survey	Yes	Yes	Yes	n/a	n/a	n/a	n/a	1	UK
Karjalainen (2010)	Usability study of office room controls	Yes	Yes	Yes	Unclear	Medium	Medium	Weak	1	FI
Liao & Dexter (2004)	Survey, and experimental study	Yes	Yes	Yes	Weak	Weak	Weak	Weak	1	UK
Malinick et al (2012)	Telephone survey	Yes	No	Yes	Strong	Medium	Medium	Weak	2	US
Meier et al, (2010)	Review	Yes	No	No	n/a	n/a	Strong	Strong	2	US
Peffer et al (2011)	Review	Yes	Yes	No	n/a	n/a	n/a	n/a	2	US
Pett & Guertler (2004)	Survey	Yes	No	Yes	Medium	Medium	Medium	Medium	1	UK
Sauer et al, (2009)	Usability study	Yes	Yes	No	Weak	Strong	Strong	Weak	1	CH
Scott et al (2011)	Evaluation	Yes	No	Yes	St/Med	Strong	Strong	n/a	2	UK/US
Shipworth (2011)	Survey	Yes	Yes	Yes	Strong	Strong	Strong	Medium	2	UK
Summerfield et al (2007)	Evaluation	Yes	Yes	Yes	Weak	Strong	Strong	Strong	2	UK

Table 1. Summary table of included studies identified in the REA process described above

Key

Columns 4-7: Ratings in these columns assess research methodology.

- ‘strong’ indicates where methods were judged as robust
- ‘medium’ indicated where some flaws were evident in the methods
- ‘weak’ indicated where major and/or numerous deficiencies were evident in the methods

Column 8: Rating in this column assesses relevance:

- a score of 2 indicates the source addressed the 5 REA research questions directly.
- a score of 1 was allocated when the source did not address the 5 REA research questions directly.

2.2 Supplementary Secondary Data

2.2.1 Energy Follow-Up Survey

To supplement findings from the REA, the review undertook secondary data analysis of the Energy Follow-Up Survey 2010/11 (EFUS) which is currently funded by DECC and carried out by the Building Research Establishment (BRE) for DECC[25]. The main aim of the 2011 Energy Follow-Up-Survey was to collect new data on the patterns of household and dwelling energy use in order to update the current modelling assumptions about how energy is used in the home.

The 2011 EFUS consisted of a follow-up interview survey of 2,616 households from a sub-set of approximately 17,000 households who had received both the physical and interview survey as part of the 2010/11 English Housing Survey (EHS)[26]. Households that had taken part in the EHS were asked if they would be willing to participate in a further study. Those who agreed were selected as potential households for the EFUS. The sample is therefore self-selecting rather than random and consequently subject to larger sampling errors than representative surveys. Of the 3,458 sample households invited to participate in the EFUS, 2,616 were interviewed giving a response rate of 76%[27].

Of the 2,616 households interviewed, 950 were selected to receive loggers to monitor internal temperatures. The aim of the survey was to get an up-to-date understanding of how energy is being used in homes. It profiled electricity use in 100 homes (to understand time-profiling of electricity use) and temperature monitoring of 1,000 homes for a full year to provide information on the temperatures to which people actually heat their homes (and how long for), as well as gathering evidence on summer overheating across the housing stock.

The EFUS methodology reports that the raw outputs from the interview survey were generally complete with few missing variable and considered good quality. It should however be remembered that much of the analysis presented in this report is based on householders' *responses* to questions rather than to actual timeclock or programmer settings recorded by inspection of these controls by the interviewers. There is therefore an inherent problem in validating the quality of this data, although the cross analysis which has been attempted with the temperature logger data goes some way to achieving this. Measurement errors were also minimised through extensive training of interviewers.

The EFUS data have been scaled up to represent the national population (and to correct for nonresponse) using weighting factors. Analysis is based on the interview sample weighted to the national level, using a weighting factor specific to the interview sample. The results

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[25] A list of all BRE EFUS analysis reports are available at – https://www.gov.uk/government/publications/energy-follow-up-survey-efus-2011 (27/01/2014).

[26] EHS is a continuous annual survey commissioned by the Department of Communities and Local Government (DCLG). In 2010 (the EHS year of which the EFUS sample is a subset) approximately 17,000 dwellings were sampled for the main interview survey, and an 8,000 dwelling sub-sample of these were selected for a physical assessment. More information regarding the EHS is available at - https://www.gov.uk/government/collections/english-housing-survey (27/01/2014).

[27] Details of the EFUS methodology were taken from both the methodology section of the Main heating system report and the Methodology report:

BRE (2014) Energy Follow-Up Survey 2011 - Report 4: Main heating systems. Prepared by the Building Research Establishment (BRE) on behalf of the Department of Energy and Climate Change. Department of Energy & Climate Change. Available at – https://www.gov.uk/government/publications/energy-follow-up-survey-efus-2011 (27/01/2014);

BRE (2014) Energy Follow-Up Survey 2011 - Report 11: Methodology. Prepared by the Building Research Establishment (BRE) on behalf of the Department of Energy and Climate Change. Department of Energy & Climate Change. Available at – https://www.gov.uk/government/publications/energy-follow-up-survey-efus-2011 (27/01/2014).

presented in this report are therefore representative of the English housing stock, with a population of 21,900 thousand households.

For the EFUS Interview survey, data were weighted back to the population targets for Government Office Region, dwelling type and tenure, using the rim weighting process. For the EFUS temperature logger sub-sample, a weighting factor was derived using logistic regression based on the profile of respondents for the Government Office Region, tenure, dwelling type and working status of household. Although the objective of the weighting factor is to provide totals that can be interpreted at the national level, readers should be aware that there may remain some uncorrected bias in the data (e.g. if the households that accepted temperature loggers differ from the population in a way that is not visible to the weighting procedure). The EFUS methodology report provides full details of the weighting process[28].

Information is provided throughout the main report and the appendices on the use of weighted EFUS data as well as the methods used to analyse the data. It should be noted that analysis of the EFUS data was conducted by *the*RTK Ltd. independently of BRE's own analysis of the EFUS data and therefore may be subject to different reported findings due to differences in variable use and coding. A full set of the data analysis tables summarised in the main report are available in *Appendix C – EFUS analyses technical appendix*.

2.2.1 Homes Energy Efficiency Database (HEED)

The review also attempted to use the Homes Energy Efficiency Database (HEED)[29].The HEED is an online resource hosted by the Energy Saving Trust (EST). It has been developed by the EST on behalf of government to register the uptake of sustainable energy measures and related survey data across the UK housing stock. The HEED records property details of approximately 50% of the homes in the UK such as building type, but not personal details of occupants. Consequently the review could not use the HEED database to examine questions concerning associations between household types and the installation of heating controls. However, the database was used to provide information on heating system installations by year and total.

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[28] BRE (2014) Energy Follow-Up Survey 2011 - Report 11: Methodology. Prepared by the Building Research Establishment (BRE) on behalf of the Department of Energy and Climate Change. Department of Energy & Climate Change. Available at – https://www.gov.uk/government/publications/energy-follow-up-survey-efus-2011 (27/01/2014).

[29] More information on the Homes Energy Efficiency Database (HEED) is available at - http://www.energysavingtrust.org.uk/Organisations/Government-and-local-programmes/Programmes-we-deliver/Homes-Energy-Efficiency-Database (27/01/2014).

Main Findings

3. What heating controls are installed and how do these vary across different properties and households?

This question focuses on the detail of controls installed as part of UK domestic heating systems, and how they are configured and controlled. Evidence on the installation of heating controls comes from published summaries of survey data from the grey literature and secondary analysis of data from the EFUS.

3.1 What heating controls are installed?

Prior to EFUS little was know about what heating controls were currently installed across the housing stock although there was high level data on general heating systems. Figures from the English Housing Surveys showed that the percentage of homes with central heating rose from 75% in 1996 to 87% in 2010 and 90% in 2011[30]. As shown in Table 2 EFUS data shows that 90% of households, 19,000 thousand households weighted to be representative of the 21,900 thousand households in the English housing stock use central heating to heat their homes.

Heating system	Number of households in thousands (weighted)	Number of households (unweighted)	Valid Percentage (weighted)	Cumulative Percentage (weighted)
Central heating	19,691	2356	*90%*	*90%*
Storage radiators	1,448	180	*7%*	*97%*
Gas fires	245	26	*1%*	*98%*
Electric heaters	399	39	*2%*	*99%*
Coal/wood/smokeless fuel fires or stoves	109	15	*1%*	*100%*
Total	21,893	2616	*100%*	

Table 2. Heating system used to heat the majority of the household in winter

[30] This data comes from both DCLG (2012). English Housing Survey: HOMES Annual report on England's housing stock, 2010. London: Department for Communities and Local Government, p. 88. Available at - https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/6748/2173483.pdf (27/01/2014). and DCLG (2013). English Housing Survey: HOMES Annual report on England's housing stock, 2011. London: Department for Communities and Local Government, p. 86. Available at - https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/211324/EHS_HOMES_REPORT_2011.pdf (27/01/2014).

Source: EFUS (2011/12); n=2616 weighted and scaled to represent the English housing stock of 21,900 thousand households.

A grey literature report[31] authored by the statutory consumer champion for England, Wales, Scotland and Northern Ireland (Consumer Focus) published findings of analysis undertaken by BEAMA which modelled data from the Energy Saving Trust (EST), and the English Housing Condition Survey 2008[32]. It suggested that over 70% of households in the UK that have a boiler do not have a full set of domestic heating controls (defined as TRVs, a programmer and room thermostats). Figure 3 below provides a breakdown of this analysis.

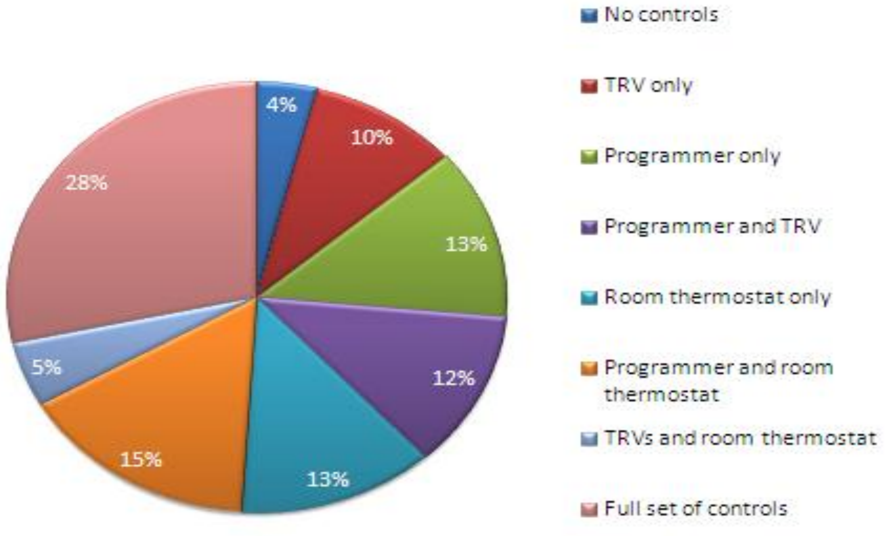

Figure 10. Percentage of UK households with a boiler with each of the main heating control types[33]

This suggests the 2008 position to have been:

- TRVs: 55%
- Programmers: 70%
- Room thermostat: 62%[34]

The 2011 EFUS data suggest that the proportion of households with central heating that have a range of controls may have increased over recent years. Whilst the EST data (published in 2008) estimated that 4% of households with central heating having no controls, the more recent EFUS data shows the figure to be 2%, as shown in Table 2 below.

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[31] Consumer Focus (2012). Consumers and domestic heating controls: a literature review. London: Consumer Focus, p.23. Available at - http://www.consumerfocus.org.uk/files/2012/01/Consumers-and-domestic-heating-controls-a-literature-review.pdf (27/01/2014).

[32] Data comes from a self-selecting survey, published in 2008, of 357,000 households conducted as part of EST's Home Energy Check.

[33] Based on a survey of 323,000 UK households. TACMA (2011). A review of current data on heating controls by TACMA. Available at - www.beama.org.uk/en/product-areas/heating-hot-water--air-movement/heating-controls (27/01/2014).

[34] Ibid

Table 2 lists the percentage of households (weighted to be nationally representative of the English housing stock) with central heating who have these nine primary heating controls. A full set of the data which the table summarises can be found in *Appendix C – EFUS analyses technical appendix*.

