How much energy could be saved by changing everyday household behaviours?

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Executive Summary

Cambridge Architectural Research has examined the potential energy savings that could be achieved by households adopting 45 ‘behaviours’ defined by DECC. Some of the behaviours describe a change in the way people use energy in their homes (e.g. ‘turn the thermostat down’), while others describe a technical upgrade (e.g. ‘insulate hot water tank’), and a small number describe both a technical upgrade *and* a change in behaviour (e.g. ‘install water efficient shower head and use twice every day’).

We have quantified the average savings per household for each of the ‘behaviours’, and made rough estimates of the number of households that could potentially adopt them. To give DECC indicative, ball-park estimates of total savings if households adopt the behaviours, we have factored up the savings very crudely, and in a way that is simple for DECC to change.

We used a tiered approach to estimating energy savings.

Tier 1: Use Cambridge Housing Model to estimate thermal energy savings

Tier 2: (Where model was not suitable) Use robust data from CAR’s library of published reports and papers about energy behaviours

Tier 3: (Where there was limited robust data available) Use published data in combination with expert judgement to formulate an estimate

Tier 4: (Where there was no robust published data for the behaviour) Use expert judgement, our own experiments, and CAR’s experience in working on household energy behaviours to formulate an estimate.

All the estimates, the assumptions and sources underpinning the estimates are clearly described in an Excel spreadsheet. We expect DECC to refine and build on this spreadsheet as more data becomes available about possible uptake of the behaviours, and in particular when another project aimed at understanding the flexibility of behaviours is complete. We recommend that readers use the spreadsheet alongside this report because the assumptions, sources and calculations are not duplicated here.

This work is not intended to give precise or definitive estimates of energy savings. We have drawn up ‘high’, ‘low’, and ‘most likely’ estimates of the energy saving from adopting narrowly-defined behaviours, but there is at least as much uncertainty about the number of households that could be persuaded to adopt the behaviours, and exactly how they do so. (The flexibility of individual target behaviours will be explored in another DECC project, due to report at the end of July 2012.)

We have constructed a simple ranking of the savings from behaviours when applied to the whole housing stock, which indicated that the total saving from changing a single behaviour across the stock could be from 49 TWh to zero (no saving).

The top six energy-saving behaviours to emerge from this work were:

1. Turn thermostat down by 2 degrees from 20℃ to 18℃ (49 TWh)

2. Turn thermostat down by 1 degree from 19℃ to 18℃ (24 TWh)

3. Delay start of heating from October to November (11 TWh)

4. Wear a thick jumper at home in the heating season (6 TWh)

5. Replace standard shower head with a water efficient shower head and use twice every day
(5 TWh)

6. Use radiator valves to turn off heating in unused rooms (4 TWh)

Given that these are the behaviours we expect to deliver biggest savings, they merit additional scrutiny, so we have also used different approaches to ‘triangulate’ or validate these savings estimates. We have also carried out limited sensitivity and uncertainty analysis on these estimates. This work is described in the main body of this report.

Introduction

Nearly a third of the UK's greenhouse gas emissions come from the domestic sector. It will be almost impossible to meet our national target of cutting GHG emissions by 80% without reducing energy use in homes. DECC urgently needs to understand more about how to encourage energy-saving behaviours in the home so it can develop policy ideas that will support and accelerate the move to a low carbon economy.

This work is part of a wider programme of work aimed at understanding household energy use. The Department already has a reasonable understanding of energy efficiency decisions in the home (e.g. deciding to install insulation), but there is still uncertainty about habitual behaviours that affect energy use (e.g. heating and hot water controls, leaving lights and appliances on, how cooking equipment and cooling equipment is used, or how people charge electronic devices).

The Department's Customer Insights Team developed a framework of 45 individual behaviours thought to save energy, but where there is uncertainty about how much energy households could save. The Department appointed CAR to estimate how much energy these 'target behaviours' could save.

