Central heating thermostat settings and timing: building demographics

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Abstract

Crucial empirical data (currently absent in building energy models) on central heating demand temperatures and durations are presented. This data is derived from the first national survey of energy use in English homes and includes monitored temperatures in living rooms, central heating settings reported by participants, along with building, technical and behavioural data. The results are compared to model assumptions with respect to thermostat settings and heating durations. Contrary to assumptions, the use of controls did not reduce average maximum living room temperatures or duration of operation. Regulations, policies and programs may need to revise their assumptions that adding controls will reduce energy use. Alternative forms of heating control should be developed and tested to ascertain whether their use saves energy in real-world settings. Given the finding that detached houses are heated for longer, these dwellings should be particularly targeted in energy efficiency retrofit programs. Furthermore, social marketing programs could use the wide variation in thermostat settings as the foundation of a ‘social norm’ program aimed at reducing temperatures in ‘overheated’ homes. Finally, building energy models that inform energy policies require firmer foundations in real world data to improve policy effectiveness. Greater coordination of data collection and management would make more data available for this purpose.

Keywords

building energy model, central heating, control systems, demand temperature, domestic heating controls, energy demand, inhabitant behaviour, thermostat setting

Introduction

The use of central heating

Use of residential central heating accounts for about 1/8th of UK carbon emissions. Policies and programs are urgently required to reduce the carbon emissions associated with its use, but that use is very poorly understood. Nearly 90% of homes are centrally heated (Communities and Local Government 2007), space heating accounts for 53% of residential carbon emissions (DEFRA 2006) and households account for around 27% of UK emissions (DEFRA 2006).

The UK government is committed, under the Kyoto Protocol, to reducing 2012 greenhouse gas emissions to 12.5% below 1990 levels (DEFRA, 2008a). The government has also set the domestic target of reducing emissions to 20% below 1990 levels by 2010 (DEFRA, 2008a). The recently enacted Climate Change Act 2008 commits the government to a legally binding target of reducing UK carbon dioxide (CO2) emissions in 2050 to 80% below those in 1990 (DEFRA, 2008b). The Act's interim target of reducing emissions by 26% by 2020 was subsequently tightened to 34% by statute (Office of Public Sector Information (OPSI), 2008).

These targets are likely to require large emission reductions from UK dwellings, especially since reductions in this sector are considered relatively low cost (CCC 2008). Any policies and initiatives aimed at significantly reducing residential CO_2 emissions must address the largest residential CO_2 emitter – central heating. And, to be effective, these policies and initiatives must be informed by sound evidence of how central heating is used.

Key determinants of a home's space heating energy use (and thus CO_2 emissions) are heating demand temperatures (thermostat settings where thermostats are used) and heating duration.

This is demonstrated in a parallel paper in this special issue journal in which Firth et al. carry out a sensitivity analysis of an energy and carbon model of the English housing stock. They find heating demand temperatures have the greatest influence; a 1% rise in heating demand temperatures is estimated to cause a 1.55% rise in CO_2 emissions. Heating duration has the second greatest influence and a 1% rise in the number of heating hours is estimated to result in a 0.62% rise in CO_2 emissions. The third most influential variable is external air temperature which is also a key determinant of space heating. Building fabric and extent of heating are other important influences on space heating energy use.

The need for data

Despite the significance of heating demand temperatures and durations, the main models used to inform residential energy and carbon reduction policy-making in the UK are based on the same core building energy model – BREDEM (the Building Research Establishment's Domestic Energy Model) – which uses assumed heating demand temperatures and heating durations. BREDEM version 8 assumes that the living room is heated to 21°C – for nine hours on weekdays (7am to 9am and 4pm to 11pm) and for 16 hours on weekends (7am to 11pm) (Anderson et. al. 2002).

The UK Government's method for the energy rating of dwellings uses the default heating regime as given in BREDEM (BRE 2005a). This method – the Standard Assessment Procedure (SAP) – is used both as a regulatory instrument (forming part of the building regulations) and as a predictive tool (predicting the likely effect of energy efficiency interventions).

Three prominent housing stock models use BREDEM as their core building energy model: the UK Domestic Carbon Model (Boardman, 2007), the model developed by Johnston et al. (2005) and the DECarb model (Natarajan and Levermore 2007). None provide evidence of using anything other than BREDEM's default heating demand temperature and duration. The Building Research Establishment's UK housing stock model, BREHOMES, uses different thermostat settings, initially based on spot measurements obtained during the English House Condition Survey, but 'fine-tuned' during the model validation process (Shorrock and Dunster 1997). There is no evidence that BREHOMES uses heating durations that differ from the BREDEM default values. All of these housing stock models are used in scenario planning to develop effective CO_2 reduction policies.

There is currently little alternative to using BREDEM's default heating demand temperatures and durations, because there have not been the comprehensive studies which could provide the necessary data for the models:

> 'The UK has had a world lead in such computer modelling through the development of Building Research Establishment Domestic Energy Model (BREDEM) and subsequently the Standard Assessment Procedure (SAP) in the domestic sector…However there is a real dearth of hard data with which to validate these models and take account statistically of variations in occupant behaviour…This difficulty in getting real data has produced an over reliance on theoretical predictions'
>
> (Oreszczyn and Lowe 2004).

The lack of data on heating demand temperatures and durations undermines the credibility of recommendations generated in predictive policy making and scenario planning processes.

The UK's new Department of Energy & Climate Change recently claimed that fitting boiler controls and thermostatic valves to radiators had a potential impact of 1.5 $MtCO_2$ per year (DECC 2009 p. 32). Their only reference for this claim was Enviros Consulting (2008, p 66), who say:

> "If the ten million homes that do not currently have modern 'standard' controls (room thermostat, electronic programmer and thermostatic radiator valves) are given them they could save around 1.5MtC."

The figure of ten million homes without modern 'standard' controls they derive from an interview with The Association of Controls Manufacturers. The same interview references, but does not cite, work done in Europe for the Energy Using Products Directive, which apparently found a gas saving of 10-30% if all three elements of a modern standard heating control system are installed. Enviros also note that the Energy Savings Trust estimates that adding 'standard' controls saves about £92 a year in fuel bills. Finally, they cite King's Lynn & West Norfolk Council (2008), which claims that heating controls will save as much as 17% on the average heating bill. However, the council document does not indicate where their figures come from. Clearly, policy-makers are struggling to find the data they need on central heating systems controls.

The UK's Energy Saving Trust (2008) claims that 'fitting the correct heating controls (timer, room thermostat and thermostatic radiator valves) could typically save you around 17% of your heating bill', but they do not cite evidence for this. In 2005, the UK government's Market Transformation Programme claimed that getting householders to use heating controls properly was one of the most promising actions for further reductions in home energy consumption. They claimed that householders 'ignoring or abusing [sic] existing heating controls' wasted about 14TWh of energy a year (Market Transformation Programme 2005 p.

36). However, by 2006, the Market Transformation Programme emphasised instead that policy makers need:

> 'field data collected from a large and representative sample of households…[to] show how [central heating] systems and controls are used in order to provide the necessary inputs for energy modelling of the effect of controls'
>
> (2006, p. 11).

In particular they want to know what temperature people heat dwellings to with and without temperature control, and the duration of heating with and without time control.

DEFRA (2008c) believe their target to reduce energy use from conventional domestic heating and hot water systems by 3.5%[i] by 2020 can be achieved at reasonable cost through three main measures, the foremost of which is that 75% of the homes that have the heating controls specified by the building regulations (timer, thermostat and thermostatic radiator valves) set and use the controls correctly by 2013. However, they recognise that:

> "the relationship between the performance of products measured under test conditions and what is achieved in real life, could lead to reduced effectiveness of the policy programme".
>
> (p. 13)

Policy makers need high quality data on the use of central heating system controls.

There have only been a limited number of studies which purposefully attempt to measure thermostat settings and central heating durations, and most of these are out-dated. One of the most significant studies was in 1978 – spot measurements of internal temperatures in 1,000 UK dwellings (Hunt and Gidman 1982). A 1984 study of 171 houses in the South Eastern Gas Board region included spot temperature measurements and reported thermostat settings and hours of use of central heating (Griffiths 1987). However, there are no reports or publications of the temperature findings. Furthermore that study could not be used to generalise results to England or the UK as it was only of owner-occupied centrally heated houses in just one English region. In 1996 the English House Condition Survey carried out spot temperature measurements on a national sample of English homes (DETR 2000). Spot measurements provide the temperature of the home at a single moment in time and as such act only a guide to thermostat settings. Recent, periodic temperature data from loggers is available only for non-representative samples of dwellings. Martin and Watson (2006) report on a study of 59 homes which received insulation upgrades in which the heating patterns used in the households are calculated from temperature loggers placed on the heating system itself. Oreszczyn et al.'s (2006) study of 1,600 low-income recipients of the Warm Front energy efficiency grant scheme included half-hourly temperature logger data. However, these recent studies do not provide nationally representative data on thermostat settings and heating patterns which could be used for policy development. Furthermore interdisciplinary surveys of home energy use are extremely rare, despite recognition for over twenty years (e.g. Vine 1986, Hitchcock 1993) that advances in this field require the *integration* of building, technical, social and behavioural measures into home energy use surveys.