Primary heating controls	Percentages (weighted)	Number of households in thousands (weighted)	Number of households (unweighted)
Overall on/off switch	98%	19,311	2,305
Boiler thermostat	97%	19,007	2,264
Central timer[35]	97%	19,130	2,284
Manual override	97%	19,024	2,272
Room thermostat	77%	15,065	1,830
Radiator control	67%	13,198	1,548
Thermostatic Radiator Valves (TRV)	66%	13,017	1,584
'Full set of controls'[36] **(TRV, a central timer, and room thermostat)**	49%	9,620	1,198
Time and temperature controls	1%	225	26
Delayed time control	1%	272	33

Table 3. Proportion of households with central heating reporting primary heating controls

Source: EFUS (2011/12); n=2356 weighted and scaled to represent the English housing stock of 19.7 million households with central heating.

The figures in Table 3 show that 98% of households have primary heating controls that include one of the following: an overall on/off switch, a boiler thermostat, central timer and manual override. It also shows that 49% (9,600 thousand households) with central heating report have a 'full set of controls' which include Thermostatic Radiator Valves (TRVs), central timer, and a room thermostat. As Table 3 illustrates, where households do vary on which heating controls they have, it is in the proportion reporting a room thermostat (77%), a radiator control (67%) or a TRV (66%).

3.2 Heating Controls by property type

The grey literature Consumer Focus report suggests the proportion of households with minimum or no controls at all was significantly higher in the rental sector compared with owner-occupied households[37].

[35] *Appendix C – EFUS analyses technical appendix - footnote 3* contains information on the differences in the percentages reporting a central timer.

[36] A 'full set of controls' was calculated by combining the responses to whether households with central heating had a Thermostatic Radiator value, a central timer, and room thermostat as a primary heating control.

[37] Consumer Focus (2012). Consumers and domestic heating controls: a literature review. London: Consumer Focus, p.23. Available at - http://www.consumerfocus.org.uk/files/2012/01/Consumers-and-domestic-heating-controls-a-literature-review.pdf (27/01/2014).

The 2010 EHS suggests owner occupied properties had the greatest potential for upgrades from boilers and heating controls (61% and 26% respectively) and that housing association and local authority properties were more likely to have implemented improvements[38]. The 2010 EHS did not look in any more detail at property types with regard to heating controls, such as privately rented properties. However, it did note that energy saving improvements were more likely to be needed in older properties.

Analysis of EFUS data suggests there is no simple relationship between property type and installation of heating controls. Table 4 below summarises householder responses data scaled up to be representative of the English housing stock from two EFUS interview questions about property; one concerning property type, and a second combining property type with age of the property.

Dwelling type	Primary heating controls (weighted percentages)			
	Room Thermostat (%)	Central Timer (%)	TRV (%)	Full set of controls (%)
purpose built flat, high rise	67	99	78	52
purpose built flat, low rise	77	98	65	49
end terrace	76	96	69	51
mid terrace	77	97	69	52
converted flat	77	97	67	51
bungalow: all ages	83	97	66	53
detached house: pre 1919	76	98	70	52
detached house: post 1919	74	96	59	43
semi-detached & terraced: pre 1919	75	98	66	49
semi-detached & terraced: 1919-1944	71	98	63	43
semi-detached & terraced: 1945-1964	82	98	61	49
semi-detached & terraced: 1965 onwards	80	97	66	53

Table 4. Proportion of dwelling types reporting primary heating controls[39]

Source: EFUS (2011/12); n=2356 weighted and scaled to represent the English housing stock of 19,700 thousand households with central heating.

Table 4 suggests little variation in the installation of primary heating controls across property age or type. EFUS responses show purpose built high rise flats to be most likely to have a full set of heating controls and most likely to have TRVs fitted. The proportion of dwelling types with primary heating controls typically varies across properties by less than 15%. Similarly the proportion of dwellings with a full set of heating controls varies by 13% across dwelling types. However, when these differences were tested for statistical significance using a series of four chi-square tests, one for each type of heating control they returned non-significant values of the

[38] DCLG (2012). English Housing Survey: HOMES Annual report on England's housing stock, 2010. London: Department for Communities and Local Government, p.105. Available at - https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/6748/2173483.pdf (27/01/2014).

[39] The data from which this table is derived, including the number of households (weighted and unweighted) which these percentages represent can be found in *Appendix C – EFUS analyses technical appendix* which accompanies this report.

chi-square statistic. Details of the chi-square tests can be found in *Appendix C – EFUS analyses technical appendix* which accompanies this report.

3.3 Heating Controls by household type

Next, the review looked at how the installation of primary heating controls might vary across household type[40], including tenure. Table 5 (below) summarises the data[41].

Household type	Primary heating controls (weighted percentages)			
	Room Thermostat (%)	Central Timer (%)	TRV (%)	Full set of controls (%)
Householder under 65	76	98	67	49
Householder 65 and over	80	96	64	49
Number of people in household				
One	76	95	59	43
Two	77	98	69	51
Three	74	98	70	52
Four	79	99	66	50
One family household				
Couple	79	98	69	53
Couple with dependent children	80	98	69	53
Tenure				
Owner occupied	78	99	67	50
Private rented	68	97	58	38
Local authority	79	92	70	56
Registered social landlord	82	95	72	58

Table 5. Proportion of household types that reported having primary heating controls

Source: EFUS (2011/12); n=2356 weighted and scaled to represent the English housing stock of 19,700 thousand households with central heating.

The results are broadly consistent with the reviews previous to EFUS analyses; the installation of heating controls does not vary to a substantial degree across household type or tenure. However, a series of chi-square tests (reported in full in *Appendix C - EFUS analyses technical appendix*) were undertaken to check the statistical significance of the observed differences. Of 16 tests (four categories of household by four types of heating controls), five yielded statistically significant test statistics:

i. Number of people in household by Thermostat (TRV)[42];
ii. Number of people in household by full set of controls[43];

[40] Wherever possible the Office for National Statistics (ONS) categories were used to define households for available EFUS data.

[41] The data from which this table is derived, including the number of households (weighted and unweighted) which these percentages represent can be found in *Appendix C – EFUS analyses technical appendix* which accompanies this report.

[42] (χ^2 = 12.63, p<.05).

[43] (χ^2 = 8.20, p<.05).

iii. Tenure by room thermostat[44];
iv. Tenure by Thermostatic Radiator Values (TRV)[45];
v. Tenure by full set of controls[46].

The figures indicate that households living in private rented accommodation are significantly less likely to have a full set of heating controls than owner occupiers, or those in local authority or registered social landlord properties. They are less likely to have room thermostats and less likely to have TRVs fitted to radiators.

The figures for the size of household suggest some smaller, but still significant differences amongst one person households; they are less likely to have Thermostatic Radiator Values (TRVs) fitted, and less likely to have a full set of heating controls than larger households. The differences were not explained, at least within the EFUS sample, by larger proportions of single people living in private rented accommodation.

3.4 Summary

The review's analysis of EFUS data show that more than 98% of households with central heating have controls of some description installed. Households reported the most commonly installed controls to include an on/off switch, a boiler thermostat, a central timer and a manual override switch. Conversely, around 2% of households reported having time and temperature controls (combined in one unit) or delayed time controls (see Table 3).

Across all dwelling types, 49% (9,600 thousand households) have a full set of heating controls (i.e. TRVs, a central timer, and room thermostats). EFUS analysis suggests some variation across households when it comes to the installation of three types of heating controls: room thermostats, radiator controls and thermostatic radiator valves (TRVs). However, more detailed analysis shows installation rates for these primary controls between type or age of dwelling are not statistically significant (Table 4).

The EFUS data analysis shows there to be only small, but some statistically significant variation in the installation of primary heating controls across household types (Table 5). Households living in private rented accommodation are least likely to have a full set of heating controls. The English Housing Survey found owner occupied properties had greater *potential* for upgrades to heating control and boilers to improve energy efficiency (26% and 61% respectively)[47]. The review's EFUS analyses found that 50% of households living in owner occupied properties have a full set of heating controls, compared with 58% living in property owned by a registered social landlord and 56% in local authority properties.

Data from EFUS suggest that the proportion of homes with a full set of heating controls has increased to 49% from the 28% suggested by the earlier EST survey. EFUS data also suggest that potential increases in the proportion of households with full sets of controls have been uneven across demographic groups.

[44] ($\chi^2 = 20.30$, $p<.01$).
[45] ($\chi^2 = 27.80$, $p<.01$).
[46] ($\chi^2 = 36.10$, $p<.01$).
[47] DCLG (2012). English Housing Survey: HOMES Annual report on England's housing stock, 2010. London: Department for Communities and Local Government. Available at – https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/6748/2173483.pdf (27/01/2014).

4. When, why and how are new heating controls installed?

The review found very little robust empirical evidence with regard to questions of when, why and how new heating controls are installed. The grey literature rather than academic papers proved to be the most ready source of information on these questions. The review also examined both the EFUS and HEED databases for additional information, but concluded that neither collects sufficiently detailed data on the installation of specific heating controls[48]. Where possible the review used other material to verify key points raised. However, it is important to note that evidence on this issue is limited.

4.1 When and why are new heating controls installed?

Based on figures cited in the 2008 TACMA survey, the 2010 Heating and Hot Water Taskforce grey literature report suggests that heating controls (excluding new builds) are most likely to be replaced at the same time as boilers and that people tend to install new heating controls when replacing existing boilers, often as a consequence of breakdown or failure[49]. It follows that increasing the numbers of households with new heating controls will be driven to a great extent by the rate at which households replace their existing boilers.

Data from the English Housing Survey[50] suggests that each year some 5% of homes replace their boilers, whilst 1.4% replace their whole central heating system. Since 2002, Building Regulations have required the installation of heating controls with systems fitted in new homes (Part L1a) and replacement boilers fitted in existing homes (Part L1b)[51]. Industry estimates that the installed base of gas condensing boilers will be around 19,300 thousand out of a total of 23,600 thousand boilers (83%) by 2020. Given that controls are likely to be replaced at the same time as boilers, this suggests a rise in the installation of heating controls that are more technologically advanced than those they replace.

Table 6 sets out estimates of installation rates for domestic condensing boilers provided by the Heating and Hot Water Taskforce in their 2010 report, and DECC's 2012 Energy Efficiency Strategy.

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[48] The HEED database 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 13,237,739), and the nature of upgrades is not recorded.

[49] Energy Efficiency Partnership for Homes (2010). Heating and Hot Water Taskforce - Heating and hot water pathways to 2020: Full report and evidence base.

[50] DCLG (2012). English Housing Survey: HOMES Annual report on England's housing stock, 2010. London: Department for Communities and Local Government. Available at - https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/6748/2173483.pdf (27/01/2014)

[51] CLG (2008). Domestic Heating Compliance Guide (2nd Edition). Department of Communities and Local Government: London. Available at - http://www.planningportal.gov.uk/uploads/br/BR_PDF_PTL_DOMHEAT.pdf (27/01/2014).

Source	Estimate of current installed base (in thousands)	Current annual installation rates (in thousands)	Estimate of potential by 2020 (in thousands)
Heating and Hot Water Taskforce (2010)[52]	7,400 out of 21,600 (34%) gas boilers	1,500	21,000
DECC (2012)[53]	9,000 out of 22,500 (40%) gas boilers	900,	16,200

Table 6. Estimates of installation rates for domestic condensing boilers

These estimates indicate a key driver of installation rates is likely to be consumer demand, however the REA found no evidence that detailed the nature of this from a consumer perspective.

4.2 How are new controls installed?

The REA did not find studies that evidenced how new controls come to be installed. However more than one study has focussed on the fact that manufacturers[54] and documentation left by installers[55] should do more to help householders manage their heating systems efficiently. For example, a report published by DEFRA stated that "people reported asking installers, plumbers and engineers to show them how to use their controls and sometimes to set their programmers"[56].

There is guidance on commissioning the system to maximise energy saving[57]. However, the UK government makes no requirement to implement it. Installers are only mandated to ensure that the system works properly and the householder knows how to use it[58]. To comply with this they can simply “provide a suitable set of operating and maintenance instructions aimed at achieving economy in the use of fuel and power in terms that householders can understand”[59].

As to how heating controls are installed, evidence reviewed suggests that installers often play a pivotal role in making key installation decisions[60].