CAR has estimated the energy savings from each of the behaviours specified, clearly listing all of the assumptions that lie behind our estimates, and where possible tying the estimates to empirical data. In some cases there was robust evidence on which to base our estimates, but in other cases the evidence base was much more limited. Where no other information was available, CAR carried out our own small-scale experiments to quantify likely savings (see Appendix, page 22).

This work was intended to be refined over time as the evidence base develops – it is by no means a finished product. The main motive for the work was to identify behaviours with large potential for savings, and those with small ones – allowing DECC to prioritise areas for future research and policy development.

Approach

We started the project by agreeing the list of behaviours with DECC. In some cases we had to make the behaviour as defined more specific, while in other cases we had to redraft a behaviour so it did not compound together multiple changes (for example "Close window at night and turn heating off or down" was changed to "Close bedroom window at night instead of leaving a little open").

Then we used modelling, our library of papers, small-scale experiments and existing knowledge to generate estimates for as many of the behaviours as possible. We put most emphasis on estimating likely savings for an average dwelling, but we have also generated indicative figures for the number of households that could adopt the behaviours. This allows DECC to see how much would be saved in total if different proportions of householders adopt the behaviours.

However, because we put more time into the estimates of energy saving than we did into the number of households, there is more uncertainty in our figures for the number of households.

All of our estimates were provided to DECC in an Excel spreadsheet, for three reasons:

1. So that it is easy for DECC to update the estimates as more robust evidence becomes available

2. So that DECC can use assessments from another consultant about how easy or hard it will be to persuade households to change their behaviour, which will dictate what proportion of homes go into the final estimate of total energy saving across the housing stock, and

3. So that DECC can see how we produced the estimate, with our assumptions and evidence presented alongside the estimates.

This report is designed to complement the Excel spreadsheet, and should be read alongside it – it does not cover the approach taken to every behaviour in detail. Instead, this report gives examples from the spreadsheet to illustrate the approach we have used.

All figures are rounded in this report. We would not claim high levels of precision in the estimates although some, based on calculation, are presented to more significant figures in the spreadsheet. This makes it more intuitive to update the spreadsheet.

There are two main methods we have used to generate our estimates:

Using the Cambridge Housing Model, the sophisticated housing energy model CAR has developed for DECC, used to underpin the *Housing Energy Fact File*, *Energy Consumption in the UK*, and various ad hoc questions needed for developing household energy policies. This is a bottom-up model that estimates energy consumption in the 16,150 dwellings surveyed in the English Housing Survey (the most robust and comprehensive survey of UK homes). The Model uses a building physics engine built around SAP, the Standard Assessment Procedure, which is used to assess compliance with the energy part of the Building Regulations[1].

Combining parameters where widely used National Statistics are available (for example, the Government estimates of total energy used in UK homes for refrigeration) with other parameters where established statistics are not available (for example, the coefficient of performance of every sort of fridge-freezer in use in homes, or the number of times per day fridge-freezer doors are opened each day in different households). Here we estimate the energy saving to come from proposed changes in behaviour using known or inferred relationships between the parameters and energy use. Often the relationships come from proven physical properties: the rate of heat transfer through a wall, for example, or the energy required to change liquid water to steam, or the heat capacity of water.

[1] The Model is described in more detail in Hughes, M. (2011) A Guide to The Cambridge Housing Model. Cambridge: CAR/DECC. Available here: www.tinyurl.com/HousingFactFile

After each estimate, we did a 'sanity check' comparison with known data to reassure ourselves that the resulting estimate was reasonable.

Example of using the Model

Twelve of the behaviours the Department asked us to include in this project lend themselves to estimates using the Cambridge Housing Model (CHM). This model includes full building physics algorithms for space heating (based on SAP 2009[2]), and detailed housing data including boiler and controls specifications for the whole English housing stock – taken from the English Housing Survey. This allows a more robust assessment of the number of households that could adopt new behaviours than simply using expert judgement.