This paper provides crucial empirical data that building energy models currently lack – that on central heating demand temperatures and durations, derived from the first national survey of energy use in English homes. This survey includes building, technical, socio-demographics and behavioural measures. The results are compared to model assumptions with respect to thermostat settings and heating durations to ascertain whether any assumptions appear to be incorrect, because incorrect assumptions could mislead policy makers.

Method

Survey overview and sampling of participants

In winter early in 2007 in England, the Carbon Reduction in Buildings (CaRB) project commenced this survey of home energy use, having been granted permission to proceed by the University of Reading Ethics Committee. During the computer assisted 45-minute face-to-face interviews, householders answered structured questions on their home's built form, heating technologies, heating practices and socio-demographics. The use of open questions would have allowed participants to provide 'other' reasons for their behaviour not covered in our structured questions. However, when using open questions, researchers cannot infer that a specific 'other' reason does *not* apply to a given participant simply because that participant did not mention that specific 'other' reason. This means that participants' 'other' responses cannot meaningfully be compared, limiting the usefulness of open questions in studies using statistics. During the interviews householders were asked if they would accommodate two temperature sensors for a year – one in the main living room and one in the main bedroom.

Households 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[ii]. 54 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%. Sampling and the face-to-face interviews were conducted on our behalf by the National Centre for Social Research – NatCen. NatCen found the low response rates were due to householders' concerns that interviewers were working either for the government as 'environmental 'spies', or for energy utilities as salespeople. The geographical distribution of the sample is illustrated in Figure 1.

Figure 1 Map of local authorities sampled in the survey

This paper explores the practices of the CaRB subsample using gas or oil fired central heating systems with radiators as their main form of heating. They comprise 84% of the CaRB sample – 358 households. The reason for focusing on this subsample is twofold. Firstly, 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" (DEFRA 2008c p. 2).

Temperature measurements, estimated thermostat settings and hours active

Monitoring central heating system settings directly on the 427 study homes would have been prohibitively expensive, so this study estimated the settings from temperature data recorded in the study homes.

Internal temperatures were measured using Hobo UA-001-08 temperature sensors which are small (about the size of a matchbox), silent and, once installed, unobtrusive. Correct sensor placement would be best achieved by a trained technician placing the sensors and asking householders not to move them. However, it would then be extremely expensive to measure temperatures in large representative sample of English homes. The temperature sensors were placed in the home either by the interviewer and the householder together, or by the householder on their own. One sensor was placed in the main living room and one in the main bedroom. An instruction leaflet was provided for interviewers and householders specifying correct placement of the sensors. While the instructions needed sufficient detail to ensure good placement, it was also important that the instructions were not so detailed as to discourage participants from accommodating the sensors, or encourage participants to ignore the instructions altogether. This trade-off between detail and simplicity of instructions may have reduced the reliability of some temperature measures. Participants were instructed to place the sensors on a shelf or other surface between knee height and head height, to place the sensors away from any heat sources (such as a radiator), to avoid a location which might be in direct sunlight during any part of the day, and to avoid a location near windows or doors. The temperature sensors were self-contained data loggers and the data was only accessed at the end of the study once the sensors had been collected from the homes.

The internal temperature monitoring was carried out over a six month period from 22 July 2007 – 3 February 2008. This time period was chosen as it contained both summer and winter months. Living room and bedroom temperatures were recorded for each 45 minute interval during the monitoring period. This recording interval allowed a long monitoring period whilst still capturing the short term temperature variations. The average temperature over each 45 minute interval was recorded by the temperature sensor at a resolution of 0.1°C. The Hobo temperature sensors had a reported accuracy of ± 0.47°C at 25°C and calibration measurements were taken before they were installed in the survey homes.

The internal temperature measurements for a single example dwelling over a single day in winter clearly show the pattern of use of the central heating system (Figure 2). The external air temperatures in the figure were taken from a nearby Meteorological Office weather station. Between 00:00 – 06:45, the heating system appeared to be not in use and the internal temperature fell as the house lost heat to the cold external air. From 06:45 the heating system switched on and raised the living room internal temperature from 16.5°C to a maximum of 19.7°C at 09:45. Then the heating system appeared to switch off and the living room temperature dropped steadily between 09:45 and 15:45. A second heating period then occurred between 15:45 and 19:30 which raised the living room temperature from 17.1°C to 20.6°C. After 19:30 the heating system appeared to be switched off and the living room temperature fell for the remainder of the evening. This heating pattern, with its early morning and late afternoon heating, is somewhat similar to the weekday default heating regime of 07:00-09:00 hours and 16:00-23:00 hours assumed by the BREDEM model (Anderson et. al. 2002). Both the living room and bedroom temperatures in this dwelling follow a similar pattern, which suggests that they are supplied by the same central heating system. In this dwelling the bedroom is at a lower temperature than the living room but in other dwellings in the study the bedrooms were warmer than the living rooms.

Figure 2 Living room, bedroom and external air temperatures, recorded at 45 minute intervals, for a single house on Monday 10th December 2007

Two variables for each dwelling are calculated using the temperature measurements: the estimated average thermostat setting; and the estimated average daily hours of active central heating use. Active central heating use is defined as times when the heating system is actually supplying heat to the dwelling. Since temperature sensor data for the whole heating season was not available, the calculations were based on the living room internal temperature measurements made over the three month period from 1st November 2007 to 31st January 2008. The assumption was made that, for any dwelling during the winter months, if the central heating system was not active (not supplying heat to the dwelling) then the living room internal temperature would fall. This was based on the fact that during winter the external air temperature is often considerably lower than the internal temperatures (as demonstrated in Figure 2) so the heat losses through the building fabric would be high. This assumption may not always hold true and there may be occasional times of high solar gains, high internal gains (from appliances and occupants) or secondary heating use (such as the use of a gas fire or other room heater) when the living room temperature did increase without the use of the central heating. However in this analysis it is assumed that, for the majority of cases, living room temperatures only increased when the central heating system was in use. Based on this assumption, the times when the central heating system was in active use was identified according to the following condition being satisfied:

$$T_{LR,i+1} - T_{LR,i} > 0 \qquad [1]$$

where $T_{LR,i}$ is the living room temperature at time interval i (°C) and $T_{LR,i}$ is the living room temperature at time interval i+1 (°C)

Once the active heating had been identified using Equation 1, the daily amount of time spent with active use of central heating was calculated for each dwelling. For example, the dwelling in Figure 2 had nine occasions of an increase in the living room temperature during the day and therefore would be estimated to have 6.75 hours (9 x 0.75 hours) of active central heating use. In the majority of cases the central heating system was in active use for a large proportion of the day. However visual inspection of the temperature measurements showed that, in some cases where the occupants were clearly not present in the home and the central heating had not been used for several days, there were occasional rises in the living room temperatures. These increases were likely caused not by central heating but by the other potential sources of heat gains in dwellings. A rules-based approach was employed to exclude such days and any day which was calculated to have an total active use of central heating of less than 2 hours was judged to be a non-heating day when the heating was not in use. In a similar manner any day with a calculated total active use of central heating of greater than 2 hours was classified as a heating day. Only the identified heating days were used to generate results and the non-heating days were excluded in any further analysis. The estimated average daily hours of active central heating use was then calculated, for weekdays, weekends and all days, using the following equation:

$$\overline{L}_{hp} = \sum_{i=0}^{n} L_{hp,i} \qquad [2]$$

where $\overline{L}_{hp}$ is the estimated average daily hours of active central heating use (hours); n is the total number of heating days (based on either weekdays, weekends or all days); and $L_{hp,i}$ is estimated hours of active central heating use of the i^{th} heating day (hours).

Thermostat settings were calculated from the living room temperature measurements by using daily maximum values. For each heating day, the maximum living room temperature was taken to be the thermostat setting used on that day. Non-heating days, during which the heating system was not in use, were excluded from the thermostat calculations. This approach may overestimate the average thermostat setting if the setting was manually adjusted during the day by the householder and if the room temperature increased above the thermostat setting because of other heat sources (such as internal gains, solar gains or a secondary heating system). However in this analysis it was assumed that the occurrence of these effects was minimal. For each house, the average thermostat setting was calculated using the following equation:

$$\overline{T}_{th} = \sum_{i=0}^{n} \hat{T}_{LR,i} \qquad [3]$$

where $\overline{T}_{th}$ is the average thermostat setting (°C); n is the total number of heating days; and $\hat{T}_{LR,i}$ is the maximum living room temperature of the ith heating day (°C).

Since this study was a large sample, it was impossible to produce a fine-grained description, for every home, of the many complex factors that interact and impact upon the use of central heating and temperature in homes. That is the value of small-*N* studies. However, this large representative survey of temperatures in English homes enables generalisation to the population of English homes.