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[52] Energy Efficiency Partnership for Homes (2010). Heating and Hot Water Taskforce - Heating and hot water pathways to 2020: Full report and evidence base.
[53] DECC (2012). Energy Efficiency Statistical Summary. Department of Energy and Climate Change: London. Available at - https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/65598/6918-energy-efficiency-strategy-statistical-summary.pdf (27/01/2014).
[54] Monahan, S. & Gemmell, A., (2011). *How occupants behave and interact with their homes: The impact on energy use, comfort, control and satisfaction*. Milton Keynes: NHBC Foundation.
[55] Pett, J & Guertler, P (2004) *User Behaviour in Energy Efficient Homes: Phase Two Report*. Association for the Conservation of Energy, London.
[56] Rathouse, K. and Young, B., (2004). Market Transformation Programme - Domestic Heating: Use of Controls. Report ID: RPDH15. DEFRA. p. 24
[57] Energy Saving Trust (2001). Controls for domestic central heating and hot water - guidance for specifiers and installers. *Good Practice Guide 302*. EST/EEBPP.
[58] Association of Control Manufacturers (TACMA) (2012) Guidance on how to comply with the 2010 Building Regulations Part L. Available at - http://www.idhee.org.uk/TACMA%20Guide%202010.pdf (27/01/2014).
[59] HM Government (2010). Building Regulations 2010. Part LB1: Conservation of fuel and power in existing dwellings. Available at - http://www.planningportal.gov.uk/uploads/br/BR_PDF_ADL1B_2010.pdf (27/01/2014).
[60] Rathouse, K. and Young, B., (2004). Market Transformation Programme - Domestic Heating: Use of Controls. Report ID: RPDH15. DEFRA. p. 24;

4.3 Summary

In general, the review has found very little independent robust empirical evidence with regard to questions of when, why and how new heating controls are installed. Given that installation is undertaken by a large number of private sector organisations, many of which are very small independent companies, the lack of a coordinated effort to collect data that could answer these questions is perhaps not surprising.

The evidence that is available is mostly from the industry and suggests that new builds apart, heating controls are most likely to be replaced at the same time as boilers. Households tend to install new heating controls when they replace their existing boilers. As to why boilers and therefore heating controls are replaced, it would appear that it is most commonly as consequence of boiler breakdown or failure[61].

Banks, N (2000). Socio-technical networks and the sad case of the condensing boiler. ACEEE Summer Study Proceedings 2000. ACEEE. Available at - http://www.eceee.org/library/conference_proceedings/ACEEE_buildings/2000/Panel_8/p8_1/paper (27/01/2014).

[61] Energy Efficiency Partnership for Homes (2010). Heating and Hot Water Taskforce - Heating and hot water pathways to 2020: Full report and evidence base.

5 How do people use their heating at present?

5.1 Analysis of EFUS data

Analyses of the EFUS questionnaire data provided useful insights into how people currently use their heating systems. Following analysis of the survey data, published research literature was examined to develop explanations for patterns of use.

5.1.1 Central heating and use of a timer

Of those households who reported having central heating in their homes[62], 5% did not use it for regular annual heating. Of the remainder of those with central heating, 90% (16,500 thousand households) said their system had a central heating timer[63]. As Table 7 illustrates, 74% of households (12,200 thousand) with central heating used the timer to switch the heating on and off. EFUS data on households who do not use a central timer found that 15% of households with central heating switched heating on and off manually, 10% switched the system on and off by turning the thermostat up or down and 1% by other means.

Household use of a central timer to control the times that the central heating is switched on and off	A timer that controls central heating		
	Weighted percentage	Number of households in thousands (weighted)	Number of households (unweighted)
Use of a central timer	74%	12,203	1,396
None use of a central timer	26%	4,391	559
Total	100%	16,595	1,955

Table 7. *Households using a central timer to control the times their central heating is switched on & off*

Source: EFUS (2011/2012); n=1,977 weighted and scaled to represent the English housing stock of 16,700 thousand households with a central heating timer.

5.1.2 Heating periods

The EFUS interview data was also used to analyse the heating periods of households with central heating. Out of the 19.6 million households with central heating, 62% (weighted to 12,200 thousand) reported their heating periods. Reported patterns of use varied little across weekdays and weekends when they were compared according to the number of times heating systems were reportedly turned on and off. As shown in tables 8a and 8b the majority of these

[62] As Table 2 illustrated, 90%, 19.6 million households weighted to be representative of the 21.9 million households in the English housing stock, used central heating to heat their home in the winter.

[63] The full set of figures and calculations for the data on central heating and timer use can be found in *Appendix C - EFUS analyses technical appendix.* As stated in the methodology section of this report, analysis in this section was conducted by RTK Ltd. independently of BRE's own analysis of the EFUS data and therefore may be subject to different reported findings due to differences in variable coding, percentage calculations and statistical analysis.

households with central heating controlled by a timer turn their systems on no more than three times each day. Of these households with one or more timed periods (assuming zero periods do not count as a valid use of ‘timed heating’), more than 98% were using three or fewer timed heating periods for both weekdays (99%) and weekends (98%) (see the last column of Tables 8a and 8b).

Table 8a shows that that 14% of households (1,800 thousand households) used one heating period, 77% (9,400 thousand households) used two heating periods, and 9% (just over a million households) use three to six heating periods on an average weekday. The figures for average heating periods over the weekend, as shown in Table 8b, were similar with 19% (2,200 thousand) using one heating period, 73% (8,700 thousand households) using two heating periods and 9% (just over 1,000 thousand households) using three or more heating periods.

Number of heating periods per day	Number (in thousands)						Mean Percentages		
	Monday	Tuesday	Wednesday	Thursday	Friday	Mean	Overall	1-6 heating periods	1-6 heating periods (cumulative)
Zero	32	43	43	32	32	36	*>0%*	-	-
One	1,757	1,753	1,753	1,768	1,772	1,761	*9%*	*14%*	*14%*
Two	9,385	9,373	9,374	9,370	9,366	9,374	*48%*	*77%*	*91%*
Three	868	859	858	858	859	861	*4%*	*7%*	*99%*
Four	78	78	78	78	78	78	*>0%*	*1%*	*99%*
Five	59	44	44	44	44	47	*>0%*	*>0%*	*100%*
Six	54	54	54	54	54	54	*>0%*	*>0%*	*100.00%*
No regular heating pattern	121							*100%*	
Total	12,353	12,204	12,204	12,204	12,204		*(62%)*[64]		
Missing or not applicable	7,338	7,459	7,459	7,459	7,459				
unknown	-	28	28	28	28				
Total not app/unknown	-	7,487	7,487	7,487	7,487	7,487	*38%*		
Total no regular heating, missing or unknown	7,490	7,530	7,530	7,519	7,519	7,518			
Total of 1-6 heating periods	12,201	12,161	12,161	12,172	12,172	12,174			
Overall total	19,691	19,691	19,691	19,691	19,691	19,691	*100%*		

Table 8a. *When you are heating your home every day, how many times does your central heating come on weekdays?*

Source: EFUS (2011/12); n=2356 weighted and scaled to represent the English housing stock of 19,700 thousand households with central heating.

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[64] This is the cumulative percentage of all heating periods.

Number of heating periods per day	Frequency *(in thousands)*	Overall percentages	Applicable percentages	1-6 heating periods percentages	1-6 heating periods cumulative percentages
Zero	94	*1%*	*1%*	-	-
One	2,230	*11%*	*18%*	*19%*	*19%*
Two	8,730	*44%*	*72%*	*73%*	*91%*
Three	843	*4%*	*7%*	*7%*	*98%*
Four	83	*>0%*	*1%*	*1%*	*99%*
Five	59	*>0%*	*1%*	*1%*	*100%*
Six	54	*>0%*	*>0%*	*>0%*	*100%*
Total	12,092	*(61%)*	*100%*	*100.0%*	
Missing, n/a or unknown	7,599	*37%*			
Total of 1-5 heating periods	11,999	*61%*			
Total	19,691	*100%*			

Table 8b
When you are heating your home every day, how many times does your central heating come on during a typical weekend?

Source: EFUS (2011/12); n=2356 weighted and scaled to represent the English housing stock of 19,700 thousand households with central heating.

Reported patterns of use by average time the heating was on also varied little across weekdays and weekends. In households where the heating was reportedly switched on and off only once, it was on for a mean average of 10 hours 24 minutes on a weekday, and 10 hours 51 minutes on a weekend day. In homes turning their systems on and off twice a day, the mean weekday average on time was 6 hours 45 minutes, compared with 7 hours 14 minutes on a weekend day. Details of average heating times can be found in *Appendix C - EFUS analyses technical appendix*.

The histograms in Figures 11a and 11b show the number of hours households reported having their central heating on for weekdays and weekends using none weighted data. Analyses comparing weekdays between each other showed very little difference between weekdays, and as Figures 11a and 11b illustrate, also little difference between weekdays and weekends[65].

Households participating in the EFUS reported having their heating on for an average of 8 hours 15 minutes a day during the week, and 8 hours 39 minutes at the weekend. The positive skew evident in both graphs shows some households having their heating on for substantially more than the mean figures.

[65] The figures used for these histograms can be found in *Appendix C - EFUS analyses technical appendix* along with methodological notes on the use of non-weighted data for these graphs.

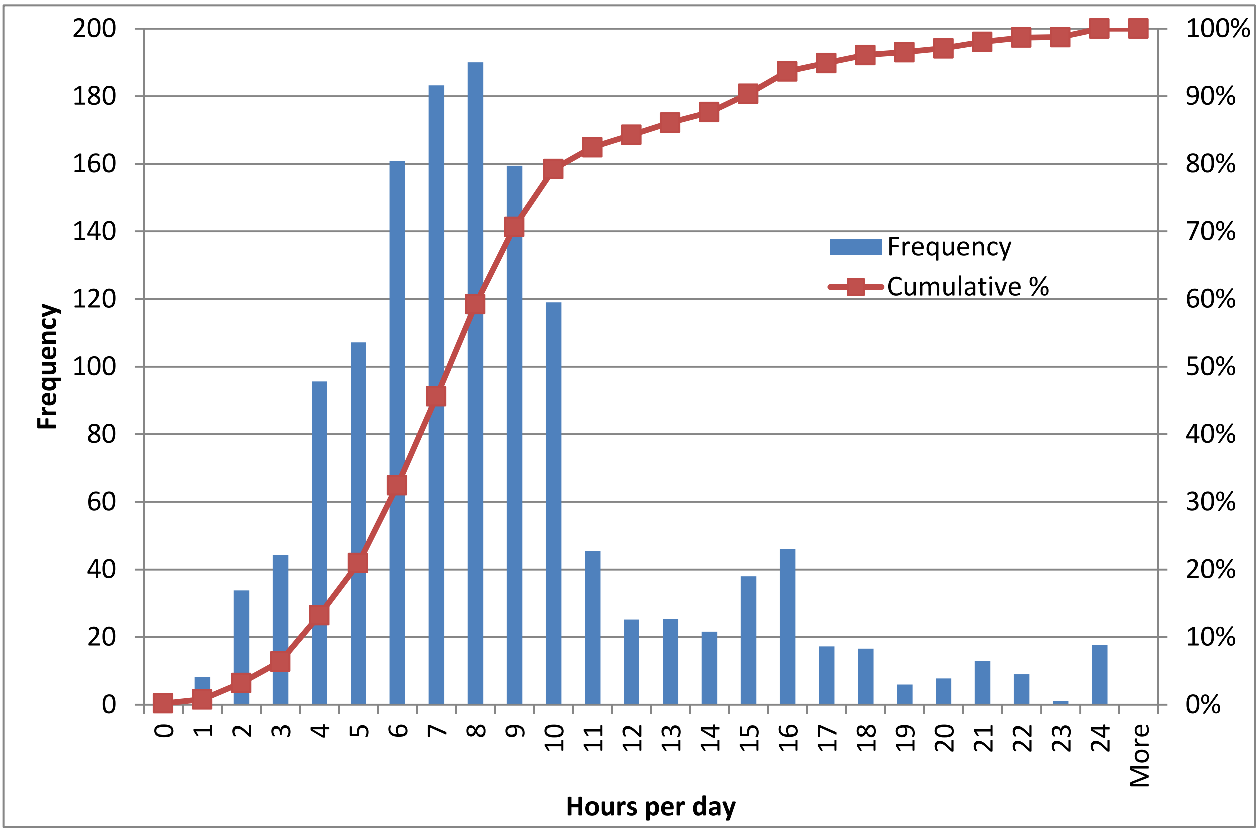

Figure 11a. Mean number of hours that central heating is reportedly on for weekdays
Source: EFUS (2011/2012); n=1394 non-weighted data

