Department of Energy & Climate Change

Smarter heating controls research program

Contents

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Overview of this document

This document describes a two stage research program designed to determine if smarter heating controls can save significant amounts of domestic energy. First it sets out the context explaining why DECC has decided to fill this key evidence gap. Second it describes the detailed aims of the research program. Third it describes the work planned. Fourth it separates research questions into different work packages. Finally it sets out some next steps to identify and act on policy implications including appointing an expert oversight panel to govern the work.

Context

Domestic buildings account for about a third of final energy use accounting for about a quarter of UK CO_2 emissions. Space heating is responsible for about 60% of domestic energy consumption, heating hot water accounts for about another 15%: a quarter of total UK energy consumption. Carbon budgets commit the UK to reduce the CO_2 this emits at least 80% by 2050.[1]

DECC is already acting to increase the uptake of fabric measures that improve the energy efficiency of properties. However, rebound effects can reduce the level of savings these measures deliver.[2] Improving heating controls may be one way to reduce this rebound.

Over 95% of homes have a boiler. Of these, 800,000 have no controls at all, almost 8 million have no room thermostat and over 70% lack the minimum levels of controls in the 2010 building regulations. Industry estimate that installing standard controls could reduce domestic energy used for heating and hot water by 30%: ensuring all homes had a timer, room thermostat and TRVs would reduce UK CO_2 emissions 4.3Mt/year by 2020, just under 1% of annual emission.[3] However, there is currently no robust evidence that standard heating controls reduce heating demand.[4]

Several studies have compared internal temperatures in buildings with different sorts of heating controls. Shipworth *et al.*, (2010) found no significant difference between the average maximum temperatures of living rooms with and without standard heating controls

[1] Domestic reductions may need to exceed 80% if other sectors, like agriculture, cannot reach this target.
[2] See for discussion, Herring, Horace and Roy, Robin (2007). Technological innovation, energy efficient design and the rebound effect. Technovation, 27(4), pp. 194–203.
[3] This is just under 1% of annual CO_2 emissions, which were 588Mt in 2010.
[4] PassivEnergy report found that 84% of homes made financial savings of on average 23% during a 12 month field trial. However, the trial included only 25 homes, participants may not have been randomly selected, there were no control groups, no baseline information was collected and 16% of homes used more energy after controls were installed.

over an entire heating season.[5] More recently Kelly *et al.* (2012), working with the same researchers, performed a more detailed analysis of the how the same internal temperature data varied across the entire year whilst controlling for key co-variates like external temperatures.[6]

This more sophisticated analysis did show some key differences. Mean daily internal temperatures were lower in homes with thermostats (0.24^{o}C on average) or TRVs (0.17^{o}C on average) than homes without them and increased with the temperature setting of the thermostat. Notably however, they found no significant difference in internal temperatures for homes controlled manually compared to those controlled with a timer or programmable thermostat. The authors conclude that it is not the presence or absence of particular controls that is important, but rather how people choose to interact with the technology that really matters.

A recent literature review[7] found that consumers find heating controls difficult to use and many do not use them effectively. It highlighted that the elderly and those in local authority housing were more likely to find their controls difficult to use and that tenants were less likely than owner-occupiers to have a full set of standard controls (thermostat, timer and TRVs).

The literature review suggested the UK market has failed to deliver the potential from standard heating controls because installers select which controls to install, not end-users, so there is no market demand for manufacturers to design more usable controls. It advocated a standard to ensure heating controls are usable and a central information resource to inform consumers. Findings from the user requirements gathering and usability testing in Stage 1 could begin to fill this gap.

In the US, modelled savings overestimated actual savings leading the market to promote heating controls as an energy efficiency measure, only to scale back support when better evidence emerged. Inaccurate assumptions about how people heated their homes lead programmable thermostats to be established within the ENERGY STAR® program in 1995 and utilities to offer rebates for their purchase. However, they were removed from the California IOU program in 2006 and the scope of the ENERGY STAR® thermostats programme was reduced following evidence that high potential savings were rarely achieved.[8] There are even reports of evaluations that show homes in the USA with

[5] Shipworth, M., S. K. Firth, et al. (2010). "Central heating thermostat settings and timing: building demographics." Building Research & Information 38(1): 50-69.