(The modelled estimates are all described in the 'Heating Assumptions+Calcs' worksheet, and marked "(modelled)" in Column 2 of the large table from page 10 of this report, and in Column B of the 'Energy+Adoption' overview in the spreadsheet.)

To illustrate how we used the model, we are going to describe step-by-step how we reached our estimate of the saving from adopting the behaviour found to save most energy: turning thermostats down by 2ºC. The 'base-case' Cambridge Housing Model assumes average thermostat settings across the whole stock of 19ºC. This is different from the default SAP assumption, based partly on our literature review[3] and partly on evidence that the heating regimes in SAP over-estimate the length of heating period at weekends[4], and adjusting the demand temperature is a simple, transparent way to account for this.

Our first step in modelling was to run the model with the base case scenario – assuming the condition and energy efficiency of all UK households can be extrapolated from the English Housing Survey. This gave us a figure for total energy use across all end-uses and all households, including space heating: both primary heating (typically central heating), and secondary heating (often a gas room-heater in the living room), as well as energy use for pumps and fans, which are often part of the energy used for space heating. The model performs a full SAP calculation of heat loss, space heating demand, and how this demand is met using the heating system efficiency for each of the 16,150 households described in the EHS. The calculation includes solar gain and internal gains from occupants and equipment, based on the number of occupants for each home.

Then we changed the thermostat setting in the Cambridge Housing Model from 19 to 18℃. (This change was made in cell E821 in the 'B Physics Parameters' worksheet

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[2] The Standard Assessment Procedure 2009, which is used to assess compliance with the Energy Efficiency part of the Building Regulations.

[3] Especially Shipworth M. et al (2009) 'Central heating thermostat settings and timing: building demographics', Building Research & Information, 38: 1, 50 — 69.

[4] BRE (2012) Energy Follow-Up Survey 2010/11 - Main Heating Systems: Interim findings from householder reported data only. London: BRE/DECC.

of the model.) On re-running the model, we calculated a new total energy use figure for all households over the year, and compared this to the original figure to ensure that the result seemed reasonable. (We used monthly weather data for 2009 for external temperature and wind speed, with regional weather data for the nine regions across England. 2009 weather data is similar to 10-year average weather.)

This showed a saving compared to the base case space heating energy of 13%. The change to thermostat setting reduced the mean temperature difference between external and internal temperatures by 8%. Heating system efficiencies and other factors imply that heating energy varies by a factor of about 3:2 to temperature difference. Taking these two facts together, a 13% saving sounds reasonable.

Example of other methods

The remaining two-thirds of the behaviours chosen by the Department did not lend themselves to modelling using the CHM. This was mainly because they related to a specific piece of equipment like a shower, fridge or oven, which are not adequately described in the English Housing Survey and which cannot be separated out in the CHM.

As an illustration, let’s consider a two-person household installing a water-efficient shower and using it twice a day (say once per person). This too was found to save considerable energy. The first step here was to estimate how much energy is used for water heating under the base case scenario of using a normal shower twice a day. We have relatively good data about which hot water systems are installed in homes from the English Housing System, so we can infer the range of system efficiencies for heating water.

We also have reasonable data about the temperature of the cold water main entering dwellings through the year, and average hot water temperatures, from the Energy Saving Trust[5]. And similarly credible data from Waterwise[6] about flow rates for showers and the range of temperatures for showers. We also know the specific heat capacity of water (how much energy is needed to raise the temperature of water by 1℃).

We combined the data together to estimate average energy use for a shower of 7 minutes with a standard flow rate of 8 litres/min. This suggested the low-flow shower head would save an average of 28 litres of hot water, resulting an energy saving of 1.1 kWh per shower, or around 800 kWh per year taking two showers per day.