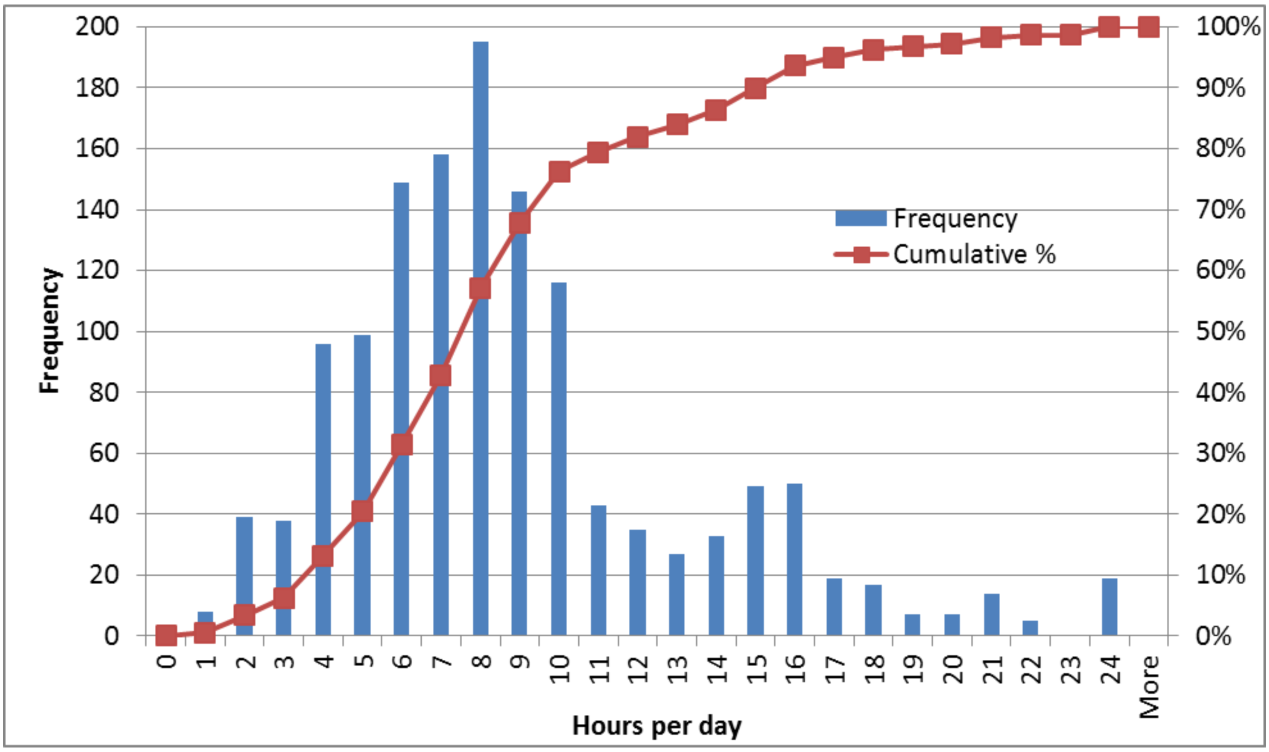

Figure 11b. Mean number of hours that central heating is reportedly on at the weekend
Source: EFUS (2011/2012); n=1369 non-weighted data.

5.1.3 Boost heating usage

To complete the picture on usage of central heating systems, a series of EFUS questions concerning the use of 'boost' heating were also analysed. The term as used in the EFUS describes switching a boiler on manually to provide additional heat outside of the programmed hours. It should be noted that 59% of households with central heating reported using boost heating. And of that only 29% of households with central heating reported relevant information on the use of 'boost' heating per week with a mere 8% on its use per day. As a result caution should be taken with these figures.

Figure 12 below shows a histogram of EFUS data on boost heating hours per week. It shows that around half of households providing week data (29% of households with central heating) reportedly used 4 hours or less with 10% using just one and 20% just two hours a week. The histogram also shows the distribution has a very long tail with some households using many more hours, some up to a maximum of 98 hours per week. Details of these weighted figures on boost heating can be found in *Appendix C - EFUS analyses technical appendix* in section *5.1.2 Boost heating usage*.

The mean number of hours boost used per week is 8.2, and the number of times per day is on average just over one hour every day with the maximum being seven times per day. All days, including weekends, are very similar.

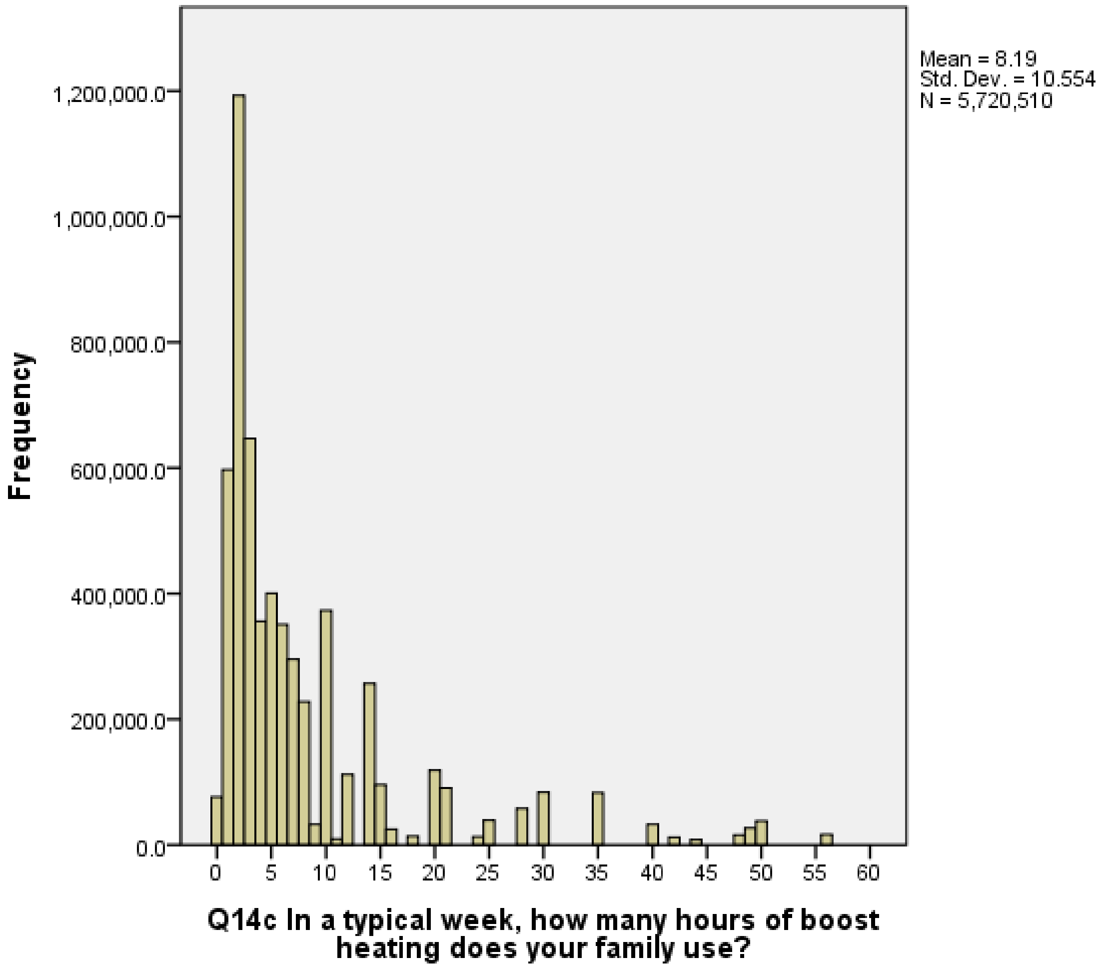

Figure 12. Mean number of hours boost heating was reportedly used by households each week

Source: EFUS (2011/12); n=850 weighted and scaled to represent the English housing stock of 5,700 thousand households reporting use of boost heating.

5.1.4 Heating density

Up to this point, data has been presented on average heating on/off periods. However, mean data can hide significant variations between households. As a consequence EFUS data was used to develop profiles of heating density. However, this analysis was not weighted as it involved extensive analysis of individual records making weighting unfeasible.

The graphs in figures 13 to 18 describe reported heating density as the proportion of homes with their heating on at different times of the day. The horizontal (x) axis is time of the day (24 hours), and the vertical (y) axis is the proportion of all with heating on.

Weekday heating density

For the first graph, Figure 13, a value of 0.7 at 09:00 means that 70% of the 216 homes with a single heating period for weekdays have heating on at this time. The sample described in each graph excludes the 40% of households reportedly with no fixed time controls.

Figure 13 shows the density of heating on for the 216 homes with reported single period heating on weekdays. The graph shows there are never more than about 75% of homes with heating on at any time, and no fewer than five per cent of homes with heating on at any time (in the early hours of the morning) probably due to homes with heating left on 24 hours a day.

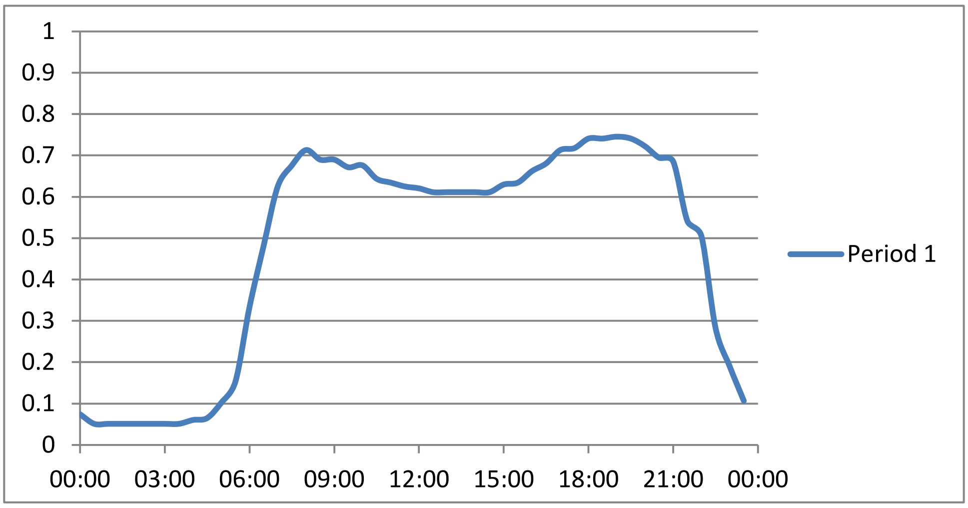

Figure 13. Average weekday heating density for households using a central timer reporting one heating period.

Figure 14 shows results for two periods from 1053 (75%) of timed homes; there are no homes with heating on overnight. For comparison, the two period SAP[66] profile is also presented. This matches the evening period reasonably well but is shifted later in the morning.

[66] Standard Assessment Procedure (SAP) measures of heated periods differ slightly when compared to EFUS definitions. A full explanation is provided in *Apendix D - SAP and EFUS data definitions of heating periods* which accompanies this report.

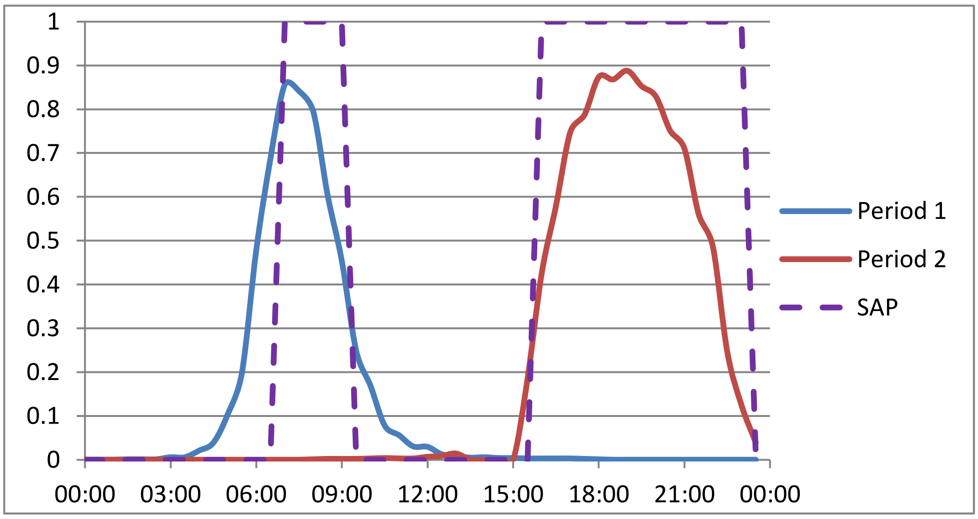

Figure 14. Average weekday heating density for households using a central timer reporting two heating period.

Figure 15 below shows the data for three daily heating periods, for 101 homes; this is similar to that for two periods with the addition of a lunchtime/afternoon less intense period.