[6] Kelly, S., Shipworth, M., Shipworth, D., Gentry, M., Wright, A., Pollit, M., Crawford-Brown, D. and Lomas, K. (2012). Predicting the diversity of internal temperatures from the English residential sector using panel methods. Applied Energy In Press. Findings shared by a co-author.

[7] Consumer Focus (2012) Consumer and domestic heating controls: a literature review.

[8] For a more detailed discussion see Moezzi, E. *et al.* (2009) Behavioural assumptions in energy efficiency potential studies. Prepared for the California Institute of Energy and Environment. Pages 58-60.

programmable thermostats consume more energy than those relying on manual thermostats.[9] In the US, inflated claims of savings from programmable thermostats persisted for many years, qualified by statements that these relied on devices being 'used properly'.

Heating control technologies are developing rapidly to include: remote control via the internet or mobile phones; sensors that can detect occupancy, open windows or doors, external temperatures; advanced heating algorithms that can learn occupant habits and preferences. Without government intervention innovation could focus on improving convenience and comfort rather than saving energy, potentially inducing the adverse effect of increasing energy use.

Aims of the program

The research program has the following main aims.

1. Establish if improving heating controls reduces the energy consumed by householders and why they do (or don't).

Despite claims from commercial organisations and considerable theoretical potential, there is currently no robust evidence that advanced heating controls reduce the energy people use to heat their homes. Rapidly emerging technologies present opportunities to radically advance the way heating controls work. The first aim of this programme is to establish whether emerging heating control technologies save energy.

2. Drive technological innovation towards maximising energy savings

Commercial organisations may seek to sell more advanced heating controls on the basis of a range of consumer benefits: convenience, home improvement, enhanced control. These need not reduce energy use. The second aim of the programme is to understand how best to harness emerging technologies to maximise how much energy the next wave of heating controls deliver.

3. Facilitate a holistic and integrated approach to overall energy reduction in buildings

Heating controls are only a part of a system that determines the energy used to heat a home. Other social characteristics (e.g. patterns of occupancy) and technical factors (e.g. heating system, thermal envelope) are also crucial. The third aim of the programme is to understand the role heating controls play in different socio-technical situations so as to guide innovation towards maximising the energy saved in a broad range of contexts.

[9] Meier, A., C. Aragon, et al. (2010). Thermostat Interface and Usability: A Survey, Lawrence Berkeley National Laboratory.

Therefore, the programme will seek to gather evidence in an appropriate range of social and technical situations.

4. Identify potential adoption paths

Of all the homes with a boiler, 38% have no room thermostats, 45% have no thermostatic radiator valves and 71% lack some part of the recommend minimum controls.[10] Building controls could mandate that new buildings installed advanced heating controls, however, over 80% of the houses standing in 2050 are already built.[11] The fourth aim of the programme would explore innovations that might accelerate the adoption of advanced heating controls by existing homes, including techniques to speed up or simplify installations. For instance, it might identify other trigger points (e.g. installing a boiler) where building controls could mandate that heating controls could be improved.

Planned work program

Overview

It is envisaged that this work will be split into two stages. Stage 1 will synthesise existing evidence, gather end-user requirements for heating controls, test the usability of existing heating control systems, specify heating control designs to trial and set out an evaluation methodology that could demonstrate if they save energy. This will combine in house work and commissioning different sorts of external expert.

Stage 2 will conduct an appropriately powered (i.e. sample size), randomised, controlled trial to evaluate the level of energy saved by heating controls. It is envisaged that the Technology Strategy Board will manage this stage through the Small Business Research Initiative (SBRI).[12]

Both stages would involve competitive tenders from research agencies, control manufacturers, installers and evaluation specialists. The work is being funded by the DECC

[10] TACMA (2010) Heating and hot water pathways to 2020. www.beama.org.uk/en/news/index.cfm/hhwt_pathways_2020_report

[11] There were 21.5 million English houses in 2010 (EHS, 2010). Approximately 120,000 new houses are built every year (House building statistical release, 2012). At this rate, there will be approximately 26.5 million houses in England in 2050.

[12] The Technology Strategy Board has implemented a scheme that helps UK public bodies to procure the development of new technologies to meet their policy objectives. Despite the word 'small', the Small Business Research Initiative (SBRI) is a competition open to companies of all sizes as a means for 'pre-commercial procurement', which is not considered to be State Aid. Instead it is viewed as a necessary precursor to a competitive procurement process where a solution is not readily available in the market.