Respondent reported thermostat settings and hours active

Of the 358 CARB07 participants with gas or oil fired central heating with radiators, 172 provided thermostat settings. The remainder do not report having a room thermostat. A few apparent coding errors have been excluded from analysis. Although nearly all thermostats are marked from 10°C to 30°C, four participants report thermostat settings of 0°C and one reports a thermostat setting of 9°C. These are most likely coding errors and they are excluded from any analysis of respondent reported thermostat settings.[iii] Excluding cases less than 10°C, the mean thermostat setting is 19.2°C and three standard deviations above the mean is 29.2°C. There are three potential outliers. These report thermostat settings of 30°C, where the next highest reported thermostat setting is 26°C, so they are clearly disconnected from the remainder of the distribution. To avoid outliers having an undue influence on the statistical tests, any analysis of respondent reported thermostat settings that follows includes only those cases reporting thermostat settings of at least 10°C and less than 30°C.

Participants with central heating were asked when they have their central heating on (in winter) during a typical weekday and a typical weekend. They stipulated the hours at which the central heating came on and went off – with a maximum of three sets of 'on-off' for each day. Their responses were manually checked for errors (e.g. blank heating times) and inconsistencies with answers to other questions, and corrected wherever reasonably possible. The on-off times were then computed into total weekday and total weekend central heating hours. These were then computed into a weighted average central heating hours per day. Of the 358 CARB07 participants with gas or oil fired central heating with radiators, 343 provided sufficient information to calculate a per day weighted average for the week. There are no potential outliers on these variables.

Respondent reported building demographics

Interviewers coded participants' accommodation type, but all other building and technology demographic variables are based on responses by participants, since a physical survey of the 427 homes would have been prohibitively expensive.

The main survey of housing in England, the English House Condition Survey, reports dwelling types in the following classifications: small terraced house, medium/large terraced house, semi-detached house, detached house, bungalow, converted flat, low-rise purpose built flat and high-rise purpose-built flat.[iv] It was not possible to classify homes in this survey into small and medium size terraces as we did not have the relevant information. Moreover, for the analysis it was important to distinguish between bungalows on the basis of how attached they were to other houses. We did not expect bungalows *per se* to have different thermostat settings or heating times to other houses. The research team did expect to find a difference between mid-terrace, semi-detached and detached houses. Consequently the dwellings were classified into the categories used in the 2001 English House Condition Survey data-set: end terrace, mid terrace, semi-detached, detached, purpose-built flat and converted flat. An end terrace house is either first or last in a row of at least three attached houses.

Participants were not asked in which year-*band* their home was built, because we needed to classify their homes into two very different year-bands – those used by both the English House Condition Survey and the SAP and BREDEM family of models. Instead participants were asked ‘In what year was your home built?’ and asked to give their best estimate if they were not certain. The English House Condition Survey reports dwelling age in the following age-bands: pre 1919, 1919 -1944, 1945 - 1964, 1965 - 1980, post 1980. There was a need to distinguish between older and newer homes built post 1980, as the authors expected to find a difference in thermostat settings and hours of central heating between these groups. The English House Condition Survey 2006 data available online distinguishes between ‘1981 to 1990’ and ‘post 1990’ (Communities and Local Government 2008). The 2005 report observes that the energy efficiency rating of the ‘post 1990’ group is substantially higher than that for the ‘1981 to 1990’ group (Communities and Local Government 2007). This age-band grouping is used in our analysis.

The roof insulation variable was developed using a range of sources. The Reduced Data SAP (Standard Assessment Procedure) is the government-approved system for measuring the energy efficiency of existing dwellings. It includes standardised methods for inferring any missing data (Elmhurst Energy Systems et al. 2006). When roof insulation levels are unknown, the RDSAP infers a level based on the year the building was built. These levels correspond to the building regulations in operation in the year of construction. The authors first classified participants’ homes into SAP year-bands. Then a variable was developed which assigned the RDSAP2005 assumed roof insulation value to each participant's home. During the interview, participants with lofts were given an explanation of insulation, asked if their lofts were insulated, and then asked the thickness of the insulation, with response options corresponding to the SAP roof insulation levels. 31 participants did not know their roof insulation thickness and 44 reported less insulation than that assumed by RDSAP for a building built in that year. Since RDSAP roof insulation levels for a given SAP year-band reflect the building regulations in operation during that period, the authors decided that it was most likely that participants' roofs had at least the levels of insulation stipulated in the RDSAP. A new roof insulation variable was then developed which assigns the 'best of' the RDSAP assumed and the respondent reported roof insulation thickness. In doing so, it was first assumed that, where a respondent reports more insulation than the RDSAP would assume, the respondent knows their level of loft insulation better than the RDSAP estimates it. Secondly it was assumed that, where a respondent reports less insulation than the RDSAP would assume, that the respondent lives in a more recent dwelling (with higher levels of insulation), and has poor knowledge of their level of loft insulation.

Participants were given an explanation of draught-proofing and asked what proportion of their windows were draught-proofed. Response options were: all, most, about half, some, and none. Several respondents reported a lower proportion of windows draught-proofed than double-glazed. It is unlikely that windows would be double-glazed and *not* draught-proofed. Consequently, where respondents reported a higher level of double-glazing than draught-proofing, the draught-proofing variable assigned the response given to the double-glazing question.

Participants with central heating were asked which of the following controls they have on their central heating: 1) room thermostat or roomstat, 2) a time clock, timer or programmer, 3) thermostatic radiator valve (TRV), 4) controller or programmable room thermostat.[v] Those participants reporting a room thermostat, roomstat, controller or programmable room thermostat were assigned the value 'roomstat' on the variable 'temperature control'. Those reporting none of these, but reporting a TRV were assigned the value 'TRV only' on the variable 'temperature control'. Participants reporting the presence of time control (a time clock, timer, programmer, controller or programmable room thermostat) were also asked if they normally run the central heating with the timer, or manually. Those without time control of their central heating system (13%) and those with time control, but who normally run their system manually (22%) were assigned the value 'manual operation' on the variable 'timer or manual operation'.

Results

Overview

Overview statistics for dwelling type and age, and respondent reported presence of central heating system controls are provided in Table 1.

Table 1 Building demographics

Overview statistics for the dependent variables – estimated and reported thermostat settings and estimated active and reported central heating hours per day – are outlined in Table 2, together with the central heating hours for weekdays and weekends.

Table 2 Central heating thermostat settings and durations

There is enormous variation in both estimated and reported thermostat settings, as indicated in the standard deviations in Table 2 and in the wide distributions in Figure 3 and Table 3. Although both the mean and the median estimated thermostat setting are 21°C, the standard deviation is 2.5°C (Table 2). Furthermore, while 30% of the sample has estimated thermostat settings of less than 20°C; 40% has estimated thermostat settings of 22°C or higher (Table 3).

Figure 3 Thermostat settings – estimated and reported

Table 3 Thermostat settings estimated and reported

There is much less variability in the estimated number of hours per day that the central heating is active (mean and median 8.4, S.D 1.5 – see Table 2 and Figure 4). In contrast there is a great deal of variability in the reported number of hours that the central heating is on (mean 9.5, median 8.0, S.D. 5.4 – see Table 2 and Figure 4).

Figure 4 Central heating hours – reported on-duty and estimated active

Thermostat settings

Thermostat settings estimated from the temperature sensors and reported by respondents are explored by building demographics in Table 4.

Table 4 Central heating thermostat settings estimated and reported – by building demographics

For estimated thermostat settings, there was a statistically significant difference amongst levels of window double-glazing and draught-proofing ($F = 6.13$, $p = 0.003$ and $F = 5.37$, $p = 0.005$ respectively for the one-way ANOVAs for unrelated samples). The Scheffé *post-hoc* multiple comparisons indicated that the most statistically significant mean difference in estimated thermostat settings (1.7°C in both cases) was that between all and some (double-glazed $p = 0.007$, 95% C.I. = 0.4, 2.9; draught-proofed $p = 0.007$, 95% C.I. = 0.4, 3.1). In other words, homes with all windows double-glazed or draught-proofed had significantly higher estimated thermostat settings than homes with some windows double-glazed or draught-proofed. No statistically significant difference exists between estimated thermostat settings in different geographical regions.

In the *sample*, homes without thermostatic control of the central heating system had mean estimated thermostat settings 0.6°C below those with thermostatic control (room thermostat or thermostatic radiator valve). However, the one-way ANOVAs for unrelated samples indicated that this difference was *not* statistically significant ($F = 1.14$, $p = 0.32$).

No correlation was found between estimated and reported central heating thermostat settings – as indicated in Figure 5. There was a slight increase in the correlation when only those homes with room thermostats in the main living room were selected – which was also the location of the temperature sensors ($r = 0.23$), but the correlation was not statistically significant ($p = 0.33$), although the lack of statistical significance *may* be somewhat due to the small sample size (*n* = 20). There was no increase in correlation when we selected only those cases using solely central heating in the main living room, or when we selected more energy efficient homes (purpose-built flats, or those built after 1990, or those with the most roof insulation, or those with all windows double-glazed).

Figure 5 Thermostat settings – reported vs. estimated

Hours of use per day

Central heating active hours per day, as estimated from the temperature sensors, and central heating hours on per day, as reported by respondents, are both explored by building demographics in Table 5.