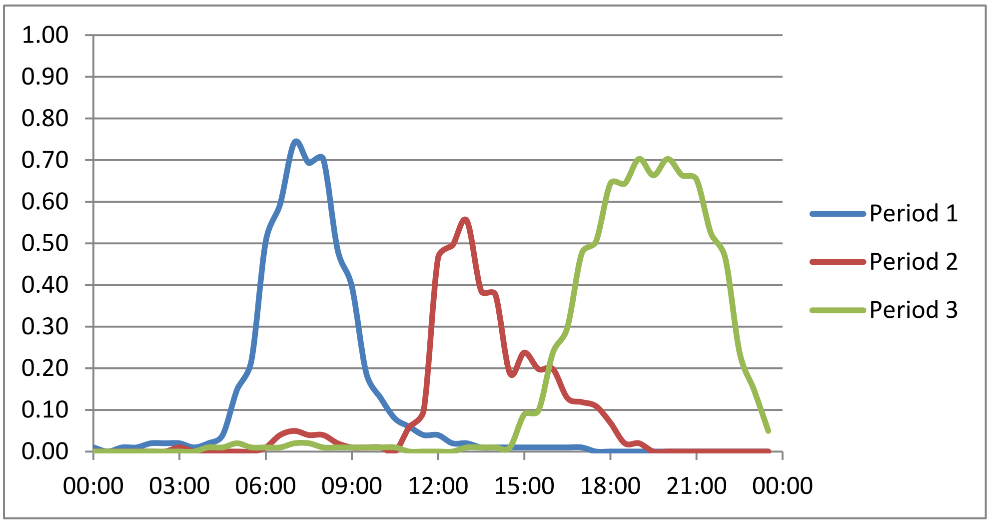

Figure 15. Average weekday heating density for households using a central timer reporting three heating period.

Weekend heating density

A very similar set of results emerge for weekends, as shown in Figures 16 to 18.

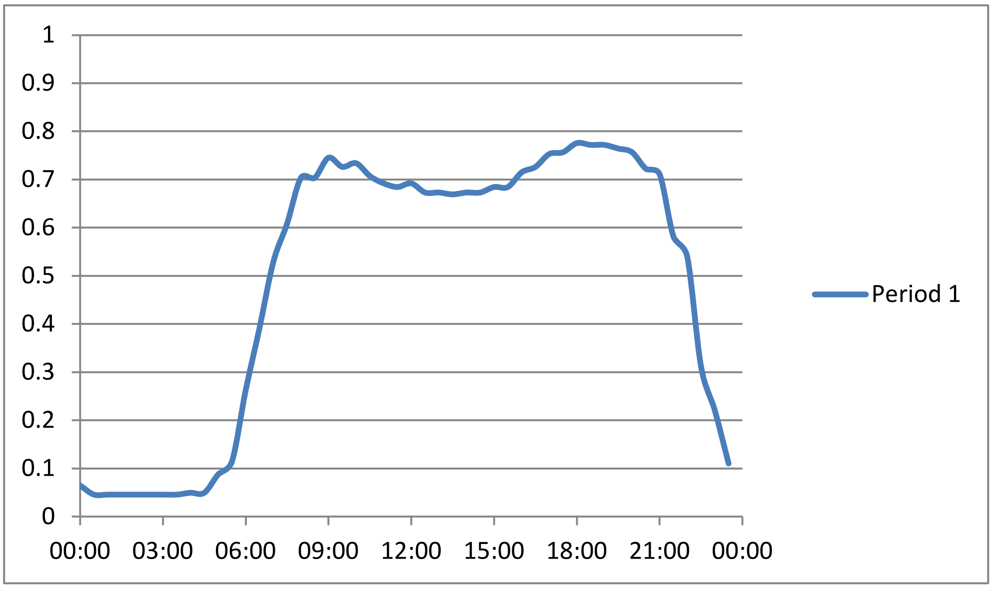

Figure 16. Weekend heating density for households using a central timer reporting one heating period.

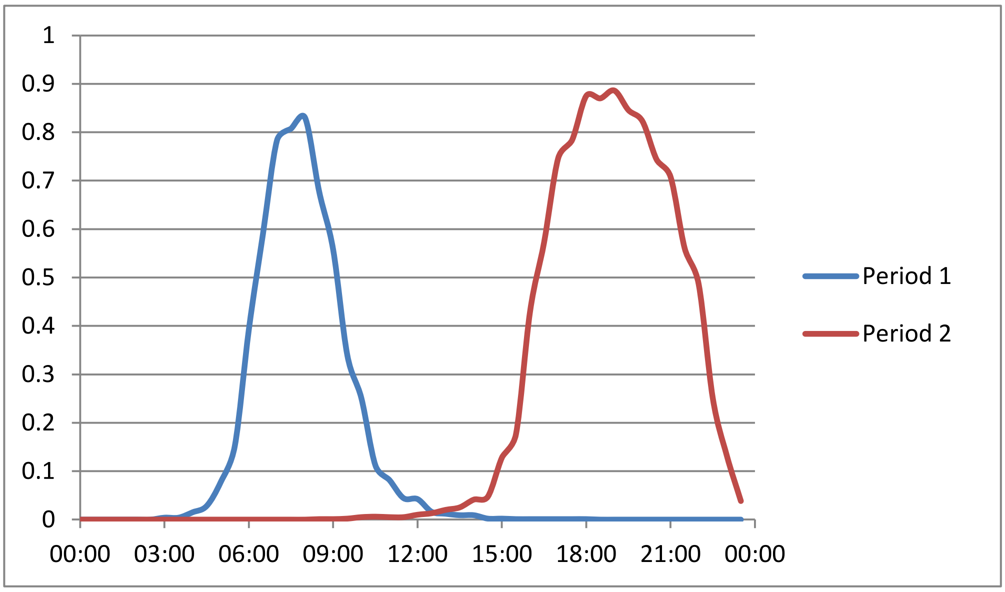

Figure 17. Weekend heating density for households using a central timer reporting two heating period.

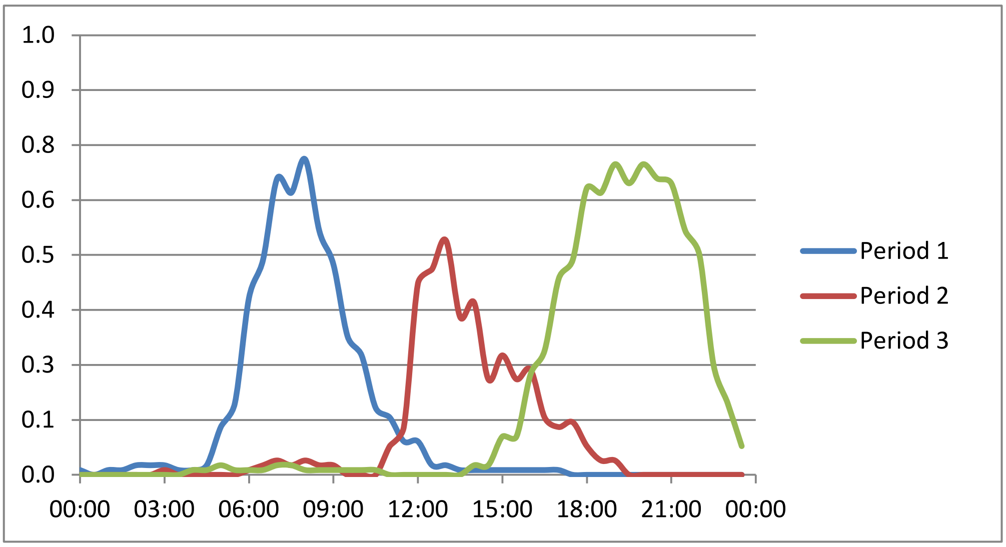

Figure 18. Weekend heating density for households using a central timer reporting three heating period.

Overall, these results show consistent modes of behaviour with fairly well defined periods which are very similar on all days for households that have a timer.

To summarise, analyses of the EFUS questionnaire data has highlighted several key points regarding how people reportedly use their heating at present:

- 74% of households (12,200 thousand) with central heating used a timer to switch their heating system on and off, 15% switch their heating on and off manually, 10% switch their heating on and off by turning the thermostat up or down, and 1% by other means;
- Of those with central heating reporting timed heating, 77% (9,400 thousand households) reportedly used two heated periods per day, and about 14% (1,800 thousand households) used one heated period, with only about 9% (just over a 1,000 thousand households) using more heated timed periods on an average weekday. Weekend periods were reportedly very similar;
- The number of reported hours the central heating is on per day varies but the mean times were calculated to be 8 hours 15 minutes a day during the week, and 8 hours 39 minutes at weekends with some households having their heating on for substantially more than the average;
- In households where the heating was reportedly switched on and off only once, it was on for an average of 10 hours 24 minutes on a weekday, and 10 hours 51 minutes on a weekend day and in homes reportedly turning their systems on and off twice a day, the average weekday on time was 6 hours 45 minutes, compared with 7 hours 14 minutes on a weekend day.
- Around half of households providing data on boost heating reportedly used 4 hours or less with 10% using just one and 20% just two hours a week but with a number of households using many more hours, some up to a maximum of 98 hours per week.
- Heating ‘density’ plots for weekdays show that for single periods most heating is on from around 7.00am to 10.00pm, while for two periods there were fairly distinct peaks around 6am to 9am and 4.00pm to 10.00pm. Weekend periods were found to be very similar though it was found that heating comes on slightly later on weekend mornings.

5.2 Evidence from published literature

5.2.1 Usability of heating controls

Evidence from the REA searches of published literature indicates reasonably consistently that a proportion of consumers do not use their heating controls as their designers intended because they find it difficult to understand how to use them[67].

A Scottish Government survey of 1407 Scottish households designed to assess the impact of their Central Heating Programme on tackling fuel poverty found that usability varied across demographic groups. Overall 9% of householders found the system 'difficult' or 'extremely difficult' to use. Pensioners reported having more difficulties than non-pensioners (10% compared to 7%), and people living in social housing were more likely to experience difficulties compared to those living in private rented accommodation (15% compared to 10%), although the survey did not look at why[68].

A study by Combe et al.[69], detailed below, also concluded that many heating controls are too complex and exclude people due to the demands placed upon their capabilities in terms of vision, reach, dexterity and thinking.

A survey of over 150 housing association tenants across 12 locations throughout the UK conducted in 2004 by the Association for the Conservation of Energy[70] reported that only 23% of householders used their systems 'consistent with best practice guidance'. A further 50% used them in a manner described as 'reasonable' (in a way that is efficient from their own perspective; i.e. they get results in a way that suits them and their lifestyle), and the remainder used their systems in an inefficient manner (defined as householders who do not use the systems effectively and do not get the best value for their lifestyle).

A study by Meier et al.[71] conducted four small scale tests in the US to gather qualitative information on the usability of programmable thermostats which found that around half of the programmable thermostats in the tests were simply used as manual on/off switches where programmers included an on/off function. Where householders were using heating system controls effectively, their key objective was not energy efficiency or saving money; it was to achieve what the researchers called 'thermal comfort', i.e. being warm enough, or cool enough. Meier et al. argued that given how poor usability lay at the heart of achieving energy savings, careful investigation into how consumers actually operate programmable thermostats was long overdue.

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[67] Boait P.J., & Rylatt R.M. (2010). A method for fully automatic operation of domestic heating. *Energy and Buildings, 42* (1), 11 -16; Peffer, T., Pritoni, M., Meier, A., Aragon, C. & Perry, D. (2011). How people use thermostats in homes: A review. *Buildings and Environment, 46*, 2529–2541.

[68] Scottish Government (2007). Assessing the impact of the central Heating Programme on tackling fuel poverty: The first three years of the programme. Available at - http://www.scotland.gov.uk/Publications/2007/03/23133305/18 (27/01/2014).

[69] Combe, N., Harrison, D., Craig, S., & Young, M. S. (2012). An investigation into usability and exclusivity issues of digital programmable thermostats. *Journal of Engineering Design, 23 (5)* p. 401-417.

[70] Association for the Conservation of Energy (2004). User Behaviour in Energy Efficient Homes. Available at - http://www.ukace.org/wp-content/uploads/2012/11/ACE-Research-2004-03-User-Behaviour-in-Energy-Efficient-Homes-Energy-Suppliers-leaflet.pdf (27/01/2014). Research from: Pett, J., and P. Guertler (2004) User behaviour in energy efficient homes: Phase 2 report. Association for The Conservation of Energy. Available at http://www.ukace.org/wp-content/uploads/2012/11/ACE-Research-2004-03-User-Behaviour-in-Energy-Efficient-Homes-phase-2-report.pdf (27/01/2014)

[71] Meier, A.K., Aragon C., Hurwitz, B., Mujumdarly, D., Perry, D., Peffer, T., & Pritoni, M. (2010). How people actually use thermostats. Proceedings of the 2010 ACEEE Summer Study on Energy Efficiency in Buildings, 2, 193-206

Further evidence suggests difficulties in understanding instructions have predictable consequences on how consumers use programmable heating controls. According to one UK online survey of 390 consumers conducted by the Open University and Milton Keynes Energy Authority in 2006, "*Most adopters of programmers (71%) and TRVs (58%) find them fairly easy or easy to use. But a few users (11%), especially the elderly, find electronic programmers with tiny buttons and LCD displays difficult to see and understand"* (p.14)[72]. 29% of survey respondents reported turning their central heating systems on and off using their room thermostats. The same report cited evidence from a questionnaire survey of 50 energy efficiency professionals to the effect that two thirds "…*felt that heating controls were difficult to understand and operate, especially for the elderly"* (p.14). A US review conducted by Peffer et al. found a further five studies that suggested elderly consumers faced particular difficulties[73].