Innovation Fund. Oversight is being provided by a panel of specialists from DECC, other Government Departments, academia and industry.

Stage 1

Stage 1 will synthesise relevant evidence, relate this to experimental hypotheses, gather end-user requirements for heating controls, test the usability of existing heating control systems, justify exactly which systems to trial and design a high-level evaluation methodology.[13] The following paragraphs illustrate the steps in this stage by considering two frequently stated hypotheses.

Evidence would be collected from peer review publications, experts and (where possible) commercial organisations. The synthesis would involve constructing a logic map that set out how heating controls affect domestic heating. This would lead to various experimental hypotheses, for example:

1) Evidence: some households heat empty rooms or leave their heating on when they go out.
Hypothesis 1: automatic heating controls could save energy by turning down heating in empty rooms or when the property is empty.

2) Evidence: many people find controls hard to use.
Hypothesis 2: occupants would save energy if their controls were easier to use.

Testing these hypotheses would require automatic heating controls that responded to occupancy in the first instance and controls that were easy to control in the second. The synthesis should involve some estimates of how much energy different heating control systems are hypothesised to save.

The next step would inform the selection of heating controls to trial in stage 2 by conducting research to gather user requirements and compare the usability of potential systems. This is a standard, albeit challenging, element of user-centred design.[14] It would ensure that systems trialled are easy to use and robust enough to deploy in a field trial. Publishing the findings would also provide consumers with information on the relative usability of different heating controls and drive innovation towards delivering simpler controls.

Heating control technologies could then be specified in the detail required to design a trial. At present, the aim is to identify a relatively affordable system manufactured in the UK as

[13] A distinction is drawn between the high-level design of the method (e.g. number of experimental conditions, definition of control group and baselines) and more detailed decisions that can be left until the trial is commissioned (e.g. recruitment screener, discussion guides, installation process).

[14] See http://nigelbevan.com/papers/International_standards_HCI.pdf for a publication outlining the recognised ISO international standards relevant in this area.

part of the Government's commitment to encourage UK based innovation.[15] This means the Nest product is currently out of scope as it is not manufactured in the UK.[16] The cost is important both for meeting the Green Deal Golden Rule, but also to make sure low income groups can afford them.

The final output from stage 1 would be the design of a randomised, controlled trial that could provide robust evidence as to whether heating controls save energy. In this example, a trial might measure how much energy was used to heat properties in three conditions:

1) Control: basic controls (e.g. on/off button)

2) Experimental condition 1: an easy to use control system (e.g. timer, one room thermostat and thermostatic radiator valves, potentially with a simple remote user interface like climote[17])

3) Experimental condition 2: an automatic system that controls heat to match occupancy.

A robust trial may need to include a relatively large sample, perhaps thousands of properties because heating demand is affected both by the property and the occupants. A large sample is required to ensure that each experimental condition contains properties which cover a suitable (and comparable) range of these factors. Statisticians would be asked to provide estimates of the sample sizes required to demonstrate savings of the size hypothesised given typical variation.

The panel would provide oversight of the decisions regarding which heating controls to trial and the high-level design of the trial methodology. **There will then be a formal decision to confirm whether an appropriately powered field trial is desirable, affordable and feasible before moving to Stage 2, especially as this may require a large sample size.**

Stage 2

Stage 2 will commission a consortium to conduct and report a randomised, controlled trial to provide robust evidence as to whether heating controls save energy. The consortium is likely to include heating controls manufacturers, installers of heating controls and monitoring tools (perhaps energy and temperature); and researchers to evaluate the impact of heating controls and understand relevant household behaviours.

It might be beneficial to partner with an energy supplier to recruit properties with smart meters already installed. This could reduce the costs of collecting historic, baseline energy use data and enable the trial to deliver findings more quickly. Clearly it would be important to obtain participants' permission to use this data and to ensure that the instillation of the

[15] http://www.bis.gov.uk/assets/biscore/innovation/docs/i/11-1387-innovation-and-research-strategy-for-growth.pdf
[16] http://www.nest.com/
[17] http://www.climote.ie/

smart meter did not introduce any unwanted artefacts (e.g. energy enthusiasts may be more likely to request a smart meter than the general population).

Research questions

This section sets out the detailed questions tackled by each stage and the work packages being conducted to answer each one (see also Figure 1).