Table 5 Central heating estimated active hours per day and reported hours on per day – by building demographics

For both central heating estimated active hours and respondent reported central heating on hours, there was a statistically significant difference between accommodation types ($F = 3.69$, $p = 0.007$; $F = 2.58$, $p = 0.04$ respectively for the one-way ANOVAs for unrelated samples). The Scheffé *post-hoc* multiple comparisons indicated that the most statistically significant mean difference in both estimated active hours and reported hours is between detached and mid-terrace houses – with detached houses heated for longer. For estimated active hours the mean difference is 1.1 hours (p =0.03, 95% C.I. = 0.1, 2.0). For reported hours the mean difference is 2.6 hours ($p = 0.09$; 95% C.I. = 0.2, 5.4).

For estimated active central heating hours, there was a difference amongst levels of window draught-proofing, but this difference was not statistically significant at the $p = 0.05$ level ($F = 2.3$, $p = 0.1$ for the one-way ANOVAs for unrelated samples). Scheffé *post-hoc* multiple comparisons indicated that the most statistically significant mean difference in estimated active hours per day (1.1 hours) is between those with all and no windows draught-proofed (p=0.11; 95% C.I. = -0.2, 2.4). Note that only 9 cases have no draught-proofing and that if there were more cases in this group, the statistical significance of this test may have improved.

Households using timers have mean estimated active central heating hours 0.4 hours longer than those using manual operation. However, the *t*-test for the equality of two means indicates this difference is not statistically significant at the $p = 0.05$ level ($t = 1.73$; p =0.09; 95% C.I. = -0.1, 0.9).

Although Government Office Region had a statistically significant effect on reported central heating hours according to the one-way ANOVA for unrelated samples (F =1.9, $p = 0.06$), the Scheffé post-hoc multiple comparisons indicated that the most statistically significant mean difference in reported hours per day (between the South East and London) was not statistically significant (p=0.60; 95% C.I. = -1.6, 7.2). No statistically significant difference was found between estimated active central heating hours in different geographical regions.

Discussion

Difficulties measuring building demographics

This study relied on respondents knowing and accurately reporting on their homes' building fabric and heating technology. A future study could usefully compare respondents' reports with those of building surveyors.

Several of the measured building demographic variables required careful development to allow harmonization with two or more measurement methods. For instance, the authors needed to classify homes into two very different year-bands – that used by the English House Condition Survey and that used by the BREDEM family of models. Consequently, instead of asking our participants in which year-*band* their home was built, they were asked in which year their home was built. In other cases, the authors had to choose one measurement method and forego the policy usefulness of being able to report our home energy survey findings with reference to both the EHCS and BREDEM.

The EHCS and its successor the English Housing Survey, is the main source of government information on housing and the energy efficiency of housing in England. The BREDEM is a family of models that are used by government in two main ways. Firstly, in the form of SAP for the energy rating of dwellings, they are used as a regulatory instrument (DEFRA 2008c). Secondly, in the form of BREHOMES, the UK housing stock model, they inform much UK government policy through the Domestic Energy Fact File (DEFF). Most core 'building demographic' variables are measured differently by the EHCS and BREDEM, despite the need for government policy to draw on them both simultaneously.

Over twenty years ago in the U.S., Vine (1986) called for home energy use surveys to use standardised measurement instruments. The UK Office of National Statistics (2003) leads a cross-government programme of work harmonising key socio-demographic measurement instruments and output variables. This work enables robust comparisons and integration of information across surveys. Serious consideration should be given to developing harmonised building demographic variables. This could enable information from the new English Housing Survey to be integrated with the BREDEM family of models, thus providing a more robust framework for energy policy making.

Variability in thermostat settings and hours active

Enormous variation was found in both estimated and reported thermostat settings – standard deviations were 2.5°C and 3.0°C respectively. This echoes the findings of many other studies. Hunt and Gidman (1982) found a standard deviation of 3.0°C in living room temperatures in their survey of 1000 homes (mean 18.3°C). [Due to differences in temperature measurement method, their mean living room temperature is not comparable to our mean estimated thermostat setting.] Rathouse and Young (2004) found wide variation in reported winter warmth preferences in their focus groups. Vine (1986) found great variability in reported summer and winter thermostat settings and Hackett and McBride (2001) found variation with respect to household cooling temperature preferences. Woods (2006) found wide variations in thermostat set points in their study of heating and cooling thermostat settings in California. Humphreys (1995) and the reviews by Shove et. al (2008), Nicol and Roaf (2005) and Brager and de Dear (1998) note the huge variation in temperatures that individuals can find thermally comfortable, even within the same society. For Chappells and Shove (2005) this variability is a policy opportunity, as it suggests a wide range of possibilities for providing thermal comfort, beyond just internal building temperatures. A policy option they suggest is encouraging the development of new insulative clothing technologies.

Although both the mean and median estimated thermostat setting were 21°C, 30% of our sample had settings of less than 20°C and 40% had settings of 22°C or higher. In his testimony to the U.S. House of Representatives hearing on the contribution of the social sciences to the energy challenge, and in his academic publications, Cialdini (2007a, 2007b, 2007c) points out that people are heavily influenced by what other people actually do. If good behaviour is the norm and this is publicised, people are motivated toward the good behaviour in order to be 'part of the crowd'. Social marketing programs could use the wide variation in thermostat settings to encourage those with high thermostat settings (say 22°C or higher) to set them at a more 'normal' level (21°C). In such a program it would also be very important to applaud existing good behaviour, or those already behaving better than average will also tend to behave more 'normally' (Schultz, Nolan, et. al. 2007). Social psychology and social marketing authors have a wealth of other advice relevant to any such program – see, for instance, Cialdini (2003, 2007a, 2007b, 2007c), Goldstein & Cialdini (2007), Mckenzie-Mohr (1994, 2000), McKenzie-Mohr & Smith (1999), National Research Council Committee on the Human Dimensions of Global Change (2002), Shipworth (2000), Steg (2008) and Stern (1992).

A great deal of variation was found in the reported number of hours per day that the central heating is on – the standard deviation was 5.4 hours. Likewise the 1996 English House Condition Survey found a large variation (standard deviation of 6.4 hours per day) in the duration for which regularly heated living rooms were reportedly heated (DETR 2000). In contrast, the current study found relatively little variation in the estimated number of hours per day that the central heating is active – the standard deviation was just 1.5 hours per day. However, the range varied from 4.7 to 12.7 hours per day. In comparison, Martin and Watson (2006), found daily heating periods varied from 2 to 20 hours. Theirs was a study of 59 homes in central England which had received insulation upgrades. They calculated heating patterns from temperature loggers placed *on* the heating system itself, their data was collected between October 2004 and May 2005, although the period of data collection varied. On the other hand, our estimated central heating hours per day were averaged over a three-month period.

Building energy efficiency – its influence on thermostat settings and hours active

Detached houses are heated for significantly longer than mid-terrace houses, according to this study's findings. There is a statistically significant difference in the mean number of hours – both for the estimated active hours (mean difference = 1.1 hours, p =0.03, 95% C.I. = 0.1, 2.0) and for respondent reported hours (mean difference = 2.6 hours, p = 0.09; 95% C.I. = 0.2, 5.4). On the other hand, Hunt and Gidman (1982) found no statistically significant differences between the internal temperatures of different dwelling types (other than converted flats, which are not considered in our study). The current findings suggest that detached houses, with more exposed walls, are being heated for longer, in order to provide the same internal temperatures as found in mid-terrace houses, and should be particularly targeted for energy efficiency improvements.

The energy efficiency rating scheme for homes – the Standard Assessment Procedure, or SAP – assumes that living room temperatures in the most energy efficient homes are on average 1.1°C higher than those in the least energy efficient dwellings (BRE 2008). The 1996 English House Condition Survey provides evidence for this (DETR 2000), as does the study of low-income recipients of the Warm Front home energy efficiency improvements grant scheme (Oreszczyn et al. 2006).

Statistically significant higher estimated thermostat settings (average daily maximum living room temperatures) were found in homes with all windows double-glazed or draught-proofed, when compared to homes with some double-glazing or draught-proofing. For both double-glazing and draught-proofing, the mean difference was 1.7°C (double-glazed p = 0.007, 95% C.I. = 0.4, 2.9; draught-proofed p = 0.007, 95% C.I. = 0.4, 3.1). This could simply be further evidence that energy efficient homes are able to be maintained at a warmer temperature than less efficient homes. However, it could also be evidence of some 'takeback' – people in more energy efficient homes demanding a higher level of energy service than people in less efficient homes.

Homes with all windows draught-proofed have the central heating active for 1.1 hours longer per day than homes with no windows draught-proofed – although this difference is not statistically significant (p=0.11; 95% C.I. = -0.2, 2.4). Only 9 of our cases have no draught-proofing; if there were more cases it is possible that the mean difference would be more statistically significant. If it were simply the case that energy efficient homes were warmer because they were more insulated, we would expect the central heating in 'all windows draught-proofed' homes to be active for *fewer* hours than the 'no windows draught-proofed' group. However, this is not the case, suggesting that higher standards of comfort may be being demanded in more energy efficient homes.