Peffer et al.'s review cited nine studies in concluding that people find programmable thermostats[74] difficult to understand and lack the confidence and motivation to overcome difficulties in programming[75]. Results from a small interview study conducted in the US suggested many use programmers as an on-off switch, often not using them to set a weekday or weekend program[76]. Commonly reported problems include displays that are difficult to read, buttons that are either too small or not clearly marked, controls installed in inaccessible places, a lack of intuitive design and an absence of supporting information or advice on how to operate controls[77]. A study into usability published in 2012 cited six papers all providing evidence of poor consumer usability[78].

5.2.2 Improving usability

Peffer et al.'s US study made several recommendations with regard to addressing usability issues, including improved feedback from thermostats to users, developing intelligent systems that reduce the need for human intervention, developing systems that would enable thermostats to communicate with other domestic appliances, and developing voice activated systems. The

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[72] Caird, S., Roy, R., Potter, S., & Herring, H. (2007). Consumer adoption and use of household energy efficient products. Report DIG-09. p.14 Available at - http://design.open.ac.uk/research/documents/OURptEnergyEffyFinalDec07Cover.pdf (27/01/2014)

[73] Peffer, T., Pritoni, M., Meier, A., Aragon, C. & Perry, D. (2011). How people use thermostats in homes: A review. *Buildings and Environment*, 46, p. 2536.

[74] Although programmable thermostats (common in many countries but not the UK) are not the same as central timers widely installed in the UK, many of the issues for users such as ergonomics, readability, understanding etc. are likely to be similar and the way times are set will often be the same (Wilhite H, Nakagami H, Masuda T, Yamaga Y, Haneda H. (1996) A cross-cultural analysis of household energy use behaviour in Japan and Norway. *Energy Policy* 24, p.795-803. Therefore it seems reasonable to draw some inferences from the studies of programmable thermostats in relation to central timers.

[75] This included a consumer reports lab test which found that participants had difficulty setting the current time and day, studies which indicated people had problems with programming desired temperatures and schedules, studies which found that buttons and/or font size of text were too small and studies which pointed to poorly understood abbreviations and terminology and confusing lights and symbols or icons (see Peffer, T., Pritoni, M., Meier, A., Aragon, C. & Perry, D. (2011). How people use thermostats in homes: A review. *Buildings and Environment*, 46, p. 2536.

[76] Meier A.K, Aragon C, Hurwitz B, Mujumdarly D, Perry D, Peffer T, & Pritoni M, (2010). How people actually use thermostats. *Proceedings of the 2010 ACEEE Summer Study on Energy Efficiency in Buildings*, 2, 193-206

[77] Shipworth, M., Firth, S.K., Gentry, M.I., Wright, A.J., Shipworth, D.., & Lomas, K.J. (2010). Central heating thermostat settings and timing: building demographics. *Building Research & Information* ,38(1), 50-69; Consumer Focus (2012). Consumers and domestic heating controls: a literature review. London: Consumer Focus. Available at - http://www.consumerfocus.org.uk/files/2012/01/Consumers-and-domestic-heating-controls-a-literature-review.pdf (27/01/2014).

[78] Combe, N., Harrison, D., Craig, S., & Young, M. S. (2012). An investigation into usability and exclusivity issues of digital programmable thermostats. *Journal of Engineering Design*, 23 (5), 401-417

review concluded that developing a set of design standards could do much to improve the usability of heating controls[79].

One of the few strands of empirical research conducted in the UK in this area comes from Combe et al.[80] mentioned above. The study looked at why older people in particular can find it difficult to use digital programmable thermostats. Whilst digital programmable thermostats are relatively rare in the UK, much of the results from this paper are still relevant to setting central heating timers and separate room thermostats which are the usual UK configuration. The samples of users were small and self-selecting, but randomly allocated to user groups within age bands.

The study found that only 3 out of all the 24 users across both younger (aged 22-44) and older (aged 62-75) groups combined were able to complete a programming task successfully. Older users found the task more difficult than their younger counterparts. Users found the system complex to operate, were frustrated by the lack of 'Confirm' or 'Enter' buttons, found written instructions unhelpfully complex, and were confused by the use of unfamiliar symbols. The study assessed the ability of older users to program one particular controller, although as the authors pointed out, there are millions of similar controllers in use in the UK.

Overall, most participants asked to complete the programming task reported getting severely frustrated with none of the older users being able to complete the programming of the thermostats. On the basis of the evidence Combe et al. made four recommendations aimed at improving usability:

1. Provide a summary of programmable settings for users, including clear on and off times;
2. Provide clear and concise instructions and face to face support;
3. Give careful consideration to the number of buttons: too few buttons led to high frustration, but too many distracted users; and
4. Use clear text labelling on control interfaces, and work towards standardizing symbols across different interfaces.

The findings are similar to a small scale Finnish study on usability conducted in non-domestic settings[81]. After conducting usability tests across four phases involving 8-15 users, the author produced usability guidelines which recommended temperature controls should have simple interfaces with clear and sufficient feedback after adjustment; be visible, easy to reach and easy to identify the controls' purpose; in addition to giving information on how to use the system and on what the system can be used for.

A study conducted in Germany by Sauer et al. also looked at the impact of various types of enhanced user support on the usability of heating controls[82]. The results suggested that the most effective support in terms of improved energy efficiency was through predictive displays. These are displays that provide users with information on energy consumption patterns

[79] Peffer, T., Pritoni, M., Meier, A., Aragon, C. & Perry, D. (2011). How people use thermostats in homes: A review. *Buildings and Environment*, 46, 2529–2541

[80] Combe, N., Harrison, D., Craig, S., & Young, M. S. (2012) An investigation into usability and exclusivity issues of digital programmable thermostats. *Journal of Engineering Design, 23* (5) pp. 401-417.

[81] Karjalainen, S. (2010). Usability guidelines for room temperature controls. *Intelligent Buildings International, 2*, 85–97.

[82] Sauer, J., Wastell, D.G. & Schmeink, C. (2009) Designing for the home: A comparative study of support aids for central heating systems. *Applied Ergonomics, 40*, 165–174.

associated with the different settings they might use. Subjective rating results also found users rated status displays highly.

Research has also shown that different controllers are likely to be suitable for different users. For example a voice-driven menu system, which is available on some controllers, may be very suitable for older people or those with poor eyesight[83].

5.2.3 Heating controls impact on energy use

UK studies in this area have recommended that alternative forms of heating control should be developed and tested to determine whether their use can save energy in real-world settings[84]. A review conducted by Monahan and Gemmell for the National Housing Building Council[85] concluded that changes in human behaviour are vital to reducing energy consumption.

A small scale international comparison using results from 5 homes by Scott et al.[86] highlighted that energy savings could be realised if controls could be set to take account of householder behaviour, for example by turning the system off when the house was unoccupied, in cases where otherwise households would have left the heating on.

In an effort to improve understanding of how providing consumers with adequate heating controls could have an impact on energy use, field trials have compared energy consumption in households with and without heating controls. An example of UK research in this field from 2004 looked at the potential for energy saving in non-domestic settings that could be achieved through improving boiler controls[87]. The study looked at 25 non-domestic heating systems across the UK located in leisure centres, schools, industrial warehouses and offices. The results showed only modest improvements for certain types of boilers.

More recently, a study by Shipworth et al. monitored the internal temperature in 358 homes with gas or oil fired central heating, both with and without heating controls, over a six month period[88]. The research looked at the practices in a subsample of households drawn from the Carbon Reduction in Buildings (CaRB) project[89].

The CaRB subsample participants (358 households) used gas or oil fired central heating systems with radiators as their main form of heating representing 84% of the total CaRB

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[83] Combe, N., Harrison, D., Craig, S., & Young, M. S. (2012). An investigation into usability and exclusivity issues of digital programmable thermostats. *Journal of Engineering Design*, 23 (5), p.401-417; Peffer, T., Pritoni, M., Meier, A., Aragon, C. & Perry, D. (2011). How people use thermostats in homes: A review. *Buildings and Environment*, 46, p.2529–2541.

[84] Shipworth, M., Firth, S.K., Gentry, M.I., Wright, A.J., Shipworth, D.., & Lomas, K.J. (2010). Central heating thermostat settings and timing: building demographics. *Building Research & Information 38(1)*, p.50-69

[85] Monahan, S. & Gemmell, A., (2011). *How occupants behave and interact with their homes: The impact on energy use, comfort, control and satisfaction*, Milton Keynes: NHBC Foundation.

[86] Scott,J.J., Bernheim -Brush, A.J., Krumm, J., Meyers, B., Hazas, M., Hodges, S. & Villar, N. (2011). PreHeat: Controlling home heating using occupancy prediction. In Proceedings UbiComp'11, September 17–21, Beijing, China.

[87] Liao, Z.& Dexter, A.L. (2004). The potential for energy saving in heating systems through improving boiler controls, *Energy and Buildings, 36*, 261–271.

[88] Shipworth, M., Firth, S.K., Gentry, M.I., Wright, A.J., Shipworth, D.., & Lomas, K.J. (2010). Central heating thermostat settings and timing: building demographics. *Building Research & Information* 38(1), p.50-69

[89] Households included in the CaRB project were selected by stratified random sample drawn from the Postcode Address File for England. To ensure a good geographic and socio-demographic spread, postcode sectors were stratified by Government Office Region and socio-economic class. Fifty four postcode sectors were selected at random in proportion to the number of addresses they covered and 21 addresses were sampled in each selected postcode sector. Out of 1134 addresses, 427 households were interviewed; a response rate of 44%.

sample. The research team focussed on this subsample because the building regulations energy efficiency rating system, the Standard Assessment Procedure (SAP) assigns the same assumptions with respect to living room temperatures for all of these systems (BRE 2008). Secondly, these systems "are installed in 83% of the housing stock, and account for 52% of CO2 emissions from the domestic sector" (p.10).

Internal temperatures in these households were measured using two sensors, one in the main living room and one in the main bedroom. Monitoring took place from 22 July 2007 – 3 February 2008. Of the 358 participating households, 172 provided thermostat settings. The remainder did not report having a room thermostat. The study found no statistically significant differences in central heating demand temperatures or durations between households that use central heating system controls and those that did not use controls.

A second study from members of the same research team developed a model to predict internal temperatures in the English residential sector[90]. The research used panel methods[91] to predict daily mean internal temperature demand across a heterogeneous domestic building stock over time. It was the first time a panel model had been used to estimate the dynamics of internal temperature demand from the natural daily fluctuations of external temperature combined with important behavioural, socio-demographic and building efficiency variables. The model confirmed links between habitual behaviours and home energy consumption. Results showed that whilst thermostats or thermostatic radiator valves (TRVs) reduced average internal temperatures, the use of programmable timers did not.

A US study published in 2007 compared energy use in 683 households with a 'modern programmable thermostat' (i.e. that met Energy Star[92] thermostat specifications) with 1,264 households matched for energy use and energy efficiency via utility billing and survey information, but with no new controls[93]. The study was a quasi-experimental matched comparisons design that used billing analysis linked to postal survey data to examine comparable energy use across the matched samples. The results found that energy use in the 683 homes with existing controls was 6% lower. The authors concluded that savings were made because the 'modern programmable thermostat' being tested were more user friendly. They suggested that it is not the provision of controls per se that is the key, but rather the extent to which consumers are able to use controls effectively that determines final energy consumption.

5.2.5 Consumer behaviour and energy use of heating controls

Added to design and installation problems are issues of consumer behaviour and how consumers use their heating controls. Peffer et al reported evidence that suggests consumers may not understand the principles of how controls influence heating system operation, or even how effective control can reduce energy use and thus fuel bills[94]. The conclusions of an international comparison study point to an acknowledgement that reducing energy consumption is likely to depend on at least two key factors: consumers having the capacity to use their

[90] Kelly S, Shipworth M, Shipworth D, Gentry M, Wright A, Pollitt M, Crawford-Brown D, Lomas K. (2013). Predicting the diversity of internal temperatures from the English residential sector using panel methods. *Applied Energy* ,102, p.601-621

[91] A panel data method allows cross-sectional and time-series data to be modelled without incurring data reduction penalties due to averaging of the temperature readings over time or across dwellings.

[92] ENERGY STAR is a U.S. Environmental Protection Agency voluntary program that helps businesses and individuals save money and protect the climate through supporting energy efficiency measures.

[93] RLW Analytics, (2007), *Validating the Impact of Programmable Thermostats*. Middletown,. CT, Prepared for GasNetworks by RLW Analytics

[94] Peffer, T., Pritoni, M., Meier, A., Aragon, C. & Perry, D. (2011). How people use thermostats in homes: A review. *Buildings and Environment*, 46, p.2529–2541.

controls as designers and engineers intended; and members of the household being motivated to save energy[95].