Comparing this with Energy Consumption in the UK 2011, telling us that average energy use for hot water is around 3,600 kWh/y per household, and the knowledge that a low-flow shower saves about half of the water used in each shower, suggests that our estimate is reasonable: a low-flow shower can save just under a quarter of

[5] EST, 2008, Measurement of Domestic Hot Water Consumption in Dwellings [pdf] Available from: http://www.bsria.co.uk/download/est-domestic-hot-water-monitoring-report.pdf [Accessed 24 Apr 2012]

[6] Walker, G., 2009 The Water and Energy Implications of Bathing and Showering Behaviours and Technologies, Waterwise [pdf] Available from: http://www.waterwise.org.uk/data/resources/27/final-water-and-energy-implications-of-personal-bathing.pdf r [Accessed 18 May 2012]

household hot water energy (excluding hot water used in appliances, like washing machines and dishwashers, which are usually cold-fill, heated by elements in the appliance).

DECC gave us early access to the unpublished Household Electricity Survey Report[7], which was directly relevant to a number of the behaviours we examined but could not model in the CHM. This report is probably the richest set of household energy behaviour data currently available, and was very helpful (although we believe the data to be biased, see[8]:

Because the households knew their behaviour was being monitored, it is likely they were more aware of their energy consumption than usual. Therefore the results are likely to be biased towards low energy usage.

More seriously - the attitude survey shows that the sample of households included were significantly more environmentally-conscious and energy-conscious than average. For example, 33% of the final study sample are classified as 'positive green' compared to a national average of 18%; and 22% are 'waste watchers' compared to 12% national average (p46). Also 51% of the study sample strongly disagree with the statement that 'I don't really give much thought to saving energy in my home', compared to 38% national average (p49).

This means the behaviour data is likely to be biased towards using less energy than average. Nevertheless, we still feel that this data is better than other sources available and we have used it where appropriate without adjustment for bias.

Caveats

SAP and the CHM assume that all households have the same heating preferences: the same thermostat setting, the same 9 hours of heating on weekdays and 16 hours at weekends, eight months of heating a year, and so on. In reality, of course, every household controls its heating system differently, and has different patterns of use for hot water, lights and appliances. On average across the whole housing stock, the estimates are close to measured energy use from the Digest of UK Energy Statistics, but there could be large variations when considering specific sub-groups of households, and even greater variations for specific individual households.

This work does not attempt to capture variation across types of household – for example, how energy use may vary with household income (low income homes often use less energy than higher income homes). Instead, this work estimates savings for a typical, average household and scales these up across the country ignoring these differences. The rationale for doing this is that there is some balancing out between the highest and lowest users.

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[7] Intertek (unpublished) Household Electricity Survey: A study of domestic electrical product usage (draft). London: DECC/AEA.

[8] Bias stems from a sample that is significantly more environmentally and energy-conscious than average, and because the households knew their behaviour was being monitored. This means the report very likely under-estimates average energy use.

We have made very crude estimates of the number of households that could adopt each behaviour, assuming a simple 50% or 75% take-up (of those where the behaviours apply). This is easy to change in the spreadsheet. We have not attempted to assess how easy or hard it will be to persuade households to change their behaviour as this will be covered in a separate, complementary, project. Although there is some uncertainty about the savings that could be achieved by adopting the behaviours, there is likely to be substantially more uncertainty about uptake. It is almost impossible to say exactly how many households might change their behaviour and, critically, whether they will sustain the behaviour change long term.

Our estimates are also based on uptake in full, as described in the behaviour: for example 'Take showers lasting 5 minutes not 7 minutes, 4 times a week'. It is likely that households will not stick rigidly to this behaviour, even if they can be persuaded to make some change – some showers may last more or less than the prescribed 5 minutes. Some weeks the household may in reality have more or less than 4 showers a week. However, these considerations lie outside the brief for this work, which is concerned with estimating how much potential there is for saving energy, rather than establishing if it would be saved in real life.

The savings from different behaviours cannot be added together simply, because successive behaviour changes have complex inter-relationships. If a household installs a low-flow shower head and takes shorter showers, for example, then total savings will be less than adding the two estimates of savings per household for these two behaviours.