Central heating controls – their influence on thermostat settings and hours active

As indicated in Table 1, the survey respondents report a much lower presence of central heating system controls in 2007 than surveyors found in the 2001 English House Condition Survey (BRE 2005b). The difference is particularly noticeable for room thermostats – 56% versus 72% for the subsamples with gas or oil fired central heating systems with radiators ($X^2 = 50$, $df = 1$, $p < 0.0001$), although there is also a significant and large difference in reported presence of timers – 87% versus 98% ($X^2 = 186$, $df = 1$, $p < 0.0001$).

The current findings suggest that many respondents do not realise they have room thermostats. Certainly Karjalainen (2007) found that Finnish office workers seemed to not recognise a room thermostat and Rathouse and Young (2004) found that many English householders participating in their focus groups did not understand the difference between room and boiler thermostats. The Energy Information Administration of the US Department of Energy found that the proportion of households reporting the presence of a programmable thermostat seemed to vary markedly depending on where in the interview the question was asked (EIA 1999). In 1997 nearly three times as many households reported having a programmable thermostat than did in 1993. However, in 1993 the question was placed in the section on conservation measures and in 1997 the question was placed in the space-heating section. In our study, the questions on central heating system controls were placed directly after a set of questions about the types of heating present in the home.

UK Government regulations, policies and programs assume that adding controls to a central heating system will reduce the energy use of that heating system. The building regulations – through SAP 2005 – assume that adding thermostatic control to a boiler-radiator central heating system will reduce living room temperatures by 0.6°C (BRE 2008). The Energy Saving Trust (2008) claims that adding heating controls will reduce heating bills by about 17%. DEFRA (2008c) expects that educating householders to use their central heating controls 'correctly' will help significantly towards plans to reduce energy use from domestic heating and hot water systems by 3.5% by 2020.

In contrast to these expectations, the sample homes *without* thermostatic control of the central heating system had mean estimated thermostat settings (average maximum temperatures) 0.6°C *below* those with thermostatic control However, this difference was *not* statistically significant, so this finding is that there no statistically significant differences exist in average maximum living room temperatures between homes with and without thermostatic control on their central heating systems. Furthermore, it was found that central heating systems operated by timer are active 0.4 hours per day *longer* than those operated manually, although the difference is not quite statistically significant (p =0.09; 95% C.I. = -0.1, 0.9). These findings should not come as a surprise. A 1986 study of room air-conditioner use in Californian apartments found that the estimated 'cooling' electricity consumption of air conditioners driven manually was 21% less than that of those driven automatically (Lutzenhiser 1992).

Conner & Lucas (1990) also found that clock thermostats did not significantly increase the incidence of thermostats being setback, in their study of over 400 single-family, electrically heated homes in the northwest US. However, they did find that homes with clock thermostats were 0.4°C cooler than those with manual thermostats. In their study of nearly 300 Wisconsin households, Nevius & Pigg (2000) found homes with programmable thermostats used about the same amount of energy for space-heating as those with manual thermostats did. One of the reasons was that many of the households using manual thermostats set back their temperatures manually. Parker, in Sachs (2004) found that homes with programmable cooling thermostats had a lower seasonal average temperature than homes with manual thermostats, and used more cooling energy. This suggests that occupants with programmable thermostats might be setting the cooling to turn on before they arrive home, whereas occupants with manual thermostats can only turn the cooling on once they are home.

In stark contrast with all of these studies, RLW Analytics (2007) found that installation of an ENERGY STAR rated programmable thermostat in U.S. homes resulted in a 6.2% reduction in total household annual natural gas consumption (90% C.I. = 4.7, 7.7). Their experimental study compared survey and billing data from 683 'test' households with that on 1,264 'control' households. They argue that the reason for the contrast between their findings and those of earlier studies, is that their study is of newer programmable thermostats, which are more user-friendly, easier to use and thus more likely to change householder's behaviour.

In conclusion, central heating system controls seem to live incognito in many homes. Furthermore, when controls *are* used, there may be no reduction in average maximum temperatures and possibly even an *increase* in operational durations – although the findings are somewhat contradictory. These findings suggest that central heating system controls may require radical re-evaluation if their future use is to result in energy savings. Karjalainen (2007) used a user-centred approach to develop new office thermostat user interfaces that were more understandable and acceptable to users. Shove, Watson *et. al.* (2007) recommend moving beyond a user-centred approach to a "practice oriented product design" approach that also pays attention to the relations *between* interconnected practices – i.e. to *systems* of practices.

Estimated and reported thermostat settings

No correlation was found between estimated and reported central heating thermostat settings, even when selecting the more energy efficient dwellings. This contrasts with Vine and Barnes (1989), who found households in highly energy efficient houses had small differences between measured temperatures and reported thermostat settings. The literature provides three main explanations for the lack of correlation between the two.

Firstly, in a study of home energy use, social desirability response bias may prompt householders to report lower thermostat settings than they actually maintain (de Vaus 2002b). If this were the primary explanation, however, one would still expect to see a correlation between reported and estimated thermostat settings. In this situation the regression equation for estimated thermostat settings would be expected to contain a positive constant coefficient and/or a slope coefficient greater than one – to convert low reported thermostat settings into higher estimated thermostat settings.

Secondly, householders seem to not understand thermostats in the way that engineers do. In Hackett and McBride's (2001) interviews with Californian householders, they found that people hesitate to describe thermal comfort in numerical terms. As already mentioned, Karjalainen's (2007) qualitative study found that Finnish office workers seemed to not recognise a room thermostat when it was shown to them, or understand its purpose. In particular, workers did not understand the symbols on the thermostat and were dissatisfied with the feedback they received from the heating system. In the current survey, around 25% less respondents reported having room thermostats than would be expected from government housing surveys. This suggests that many of our respondents may not realise they have room thermostats. Indeed, as mentioned above, Rathouse and Young (2004) found that many

English householders did not understand the difference between room and boiler thermostats and did not know how to use these controls.

Finally, householders may adjust their thermostats fairly frequently. Certainly, Woods (2006) found in their Californian study that people changed both heating and cooling thermostat set points very frequently. We asked participants for a single thermostat setting. However, this may not adequately represent their use of their thermostats and indeed many authors point out that individuals tend to adjust thermostats according to conditions, occupancy and their own varying preferences (Vine 1986, Hackett and McBride 2001, Shove et. al. 2008). This tendency to adjust thermostats is exacerbated due to members of the same household often preferring different temperatures (Rathouse and Young 2004). Moreover Kempton (1984) found that a significant minority of households turn the thermostat up high in the (erroneous) belief that the home will heat up faster, and then turn it down when the home is warm enough. The estimated thermostat settings are, in effect, the estimated average daily *maximum* temperature, whereas reported thermostat settings may be the household's *typical* daily thermostat settings.

Conclusion

UK Government regulations (e.g. SAP), policies (e.g. from DEFRA) and programs (e.g. of the Energy Saving Trust) assume that adding controls to central heating systems will reduce their energy use. However, findings from this study suggest that households that use central heating system controls have no lower demand temperatures or durations than households that do not use controls. However, the experiment conducted by RLW Analytics (2007) suggests that adding *modern* central heating system controls *does* reduce energy consumption.

The efficiency of data collection can and should be substantially improved. UK government home energy conservation policies rely on the BREDEM family of models for regulation (the SAP) and policy direction (BREHOMES). However, the most important source of data on English homes is the English Housing Survey and data from this survey is of limited use for informing SAP regulations and BREHOMES-informed policies – for two reasons. Firstly, many key building demographic variables are measured differently in the English Housing Survey and the BREDEM family of models. Secondly, the English Housing Survey does not collect data on energy consumption. This results in both a duplication of data-gathering effort and a dearth of data from representative samples of the population. Evidence-informed energy policies require far more coordinated data collection and management.

Policies and programs could fruitfully target specific groups of homes and households. Firstly, detached houses are heated for significantly longer, so energy efficiency retrofit programs should target them early on. Secondly, social marketing programs could use this study's evidence on average thermostat settings as a basis for a 'social norm' social marketing program aimed at reducing temperatures in 'overheated' homes.

Many people may not recognise or understand their central heating system controls. Programs could be developed to help them understand and operate their existing heating controls more efficiently. Furthermore, new controls should be developed that appeal to householders, are intuitively useable by them and make it easy for householders to reduce their heating energy use.[vi] .

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Table 1 ***Building demographics***

Table 1 Building demographics

	CaRB 2007 N	CaRB 2007 %	EHCS %
Accommodation Type[a]			
End Terrace	35	9.8	11.3
Mid Terrace	53	14.8	21.4
Semi Detached	110	30.7	29.7
Detached	109	30.4	13.9
Purpose Built Flat	32	8.9	20.4
Other	19	5.3	3.3
X^2	106.1		
df	5		
p	<0.0001		
Accommodation Year[b]			
Pre 1919	51	14.3	21.7
1919 to 1944	70	19.7	18.2
1945 to 1964	83	23.3	19.8
1965 to 1980	76	21.3	22.0
1981 to 1990	41	11.5	8.3
Post 1990	35	9.8	9.9
X^2	16.1		
df	5		
p	0.007		
Reported Presence of Central Heating System Controls[c]			
Room Thermostat	199	55.7	72.4
None	158	44.3	27.6
X^2	50.0		
df	1		
p	<0.0001		

	CaRB 2007 N	CaRB 2007 %	EHCS %
Room Thermostat or Thermostatic Radiator Valves	276	77.3	87.8
None	81	22.7	12.2
X^2	36.7		
df	1		
p	<0.0001		
Timer	309	86.6	97.6
None	48	13.4	2.4
X^2	185.9		
df	1		
p	<0.0001		

[a] Dwelling types – CaRB data is compared to raw data from the 2001 English House Condition Survey, as explained in the methods section.