This is supported by the findings of two other studies gathered by the REA. The first is a qualitative study that involved interviews with 50 householders across 4 geographical locations in the UK[96]. The study questioned people in detail about a variety of domestic energy efficiency interventions and concluded that any evaluation of energy saving interventions should include methods that would enable research to understand the complex social and cultural factors driving household energy demand.

The second reported on an on-going post-occupancy evaluation of a UK EcoHomes site[97]. It examined the energy performance of buildings alongside measures of consumer comfort and satisfaction. The study reported that for their sample, energy-efficiency behaviours accounted for just over half (51%) of the variance in heat consumption. As a consequence, they concluded that consumer behaviour needed to be monitored more effectively when modelling the impact of energy saving interventions on carbon emissions.

Druckman et al. in their study discussed the phenomenon known as the 'rebound effect[98]. The rebound or 'take back' effect describes a situation where estimated energy saving initiatives are frequently not realised in practice. This is in part because they do not account for consumer behaviour, which applied in real world, home settings may result in an increase rather than decrease in overall energy consumption. Using existing data to model household behaviour, Druckman et al. estimated the rebound effect to be around 34% for a suite of three 'green' household actions, which included reducing internal temperatures by one degree centigrade by means of the thermostat.

Issues concerning the rebound effect are further illustrated in a study designed to examine the effect of a major domestic energy efficiency refurbishment programme on domestic space heating fuel consumption[99]. The study collected property and energy consumption data from 1,372 homes across five urban areas in England. Temperatures in the main living room and main bedroom of each dwelling were monitored at half hourly intervals for two periods of between two to four weeks over two winters. The results showed that hypothesised improvements in energy efficiency from the installation of gas central heating failed to materialise, even after taking into account the increased temperatures in the post-intervention properties. The authors explained the results, in part, by the observation that in homes with new central heating systems, householders opened windows more often and for longer. Once again, behaviour played a key intervening role in relationships between consumer control of their heating and energy savings.

[95] Wilhite H, Nakagami H, Masuda T, Yamaga Y, Haneda H. (1996) A cross-cultural analysis of household energy use behaviour in Japan and Norway. *Energy Policy* 24, p.795-803.

[96] Crosbie, T. & Baker, K. (2010). Energy-efficiency interventions in housing: learning from the inhabitants. *Building Research & Information*, 38 (1), p.70-79.

[97] Gill, Z.M., Tierney, M. J., Pegg, I. M., & Allan, N. (2010) Low-energy dwellings: the contribution of behaviours to actual performance. *Building Research & Information*, 5, p.491–508.

[98] Druckman, A., Chitnis, M., Sorrell, S. & Jackson, T. (2011). Missing carbon reductions? Exploring rebound and backfire effects in UK households. *Energy Policy*, 39, p.3572–3581.

[99] Hong, S.H., Oreszczyn, T., Ridley, I. & the Warm Front Study Group (2006). The impact of energy efficient refurbishment on the space heating fuel consumption in English dwellings. *Energy and Buildings*, 38, p.1171–1181.

5.3 Summary

Analysis of the EFUS interview data has served to provide a more detailed picture of how households reportedly currently use their central heating. 74% of households with central heating used the timer to switch the heating on and off, with 15% doing so manually and 10% by turning the thermostat up or down. Around three quarters reportedly turn their heating on and off twice a day, and have it turned on for an average of just over six hours a day. Peak times are reportedly from 6.00am until 9.00am, and then again from 4.00pm to 10.00pm. Households that reportedly have their heating turning on and off just once each day have the heating on for an average of just over ten and a half hours every day. Across all households, the reported average daily heating time is around eight and a half hours.

Research evidence indicates that a proportion of domestic consumers have usability issues with regard to central heating controls. As a consequence, they are not able to use their heating controls as designers intended them to be used. Commonly reported problems include displays that are difficult to read, buttons that are either too small or not clearly marked, a lack of intuitive design, controls installed in inaccessible places, and an absence of supporting information or advice on how to operate controls. Evidence suggests that where consumers have problems using programmable timers, they may use these devices as simple on/off switches. This is supported by analysis of EFUS data showing around a quarter of households with a central timer not using it to switch their heating on and off.

The evidence also indicates that the usability of heating controls needs to be improved to enable consumers to use their heating effectively. Many heating controls are too complex and posse difficulties for people in terms of vision, reach, dexterity and thinking. Simple interfaces with clear and sufficient confirmatory feedback on when adjustments have been made are needed; especially for groups who are known to experience difficulties in using their heating controls (e.g. older people). Studies have recommended that alternative forms of heating controls should be developed and tested and that general usability may be improved by a set of design standards for manufacturers of heating controls.

In addition to design problems is a more general issue related to consumers not understanding how heating controls influence the operation of heating systems. Evidence suggests that for a significant proportion of people, usage is driven not by concerns over energy use or cost, but by the desire to be warm and comfortable. This effect may also play a part in the ‘rebound effect,’ where calculated energy savings are not achieved because consumer behaviour serves to respond to the energy saving measures in ways that serve to raise rather than lower consumption.

6. What can be learnt from previous evaluations of whether heating controls affect energy demand?

This section provides a brief description of evaluation studies the review has identified, the experimental designs those studies used and what they have concluded with regard to the relationship between energy demand and the type of heating controls installed in homes.

The review found few recent robust UK evaluations of the relationship between heating controls and energy demand. The following section focuses on the three robust studies identified through the review.

6.1 Shipworth et al, (2010)

Michelle Shipworth et al. provided empirical data on central heating demand temperatures and durations, and linked it to self-reported interview data on central heating controls[100]. Data were collected across the winter of 2007 as part of the Carbon Reduction in Buildings (CaRB) project. As described in the previous section of the report, the study used a sub sample taken from the CaRB sample drawn from a national sample of 1134 addresses randomly selected from 54 stratified postcode sectors in England, with 427 households agreeing to be interviewed.

Interviewers asked householders a series of structured questions on the construction of their home, heating technologies, heating practices and socio-demographics. With the householders' permission, temperature sensors were installed in the 427 homes, one in main living room, and one in the main bedroom. Internal temperature monitoring was carried out over a six-month period from 22 July 2007 – 3 February 2008. Two variables were calculated for each dwelling using daily temperature measurements taken at 45 minute intervals: heating demand temperatures (thermostat setting); and heating duration (the estimated average daily hours of active central heating use). Their analysis concentrated on a CaRB subsample using gas or oil fired central heating systems with radiators as their main form of heating, comprising 84% of the CaRB sample – 358 households[101].

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[100] Shipworth, M., Firth, S.K., Gentry, M.I., Wright, A.J., Shipworth, D. & Lomas, K.J. (2010). Central heating thermostat settings and timing: building demographics. *Building Research & Information* 38(1), p.50-69.

[101] This was done due to the building regulations energy efficiency rating system, the Standard Assessment Procedure (SAP) assigning the same assumptions with respect to living room temperatures for all of these systems and because these systems are installed in 83% of the housing stock, and account for 52% of CO_2 emissions from the domestic sector.

When analysing their data, Shipworth et al. divided households into two groups: those with thermostatic control over their central heating system, and those without thermostatic control. The study reported no statistically significant differences in average maximum living room temperatures between homes with and without thermostatic control on their central heating systems.

6.2 RLW Analytics (2007)

A second relevant study, conducted against a political backdrop in which the US Environmental Protection Agency (EPA) was proposing to drop Energy Star® labelling for programmable thermostats on the basis that "….*thermostat manufacturers failed to provide any data to show that installing ENERGY STAR thermostats results in energy savings*"[102] (p.1).

In response, GasNetworks a collaborative of local natural gas companies serving New England, commissioned a study to evaluate the extent to which homes with programmable thermostats used less energy than similar homes without. As described earlier in this review, the study compared energy use in 683 households with a 'modern programmable thermostat' (i.e. that met Energy Star thermostat specifications) with 1,264 households matched for energy use and energy efficiency with existing controls.

All the households involved in the study were customers of GasNetworks affiliate companies. Researchers were able to access customer billing data from households participating in the GasNetworks EnergyStar® Qualified Thermostat Rebate Program. A minimum of two years, and a maximum of three years billing consumption history was obtained from each household from April 2003 to March 2006.

Billing data was supplemented with survey data. The study acquired complete and usable survey and billing information from 683 households. These were matched on an approximate 2:1 basis to the non-participant pool using the survey information. In this way, the study used a matched-comparisons design to control for intervening variables. The results found that energy use in the 683 homes with the Energystar thermostat was 6% lower than in the matched comparisons. When asked about the ease of use, 41% of participants and 21% of the control group found their programmable thermostat easy to use. The authors concluded that savings were made because the newer controls were more user friendly. They suggested that it is not the provision of controls per se that is the key, but rather the extent to which consumers are able to use controls effectively that determines final energy consumption. They also suggested that the failure of other studies to find significant energy savings attributable to heating controls could be due to poor usability of those controls (p.3).

The Energy Star programme suspended labelling of programmable thermostats in 2009. In discussion leading up to that decision, David Shiller, the Energy Star Marketing Manager for the EPA, cited five research studies, each of which showed that the device itself does not save

[102] RLW Analytics, (2007), *Validating the Impact of Programmable Thermostats*. Middletown,. CT, Prepared for GasNetworks by RLW Analytics.

energy, but instead, actual energy savings depend on user behaviour[103], a point also made in UK studies[104].

6.3 Malinick et al (2012)

To look in more detail at how user behaviour can influence the capacity of heating controls to deliver energy savings, Malinick et al. evaluated a programmable thermostat program for small businesses[105]. The evaluation was designed to assess actual energy savings and to test the classification of consumers based on the four scenarios described below. Whilst the study was not conducted in domestic buildings, the findings may provide learning points.

Malinick et al. used data from a programmable thermostat evaluation conducted with small businesses. The evaluation was designed to assess actual energy savings and to test the classification of consumers based on the four scenarios described below.

Data were collected via 194 telephone surveys with small business customers that participated in a 2010 program where their older manual thermostats were replaced with programmable models. Interviews were conducted over the period of one month between late April to late May, 2011. This replacement of controls was part of a programme being implemented by local utilities designed primarily to attain energy savings.

The authors concluded that the programme would be unlikely to meet energy saving expectations. Their assessment of small businesses suggested that user behaviour was '*the single most important factor*' (p170) influencing likely energy savings rather than access to new thermostats In terms of the four behaviour driven outcome scenarios described, the study found that around two-thirds of the responding small business customers were already practicing energy saving behaviours by manually adjusting their old thermostats. This, they claimed, suggested similar thermostat operating behaviours in small business and domestic settings. The authors concluded that if programmable thermostat programmes are solely built on the underlying assumption that all old thermostats were operated using constant settings, actual impacts for the program are '*destined to disappoint*' (p. 171). Their results indicated, they suggested, that the design of evaluations to assess whether heating controls affect energy demand requires reconsideration of the assumptions underlying expected per-unit energy savings.

6.4 Discussion

This section of the review has aimed to look at what can be learnt from previous evaluations of whether heating controls affect energy demand. In general, researchers have conducted

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[103] David Shiller. Programmable Thermostat: Programme Proposal. Energy Star Presentation. Available at - http://www.energystar.gov/ia/partners/prod_development/revisions/downloads/thermostats/Proposal_011106.pdf (27/01/2014).

[104] E.g. Crosbie, T. & Baker, K. (2010). Energy-efficiency interventions in housing: learning from the inhabitants. *Building Research & Information*, 38 (1), p.70-79.

[105] Malinick, T., Wilairat, N., Holmes, J., Perry, L. & Ware, W. (2012). Destined to Disappoint: Programmable Thermostat Savings are Only as Good as the Assumptions About Their Operating Characteristics. In Proceedings of the 2012 ACEEE Summer Study on Energy Efficiency in Buildings

relatively few robust evaluations of the relationship between heating controls and energy demand, particularly in the UK.

However, the lesson to be drawn from the relatively few evaluations suggest the impact of heating controls on energy demand is mediated by the introduction of a new control and user behaviour.

Specific learning from previous evaluations suggests that the following would be useful to inform whether heating controls affect heating demand. Careful consideration might usefully be given to having:

1. Objective and consistent measurements of what constitutes improved control[106];
2. Independent and robust outcomes measures, ideally collected via internal monitoring in homes, that include heating demand temperatures (thermostat settings); and heating duration (the estimated average daily hours of active central heating use)[107];
3. An experimental design, at the very least involving a matched-comparisons, that enables the study to control for intervening variables[108];
4. A clearly articulated set of hypothesised relationships between user behaviours and energy saving outcomes that can drive the identification of key variables requiring measurement[109];
5. A set of user behaviour measures pre and post the installation of improved controls that can be used to monitor behaviour change[110]; and
6. Access to billing information that would allow energy consumption to be measured[111].