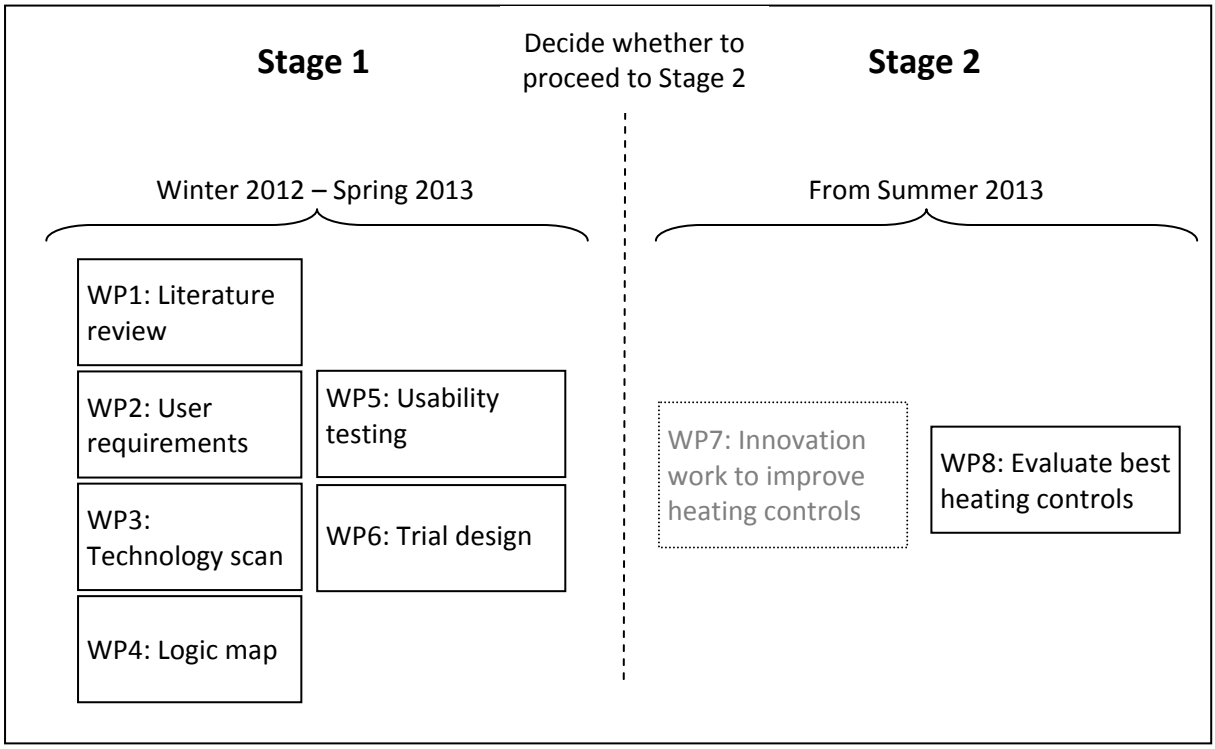

Figure 1 – Schematic of work packages planned with approximate timescales

Stage 1

1. What additional evidence exists on how heating controls affect domestic energy demand?
   DECC will commission a **literature review** (WP1) of robust peer-reviewed publications, but also draw together available data from other sources should it be made available (e.g. commercial reports).

2. What do users require from heating controls?
   DECC will commission **user requirements research** (WP2) to understand existing user experiences of heating controls, including their frustrations.

3. How could heating controls be improved in the near term?
   DECC will conduct a **technology horizon scan** (WP3) of near to market heating controls to map emerging technologies to the user requirements identified by WP2.

4. How could improved heating controls affect domestic energy use?
   DECC will construct a detailed **logic map** (WP4) setting out exactly how changing heating controls is hypothesised to affect domestic energy demand. For instance, thermostats save energy by turning heating off in situations where occupants forget switch off heating (if they only have an on/off switch); automated heating systems save energy by turning off heating in empty rooms or unoccupied properties.

5. How usable are different potential trial heating control systems?
   DECC will commission **usability testing** (WP5) of the type previously conducted in the UK and US[18] to compare how easy participants find it to use different types of heating controls to perform the key tasks identified by WP2. This will collect standard metrics (e.g. task completion rate, task completion time, error rate) to objectively compare how usable different systems are.