[b] Dwelling age – CaRB data is compared to the 2006 English House Condition Survey data (Communities and Local Government 2008).

[c] Reported presence of central heating system controls – CaRB data is compared to English House Condition Survey 2001 – weighted averages for gas or oil fired boiler central heating systems with radiators (derived from Tables 1.9 and 1.14 in BRE 2005b).

Table 2 ***Central heating thermostat settings and durations***

Table 2 Central heating thermostat settings and durations

Variable	Mean	S.D.	Median	N	95% C.I.
Thermostat Setting °C – Estimated from Loggers	21.1	2.5	21.3	195	20.8, 21.5
Thermostat Setting °C – Respondent Reported	19.0	3.0	20.0	164	18.6, 19.5
CH Hours per day estimated active on weekdays	8.2	1.5	8.2	196	8.0, 8.4
CH Hours per day estimated active on weekends	8.4	1.5	8.4	196	8.2, 8.6
CH Hours per day estimated active average over week	8.3	1.5	8.3	196	8.1, 8.5
CH Hours per day reported used on weekdays	9.4	5.4	8.0	344	8.9, 10.0
CH Hours per day reported used on weekends	9.8	5.4	8.5	344	9.2, 10.4
CH hours per day reported used average over week	9.5	5.4	8.0	343	9.0, 10.1

Table 3 ***Thermostat settings estimated and reported***

Table 3 Thermostat settings estimated and reported

Thermostat Setting °C Estimated			Thermostat Setting °C Reported		
Values	%	Cumulative %	Values	%	Cumulative %
13.1-17.9	8.7	8.7	10-17	26.8	26.8
18.0-18.9	7.7	16.4	18	12.8	39.6
19.0-19.9	13.9	30.3	19	6.1	45.7
20.0-20.9	17.4	47.7	20	29.9	75.6
21.0-21.9	12.3	60.0	21	7.3	82.9
22.0-22.9	16.9	76.9	22	8.5	91.5
23.0-23.9	11.8	88.7	23	1.2	92.7
24.0-27.3	11.3	100	24-26	7.3	100

Table 4 ***Central heating thermostat settings estimated and reported – by building demographics***

Table 4 Central heating thermostat settings estimated and reported – by building demographics

	Thermostat Setting °C Estimated				**Thermostat Setting °C Reported [a]**			
	Mean	95% CI for the Mean	SD	N	Mean	95% CI for the Mean	SD	N
Accommodation Type [b]								
End Terrace	21.2	19.6, 22.7	3.2	19	19.2	17.5, 20.8	2.7	13
Mid Terrace	21.0	20.1, 21.9	2.3	29	19.3	18.1, 20.4	2.6	22
Semi Detached	21.6	21.0, 22.3	2.3	55	18.8	17.9, 19.7	3.3	49
Detached	21.0	20.4, 21.6	2.5	70	19.3	18.6, 20.1	2.9	59
Purpose Built Flat	21.6	20.3, 23.0	2.4	14	18.5	15.9, 21.1	4.3	13
F	0.71				0.33			
p	0.59				0.86			
Accommodation Year Built								
Pre 1919	**20.1**	19.1, 21.0	2.3	25	18.9	17.7, 20.2	2.4	17
1919 to 1944	21.3	20.4, 22.2	2.8	36	18.8	17.4, 20.3	3.4	25
1945 to 1964	**21.9**	21.3, 22.5	1.9	45	19.8	18.7, 21.0	3.2	33
1965 to 1980	21.0	20.3, 21.8	2.8	51	19.1	18.0, 20.2	3.3	38
1981 to 1990	20.8	19.6, 22.0	2.8	23	18.6	17.6, 19.5	2.2	24
Post 1990	20.8	19.5, 22.1	2.3	14	18.5	17.3, 19.8	3.1	26
F	1.94				0.71			
p	**0.09**				0.62			
Roof Insulation								
> 100mm; U < 0.40	21.2	20.5, 21.8	2.3	55	19.1	18.3, 19.8	2.9	54

	Thermostat Setting °C Estimated				Thermostat Setting °C Reported [a]			
	Mean	95% CI for the Mean	SD	N	Mean	95% CI for the Mean	SD	N
= 100mm; U = 0.40	21.1	20.4, 21.8	2.5	58	19.2	18.6, 19.8	2.0	44
< 100mm; U > 0.40	21.5	20.8, 22.2	2.5	54	19.0	17.9, 20.2	3.9	46
F	0.47				0.3			
p	0.62				0.97			
Windows double-glazed								
All	**21.5**	21.1, 21.8	2.4	150	19.1	18.6, 19.6	3.0	133
Some	**19.8**	18.8, 20.8	2.5	27	18.7	16.9, 20.5	3.7	19
None	20.3	18.7, 21.9	3.2	18	19.3	17.6, 20.9	2.6	12
F	6.13				0.16			
p	**0.003**				0.85			
Windows draught-proofed								
All	**21.4**	21.0, 21.7	2.4	162	19.0	18.5, 19.5	3.0	140
Some	**19.6**	18.4, 20.9	3.0	24	18.6	16.9, 20.4	3.3	17
None	20.5	18.1, 22.9	3.1	9	19.9	17.3, 22.4	2.8	7
F	5.37				0.40			
p	**0.005**				0.67			
Temperature Control								
Roomstat	21.2	20.8, 21.7	2.4	117				
TRV [c] only	21.3	20.5, 22.2	2.6	39				
None mentioned	20.6	19.6, 21.5	2.9	39				
F	1.14							
p	0.32							
Roomstat Location [d]								
Main Living Room	21.3	20.4, 22.1	2.0	22	18.7	17.5,19.8	3.4	37

	Thermostat Setting °C Estimated				Thermostat Setting °C Reported [a]			
	Mean	95% CI for the Mean	SD	N	Mean	95% CI for the Mean	SD	N
Hall	21.1	20.4, 21.7	2.6	63	19.1	18.6, 19.7	3.0	102
t	0.32				-0.82			
p	0.75				0.41			

	Thermostat Setting °C Estimated				Thermostat Setting °C Reported [a]			
	Mean	95% CI for the Mean	SD	N	Mean	95% CI for the Mean	SD	N
Government Office Region								
North East	20.3	19.4, 21.2	1.5	14	19.3	17.2, 21.4	3.3	12
Yorkshire & the Humber	20.9	19.8, 22.1	2.5	20	17.1	15.7, 18.6	2.8	16
North West	21.2	19.9, 22.5	3.0	24	18.7	17.3, 20.0	2.4	15
East Midlands	21.5	19.8, 23.2	2.7	12	18.2	16.4, 20.0	2.5	10
West Midlands	21.2	20.5, 22.0	1.9	25	19.1	17.1, 21.1	4.7	23
South West	21.0	20.2, 21.8	2.3	33	20.2	19.0, 21.4	2.2	15
East of England	21.5	20.2, 22.8	2.9	21	19.3	18.1, 20.5	2.4	17
South East	21.0	19.9, 22.1	3.1	32	18.8	18.1, 19.6	2.2	36
London	21.7	20.1, 23.2	2.7	14	20.3	18.8, 21.7	3.1	20
F	0.37				1.73			
p	0.94				0.10			

Note: F-statistics are for one-way ANOVAs for unrelated samples. Where the F-statistic is statistically significant to the level of $p < 0.1$, Scheffé post-hoc multiple comparisons were computed and the most statistically significant mean difference is highlighted. T-tests were for the equality of two means and equal variances were assumed.

[a] Includes only thermostat settings above 9°C and below 30°C.

[b] Converted flats and other accommodation excluded from this analysis due to insufficient numbers.

[c] A TRV is a thermostatic radiator valve.

[d] Roomstats located in rooms other than the main living room or hall are excluded from this analysis due to insufficient numbers.