[106] Peffer, T., Pritoni, M., Meier, A., Aragon, C. & Perry, D. (2011). How people use thermostats in homes: A review. *Buildings and Environment*, 46, p.2529–2541.
[107] Shipworth, M., Firth, S.K., Gentry, M.I., Wright, A.J., Shipworth, D.., & Lomas, K.J. (2010). Central heating thermostat settings and timing: building demographics. *Building Research & Information* 38(1), p.50-69
[108] RLW Analytics, (2007), *Validating the Impact of Programmable Thermostats*. Middletown,. CT, Prepared for GasNetworks by RLW Analytics
[109] Malinick, T., Wilairat, N., Holmes, J., Perry, L. & Ware, W. (2012). Destined to Disappoint: Programmable Thermostat Savings are Only as Good as the Assumptions About Their Operating Characteristics. In Proceedings of the 2012 ACEEE Summer Study on Energy Efficiency in Buildings
[110] Ibid
[111] RLW Analytics, (2007), *Validating the Impact of Programmable Thermostats*. Middletown,. CT, Prepared for GasNetworks by RLW Analytics

7. What gaps in existing evidence are there that should be filled?

In addressing a general gap in evidence related to most areas within this domain, this section of the review lists evidence gaps and highlights areas which could plausibly be filled by a field trial were one to be conducted.

Whilst the review identified some reports of field trials, the majority are US based evaluations of programmable thermostats. Some of the key issues identified in US research are pertinent; in particular, the role that usability of heating controls plays and the need to monitor consumer behaviour when assessing the impact of installing new controls.

However, the fact remains that there is a gap in the evidence with regard to UK research to assess whether heating controls affect energy demand[112]. Shipworth et al.[113] suggest that the lack of robust empirical investigations into this issue is attributable, at least in part, to the lack of national data on central heating demand temperatures and durations. The authors argued that evaluation of the impact of heating controls on energy demand requires accurate data on the temperatures people heat their homes to, and the amount of time people have their central heating turned on.

An evidence gap also exists with regard to the role of consumer behaviour in potential relationships between energy saving and domestic installation of improved control technologies. Evidence reported in this review and additional analyses of the EFUS data suggests that up to 25% of households with central heating systems with a central do not use it to control when the heating is switched on or off. However, as the paper by Malinick and his colleagues discussed[114], it may be wrong to assume that people using manual controls are universally failing to use their heating systems in an energy efficient manner.

A further gap in knowledge concerns the availability of robust, independent information on how people are using heating controls, linked to outcome data on heating demand temperatures and durations.

The difficulty in approaching this is illustrated by recent research commissioned by TACMA which commissioned Salford University to conduct independent tests on the performance of

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[112] Market Transformation Programme (2006) Evaluation of heating controls - Phase 1. RPDH19. Didcot, Market Transformation Programme - DEFRA. Available at – http://webarchive.nationalarchives.gov.uk/20090705012657/http://mtprog.com/spm/files/download/byname/file/rpdh19_03.pdf (27/01/2014).

[113] Shipworth, M., Firth, S.K., Gentry, M.I., Wright, A.J., Shipworth, D.., & Lomas, K.J. (2010). Central heating thermostat settings and timing: building demographics. *Building Research & Information* 38(1), p.50-69

[114] Malinick, T., Wilairat, N., Holmes, J., Perry, L. & Ware, W. (2012) Destined to Disappoint: Programmable Thermostat Savings are Only as Good as the Assumptions about Their Operating Characteristics. In Proceedings of the 2012 ACEEE Summer Study on Energy Efficiency in Buildings.

heating controls in their Energy House facility[115]. The tests showed how different levels of thermostatic control affects room temperatures and hence energy use, under experimental conditions. Use of TRVs brought large additional savings compared to just a room thermostat. However, as the report points out, savings in real homes will vary very widely due to occupant behaviour, thermal properties of the house and the heating system and radiator sizing. It is this level of detail that existing evaluations lack, and should therefore be considered to be a evidence gap.

The review found only a narrow range of empirical evidence on issues on when, why and how new heating controls are installed. That information could evidently be useful in developing models of replacement rates. It could be collected by adding questions to either the EHS or, should it be repeated, the EFUS.

Research has also highlighted that usability should be a key concern of a field trial designed to assess the impact of heating controls on energy savings for the reasons already highlighted[116]. However, rather than addressing this issue in an evaluation, it may be that such issues would be best addressed by a separate study conducted to inform the design of controls to be tested in a field trial.

As noted earlier in the review, an important strand of new product development has set out to automate some or all of the parameter setting process so that the task of adjusting times or temperatures is wholly or partly lifted from the user. Described by some authors as 'smart'[117] or 'passive' heating controls, these systems automate time setting by detecting occupancy and household activity using a variety of sensors. Because these systems are so new, evidence of efficacy certainly represents a gap; research has so far collected very little in the way of independent evidence to test their impact on energy savings relative to more conventional controls.

[115] TACMA (2013). Results of Research Carried Out on the Effectiveness of Domestic Heating Controls by the University of Salford,July 2013. Unpublished report. Available at http://www.beama.org.uk/en/utilities/document-summary.cfm/docid/10170869-0D20-4FE8-A9BBBC9E9E5A9508. (27/01/2014).

[116] E.g. Boait P.J., & Rylatt R.M. (2010). A method for fully automatic operation of domestic heating. *Energy and Buildings*, 42 (1), p.11 -16

[117] Boait P.J., & Rylatt R.M. (2010). A method for fully automatic operation of domestic heating. *Energy and Buildings*, 42 (1), p.11-16

8. Summary

DECC set out five detailed research questions the review needed to address:

1. What heating controls are installed and how do these vary across different properties and households?
2. When, why and how are new heating controls installed?
3. How do people use their heating at present?
4. What can be learnt from previous evaluations of whether heating controls affect energy demand?
5. What are the evidence gaps that should be filled?

The available evidence can be summarised thus:

What heating controls are installed and how do these vary across different properties and households?

Data reported by industry suggested that over 70% of households in the UK in 2008 that have a boiler do not have a full set of domestic heating controls (defined as TRVs, a programmer and room thermostats). However analysis of EFUS data for this Rapid Evidence Assessment has found that the proportion of households with central heating that have a range of controls (including a programmer, room thermostat and TRVs) has increased over recent years to 49%;

Analysis of the EFUS data suggests no simple relationship exists between property type and the installation of heating controls. Statistical tests revealed no significant differences between property types in terms of heating controls installed;

In terms of household type and tenure, the EFUS data revealed only a few statistically significant differences. Households living in private rented accommodation are significantly less likely to have a full set of heating controls than households living under other forms of tenure. They are less likely to have room thermostats and less likely to have TRVs fitted to radiators;

The figures for size of household suggested one person households are less likely to have TRVs fitted, and less likely to have a full set of heating controls, than larger households.

Analysis of EFUS data further suggests that increases in the proportion of households with full sets of controls have been uneven across demographic groups, so levelling out disparities identified in earlier surveys.

When, why and how are new heating controls installed?

In general, the review has found very little independent robust empirical evidence with regard to questions of when, why and how are new heating controls installed. Specifically:

- Evidence on this question is largely limited to statistics collected by the industry and should be interpreted as such;
- Heating controls are typically installed either when a new home is built, or when an existing boiler is replaced;
- Boilers and therefore heating controls are replaced most commonly as consequence of boiler breakdown or failure;
- Independent survey data suggest that each year, five per cent of households across England replace their boilers, whilst just over one per cent replaces their entire central heating system;
- In the majority of cases, installers rather than consumers take decisions on the characteristics of heating systems installed, including heating system controls.

How do people use their heating at present?

Analyses of EFUS highlighted a number of key points regarding how people reportedly use their heating at present:

- 74% of households (12,200 thousand) with central heating used the timer to switch the heating on and off, 15% switched their heating on and off manually, 10% switched the system on and off by turning the thermostat up or down, and 1% by other means;
- Of those with central heating reporting timed heating, 77% (9,400 thousand households) reportedly use two heated periods per day, and about 14% (1,800 households) reportedly one heated period, with only about 9% (just 1,000 thousand households) using more heated timed periods on an average weekday with weekends being similar;
- The number of reported hours on per day varies but the mean times are 8 hours 15 minutes a day during the week, and 8 hours 39 minutes at weekends with some households having their heating on for substantially more than the mean figures;
- In households where the heating was reportedly switched on and off only once, it was on for an average of 10 hours 24 minutes on a weekday, and 10 hours 51 minutes on a weekend day and in homes reportedly turning their systems on and off twice a day, the average weekday on time was 6 hours 45 minutes, compared with 7 hours 14 minutes on a weekend day.
- Around half of households providing data on boost heating reportedly used 4 hours or less with 10% using just one and 20% just two hours a week but with some households using many more hours, some up to a maximum of 98 hours per week.
- Heating ‘density’ plots for weekdays show that for single periods most heating is on from around 7.00am to 10.00pm, while for two periods there are fairly distinct peaks around 6am to 9am and 4.00pm to 10.00pm. Weekend periods were found to be very similar though heating comes on slightly later in the mornings.

Usability is likely to be a key driver for enhanced use of central heating controls for domestic consumers. Where consumers have problems using programmable timers, they may use these devices as simple on/off switches.

Research demonstrated that a key objective for many householders is to achieve thermal comfort rather than energy efficiency – although the term thermal comfort is evidently a subjective term.

What can be learnt from previous evaluations of whether heating controls affect energy demand?

To the extent that changes in energy consumption depend at least in part on changes in consumer behaviour, it may not be prudent to make assumptions about potential energy savings based solely on the numbers of households with full controls.

There is little in the way of consistent evidence that improved domestic heating control technologies deliver energy savings. Academic papers gathered by the REA suggest the failure to find consistent evidence may be a consequence of poor experimental design. The impact of heating controls on energy demand is mediated by user behaviour.

Lessons that might be learnt from previous evaluations include:

- Having robust and consistent definitions of control technologies;
- Monitoring actual house temperatures and heating durations;
- Using matched-comparisons research designs;
- Developing a clearly articulated logic model that identifies key output and outcome variables;
- Measuring consumer behaviour carefully; and
- Talking to energy supply companies about the possibility of accessing household billing data.

What gaps in existing evidence are there that should be filled?

Substantive evidence gaps remain in this area. The absence of national data on central heating demand temperatures and durations is at least in part responsible for the paucity of robust evaluations. Not enough is known about the role of consumer behaviour in potential relationships between energy saving and heating control technologies. Only a narrow range of empirical evidence exists on when, why and how new heating controls are installed. Several aspects of heating controls and consumer usability require further research. Research has shown usability to be a critical consideration when assessing the impact of heating controls on energy savings. We clearly lack knowledge of optimum design, particularly when, as has been suggested, different groups of consumers may face different issues in this context.

9. Conclusions

This Rapid Evidence Assessment set out to synthesise evidence on how heating controls affect domestic energy demand via five research questions. The purpose of the Rapid Evidence Assessment was to support subsequent thinking relating to a possible trial that could detect any energy reductions associated with improving control technologies against a background of considerable variation in energy use across different households. Finally it aimed to derive from the available research evidence an estimate of how much energy could be saved, in principle, by improving heating controls[118].

The Rapid Evidence Assessment has established that to date little evidence is available with which to understand and interrogate the domain, suggesting that domestic heating and the part consumers play in it has attracted insufficient attention from researchers.

Published reviews, and the few field trial evaluations that have been done, have largely failed to provide a consistent body of evidence as far as the capacity of heating control technology to contribute to energy savings. Whilst much of the available empirical evidence comes from the US, as other reviews have argued, findings are nevertheless relevant to the UK.

Evaluation research in the area, such as it is, can broadly be divided into two strands. The first can be characterised as studies that have looked at the impact of improving the usability of traditional controls that retain time and temperature setting as a manual activity. As one US review put it[119], research in the area has suffered from inconsistent definition of terms (e.g., programmable thermostat, setpoint, zones), as well as small sample sizes that have compromised the generalizability of results.

The second strand serves to identify that evaluation has largely failed to take into account the extent to which human behaviour mediates the relationship between new technological advances and energy savings.

Finally, the Rapid Evidence Assessment has highlighted the lack of robust and consistent evidence of the impact changes to heating controls have on energy use; as a consequence, it is very difficult to produce reliable estimates of how much energy could be saved, in principle, by improving heating controls.

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[118] DECC research specification Ref: TRN 546/12/2012 (p.7). http://www.government-online.net/evidence-review-of-how-heating-controls-affect-domestic-energy-demand/. (27/01/2014).

[119] Peffer, T., Pritoni, M., Meier, A., Aragon, C. & Perry, D. (2011). How people use thermostats in homes: A review. *Buildings and Environment*, 46, p.2529–2541.

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