6. How could a trial collect robust evidence to test if improved heating controls save energy?
   DECC staff will work with the oversight panel to **design a hypothetical trial** (WP6) answer the following questions:
   a) What is the control group (e.g. households with basic on/off switches but no thermostat or timer?)
   b) How many interventions are there (e.g. install easy to use controls, install automated controls)?
   c) What is the control intervention (e.g. conduct the same set up procedure including installing monitoring equipment, but do not install new controls)?
   d) How large are hypothetical energy savings estimated to be (including confidence intervals)?
   e) What range of situations do we need to collect data from to be confident we can validly generalise the findings more widely: property types, tenure types, income levels, household size, household composition, occupancy pattern etc.?
   f) What baseline data could we use to compare with an experimental effect: hourly/daily/weekly/annual gas/electricity consumption, internal temperature, external temperature?
   g) Is this data available for any households?
   h) How much does domestic energy demand vary across these situations at present?

[18] Meier, A., Aragon, C., Pefer, T., Perry, D., Pritoni, M. (2011) Usability of residential thermostats: preliminary investigations. Building and Environment, 46, 1891-1898. Karjalainen, S. (2010). Usability guidelines for room temperature controls. Intelligent Buildings International (2), 85-97. Ricability (2004) Taking control – a guide to buying or upgrading central heating controls.

i) How large a sample is required to detect an effect of our interventions (using estimates in d), given the likely level of variation in our sample (using estimates from h)?

j) How could participant households be randomly selected and randomly assigned to different experimental conditions in an ethical way?
How would observation biases (e.g. the Hawthorne effect) be removed?

Stage 2

1. Do improved heating controls reduce domestic energy consumption? How much energy, if any at all, do improved heating controls save? Why do/don't improved heating controls reduce domestic energy consumption?
   DECC will commission a consortium to conduct a trial to **evaluate** if improved heating controls reduce domestic energy consumption and if so, how much they save, why they saved this much and how they could save more (WP8).

   Notably, it is possible that Stage 1 may find that there is no current smart heating control system that is suitable for trial. If this were the case, then some **innovation work** may be required, for instance to move early prototypes forward so they could be deployed in a trial (WP7).

Next steps

Governance

A multi-tiered governance arrangement will be set up to steer this program. At a working level, Matthew Lipson will lead the work, Emma Owen will provide technical support and Alex Jack will provide project management assistance.

An oversight panel will be created to provide expert guidance including the following:

- Internal DECC experts: Liz Owen, Siobhan Campbell, David MacKay, Duncan Millard, David Wagstaff, Jane Denett Thorpe, Steven Jones, Michael Harrison (TBC)
- External expertise required (and potential providers):
  - Signpost to relevant industry evidence and provide guidance on what technologies can deliver (Colin Timmins, TACMA/BEAMA)
  - Design, accessibility and usability (Mat Hunter, Head of Design at the Design Council)
  - Awareness of existing literature (academics)
  - Evaluation design (academics)
- Other government departments: CLG (Paul Decort), Cabinet Office (Laura Haynes)

Finally, the DECC R&D panel will be formally consulted on whether to proceed to Stage 2.

Policy implications

The programme is likely to have implications for policy. However, without prejudging the findings, it is difficult to set out what these implications will be. Therefore this section briefly explores the findings that might emerge to illustrate some of the potential implications.

For instance, the programme might show that advanced heating controls saved significant energy. First, the standard of heating controls mandated by Part L of Building Regulations could be updated. Second, advanced heating controls could be included within the Green Deal.[19] Third, it could inform whether the Smart Meters programme promoted advanced heating controls within the mass roll out as part of a the smart home. Conversely, if the programme provided robust evidence that heating controls did not save energy, these policies could be improved by making different changes.

Another possibility is that the programme might show that emerging technologies have considerably more potential than is currently being realised. For instance, commercial innovation may focus on improving convenience and comfort rather than saving energy. Alternatively they might target more affluent homeowners with relatively expensive solutions rather than ensuring solutions are accessible to lower income groups and tenants. In this case the implications might be to develop innovation policies that encourage the development of affordable heating control technologies that focus more on saving energy.

A key aspect of the program will therefore be to work through these policy implications.

[19] Standard heating controls are included as a Green Deal measure. Advanced heating controls could become eligible for Green Deal Finance in three ways: (1) modify the in-use factor for heating controls; (2) introduce advanced heating controls as a new sub-category of heating controls; (3) introduce advanced heating controls as an entirely new category within RdSAP. The Green Deal policy team are actively exploring what evidence would be add a measure in each case.