Table 5 ***Central heating estimated active hours per day and reported hours on per day – by building demographics***

Table 5 Central heating estimated active hours per day and reported hours on per day – by building demographics

	Central Heating Active				**Central Heating On**			
	***Estimated* Hours Per Day**				***Reported* Hours Per Day**			
	Mean	95% CI for the Mean	SD	N	Mean	95% CI for the Mean	SD	N
Accommodation Type[a]								
End Terrace	8.3	7.5, 9.1	1.7	20	8.8	6.6, 11.0	6.1	33
Mid Terrace	**7.7**	7.1, 8.2	1.4	29	**8.3**	6.7, 9.8	5.4	52
Semi Detached	8.3	8.0, 8.7	1.4	55	9.8	8.8, 10.8	5.2	103
Detached	**8.7**	8.4, 9.1	1.4	70	**10.9**	9.8, 11.9	5.3	106
Purpose Built Flat	7.6	6.8, 8.5	1.5	14	8.8	6.6, 11.0	6.0	32
F	3.69				2.58			
p	**0.007**				**0.04**			
Accommodation Year Built								
Pre 1919	8.1	7.6, 8.6	1.3	25	8.8	7.5, 10.2	4.8	50
1919 to 1944	8.1	7.6, 8.6	1.4	36	9.0	7.8, 10.2	4.8	64
1945 to 1964	8.3	7.8, 8.8	1.6	46	9.3	8.2, 10.5	5.1	80
1965 to 1980	8.5	8.0, 8.9	1.6	51	10.3	9.0, 11.7	5.8	72
1981 to 1990	8.1	7.4, 8.9	1.7	23	8.8	7.3, 10.4	5.0	41
Post 1990	8.3	7.6, 9.0	1.3	14	11.2	8.7, 13.8	7.4	34
F	0.39				1.41			
p	0.86				0.22			
Roof Insulation								
> 100mm; U < 0.40	8.2	7.9, 8.6	1.4	55	10.0	8.8, 11.2	6.0	98
= 100mm; U = 0.40	8.6	8.2, 8.9	1.5	58	9.4	8.4, 10.5	4.8	85

	Central Heating Active				Central Heating On			
	Estimated Hours Per Day				*Reported* Hours Per Day			
	Mean	95% CI for the Mean	SD	N	Mean	95% CI for the Mean	SD	N
< 100mm; U > 0.40	8.3	7.9, 8.7	1.5	55	9.3	8.3, 10.3	5.1	105
F	0.70				0.49			
p	0.50				0.61			
Windows double-glazed								
All	8.4	8.1, 8.6	1.5	151	9.7	9.0, 10.4	5.7	261
Some	8.2	7.6, 8.8	1.5	27	9.2	7.8, 10.5	4.4	44
None	7.7	6.8, 8.6	1.8	18	9.0	7.4, 10.7	5.0	38
F	1.58				0.36			
p	0.21				0.70			
Windows draught-proofed								
All	**8.3**	8.1, 8.6	1.5	163	9.7	9.0, 10.3	5.7	274
Some	8.2	7.5, 8.8	1.5	24	8.8	7.4, 10.1	4.3	43
None	**7.3**	5.9, 8.6	1.8	9	9.8	7.6, 11.9	5.2	25
F	2.30				0.53			
p	**0.10**				0.59			
Time Control								
Timer / Controller	8.3	8.1, 8.5	1.5	172	9.4	8.8, 10.0	5.1	297
None Mentioned	8.1	7.4, 8.7	1.6	24	10.7	8.6, 12.9	7.1	45
t	0.74				-1.23			
p	0.46				0.23			
Timer or Manual Operation								
Timer / Controller	8.4	8.2, 8.6	1.4	134	9.2	8.7, 9.8	4.5	226
Manual Operation	8.0	7.6, 8.4	1.7	62	10.2	8.9, 11.4	6.8	116
t	1.73				-1.31			

	Central Heating Active *Estimated* Hours Per Day				Central Heating On *Reported* Hours Per Day			
	Mean	95% CI for the Mean	SD	N	Mean	95% CI for the Mean	SD	N
p	**0.09**				0.19			
Government Office Region								
North East	7.7	6.8, 8.6	1.6	14	8.4	6.1, 10.7	4.1	15
Yorkshire & the Humber	8.1	7.6, 8.7	1.2	20	9.2	7.4, 11.0	5.3	36
North West	8.6	8.0, 9.1	1.3	24	9.5	7.8, 11.1	5.8	50
East Midlands	8.2	6.9, 9.4	2.0	12	9.1	6.8, 11.4	5.7	26
West Midlands	8.7	8.2, 9.1	1.2	26	10.7	9.0, 12.4	5.3	40
South West	8.3	7.7, 8.9	1.7	33	8.2	7.0, 9.5	4.3	48
East of England	8.7	8.0, 9.4	1.5	21	11.2	9.1, 13.3	5.6	30
South East	8.2	7.6, 8.8	1.6	32	**10.8**	9.1, 12.4	6.2	58
London	7.5	6.8, 8.3	1.4	14	**8.0**	6.5, 9.4	4.6	40
F	1.30				1.90			
P	0.25				**0.06**			

Note: *F*-statistics are for one-way ANOVAs for unrelated samples. Where the *F*-statistic is statistically significant to the level of $p = 0.1$, Scheffé post-hoc multiple comparisons were computed and the most statistically significant mean difference is highlighted. *T*-tests are for the equality of two means and equal variances were assumed for estimated active hours per day, but not assumed for reported hours per day.

[a] Converted flats and other accommodation excluded from this analysis due to insufficient numbers.

Figure 1 ***Map of local authorities sampled in the survey***

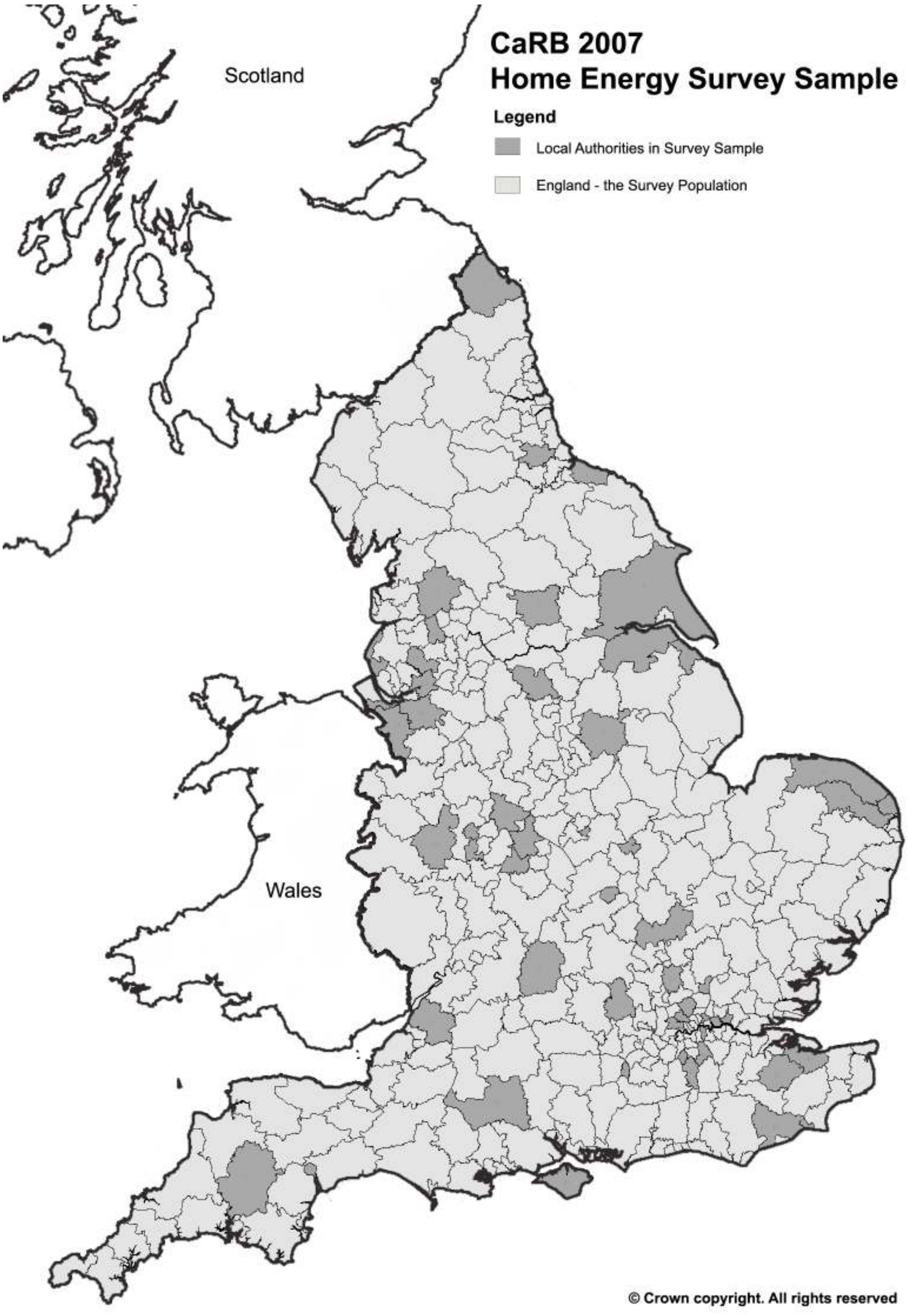

Figure 1 Map of local authorities sampled in the survey [TIFF version also provided]

Figure 2 ***Living room, bedroom and external air temperatures, recorded at 45 minute intervals, for a single house on Monday 10th December 2007***

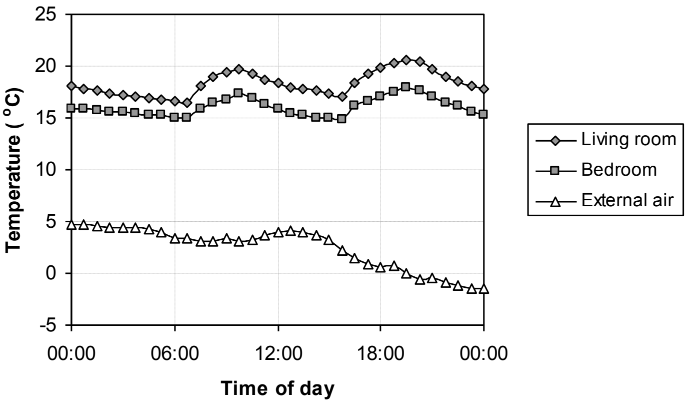

Figure 2 Living room, bedroom and external air temperatures, recorded at 45 minute intervals, for a single house on Monday 10th December 2007

Figure 3 ***Thermostat settings – estimated and reported***

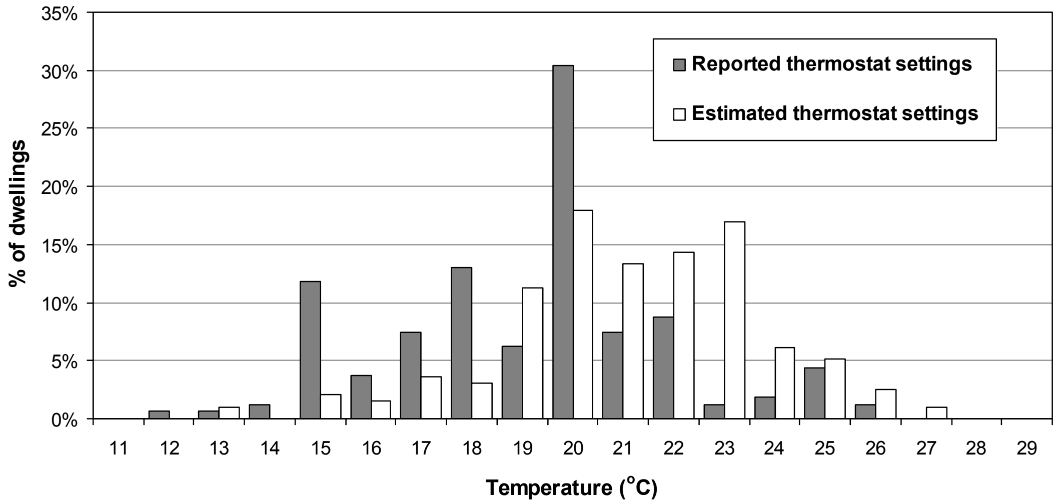

Figure 3 Thermostat settings – estimated and reported

Figure 4 ***Central heating hours – reported on-duty and estimated active***

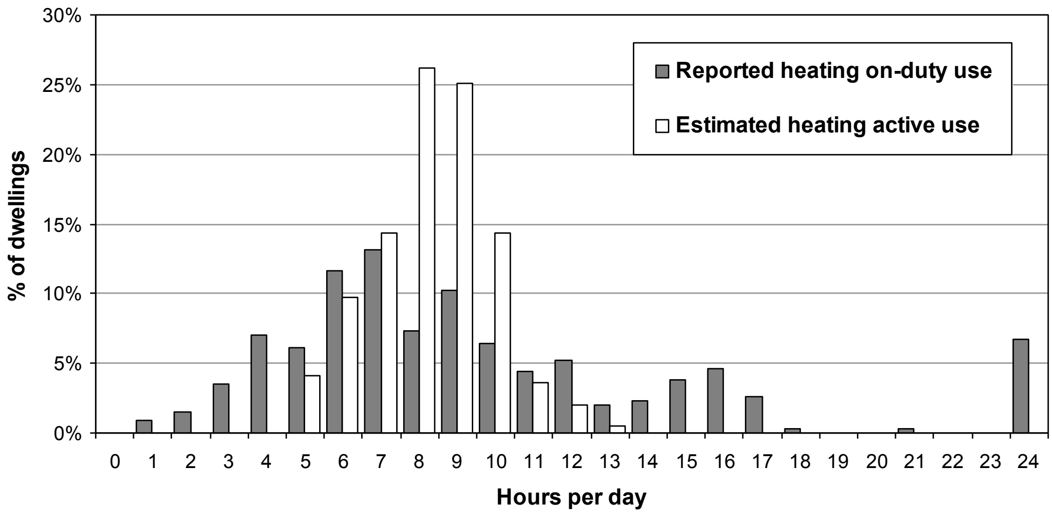

Figure 4 Central heating hours – reported on-duty and estimated active

Figure 5 ***Thermostat settings – reported vs. estimated***

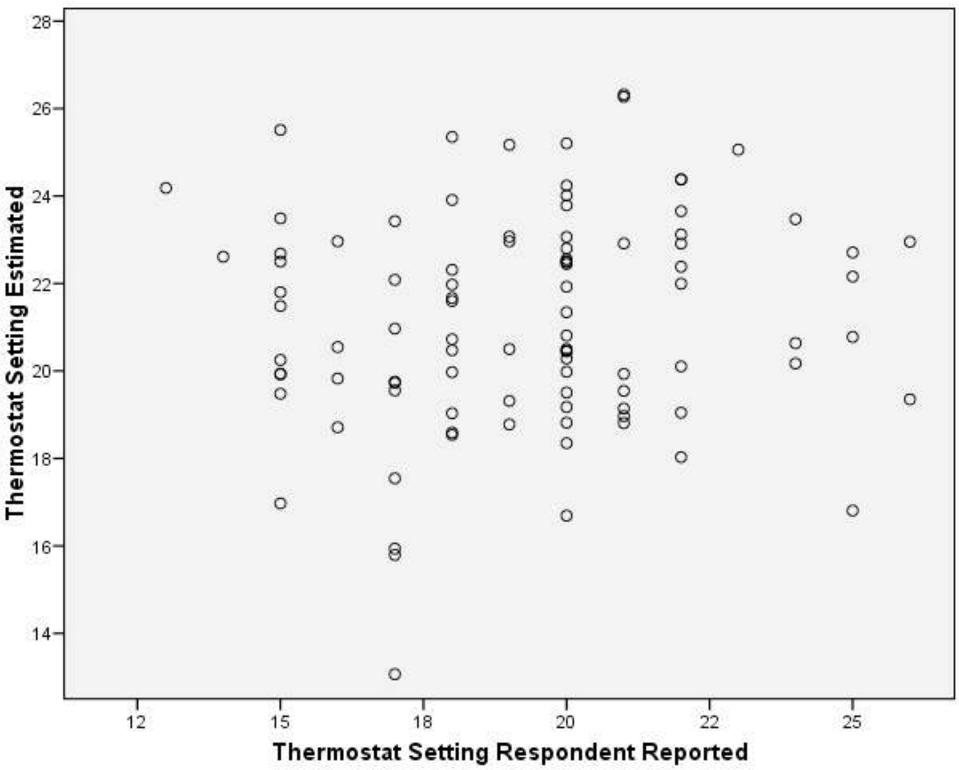

Figure 5 Thermostat settings – reported vs. estimated

Endnotes

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[i] 'The proposed P1 target would result in energy use from conventional domestic heating and hot water systems falling to 400.5 TWh by 2020. This would represent an energy saving of 14.5 TWh (0.8 MtC, 2.9 Mt CO2) over the Reference projections for 2020' (DEFRA 2008c, p. 4).

[ii] Postcode sectors were stratified by the percentage of households where the Census Household Reference Person was in National Statistics' Socio-economic Classification category 1 or 2 – i.e. employers in large organisations, managers, professionals, and higher technical and supervisory occupations

[iii] Outliers can have undue influence on parametric statistical tests, as well as on summary statistics (de Vaus 2002a). This is particularly problematic when comparing groups (e.g. those in different types of accommodation), especially if some groups have relatively small numbers of cases. Outliers are those cases disconnected from the remainder of the distribution, and 2-3 standard deviations from the mean.

[iv] Bungalows are all single-storey houses; all other houses have more than one floor. Terraced houses are in rows of at least three attached houses. A semi-detached house is attached to one other house. A converted flat is created when a house is converted into two or more flats, or a former non-residential building is converted into one or more flats.

[v] Explanations of each of these controls were given as follows: A room thermostat or roomstat is used to choose the temperature the home should reach when the heating is on. It is usually found in the living room, dining room or hallway. Room thermostats may have a dial marked with the numbers 10, 15, 20, 25, and 30, or they may be digital. A time clock, timer or programmer is used to set the times the heating comes on and goes off. Newer programmers

are digital. A thermostatic radiator valve controls a single radiator and is used to keep a room at a different temperature to the rest of the home. Thermostatic radiator valves usually have a dial marked with a * and numbers from 1 to 5. A controller or programmable room thermostat is used to set the times the heating is on as well as the temperature the home should reach when the heating is on. They are digital. Illustrations of these controls were also provided.

[vi] A multi-university, multi-disciplinary research project just under way – Carbon, Comfort and Control, led from University College London, is doing just this – applying a user-centred approach to developing new forms of heating control that *do* save energy.