Uncertainty

We have offered a range for all of our energy estimates: 'low', 'high' and 'most likely'. This provides an estimate of the scale of uncertainty in our estimates of energy savings, and is better than offering a single point estimate, which is misleading. We are almost certain that the average true savings per household lie somewhere between our low and high values, and although it was not possible to perform statistical tests on the estimates, readers can think of the range as capturing an estimate of about 95% of the actual range of values. (In line with the standard statistics test of a '95% confidence interval.)

In reality, the range of savings in an individual household could be a lot greater than the ranges we have offered – because of the compounding effect of very rare combinations of behaviours and characteristics. Let's say, for example, that Household A prefers bright lights (say 3 100W bulbs in each room) and doesn't like energy-efficient compact fluorescent bulbs. Let's say the same household is not concerned about how much energy it uses, and leaves the lights on in every room of the house nearly all the time when it is dark.

When Household A adopts the 'Turn lights off in unused rooms' behaviour there is a big change and the savings would be considerable – much more than our estimate. However, this (unlikely) scenario is offset by households at the opposite end of the spectrum who have nearly all efficient bulbs and who are already good at turning lights off in unused rooms.

Conversely, let's say that Household B never cooks at home – they always eat out or buy take-aways. The saving they would achieve from 'Putting lids on saucepans', for example, would be zero – lower than our estimate for this saving. Again, this extreme case is very unlikely, and it is offset when thinking about savings across the whole stock, where there are also households that cook much more than average, who would achieve higher savings.

This means that our high/low ranges are not intended to cover the extreme cases for individual households – instead they cover the uncertainty when estimating likely savings across the whole housing stock.

There is much greater uncertainty for some of the estimates than for others, as you would expect. For behaviours where there is little or no empirical data, where we have typically relied heavily on expert judgement (e.g. using chemical inhibitor in heating systems to reduce sludge and scale), we have offered a much wider range of possible energy saving outcomes.

This report estimates energy savings in kilowatt hours (kWh) throughout, as DECC asked. However, this says nothing about costs or carbon emissions resulting from energy savings. This is important because it omits the current large discrepancy between prices and carbon emissions of electricity and gas. A kWh of electricity is currently around three times the cost of gas, with around three times the CO_2 emissions. If we reported savings as current CO_2 or costs, the rankings would be different.

Uncertainty and distributions

The 'most likely' values cited are the mean savings unless there is evidence for a skewed distribution of savings across households – which there often is. In this case the 'most likely' value is derived from the calculation linking input variables to the energy estimate, using more common values for the significant input variables.

For example, in the 'Putting lids on saucepans' example, four parameters are relevant: how many times the hob is used each year, how much energy is used by the hob each time, how much less energy is used when the lid is on a saucepan, and what proportion of saucepan events use and don't use lids. All four of these parameters vary from household to household, and the algorithm that links them together is a simple multiplication. To calculate the 'most likely' value we used means for the first two variables, a published source that suggested a skewed distribution for 'extra energy with no lid'[9] and CAR's judgement about the distribution of 'what proportion don't use lids but could'[10] – based on our own experience of cooking with and without lids on saucepans. (We did this for each behaviour in turn, and then looked in more detail at the four that appeared to bring largest savings.)

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[9] Low estimate – 30% more energy, high estimate – 100% more energy, 'most likely' estimate (from a published source) – 60% more energy.

[10] Low estimate – 50%, high estimate – 75%, 'most likely' estimate (using our judgement) 60%.

CAR has looked at uncertainty in the Cambridge Housing Model in great detail, and we are in the process of writing up this work for publication[11]. This work is directly relevant to the estimates of savings presented here that were generated using the CHM. We have completed a full sensitivity analysis, varying each input parameter to the model at a time, and examining the parameters' impact on modelling outputs. This tells us that the 13 most significant parameters in the model are as shown in the table below. (The 'normalised sensitivity coefficient' tells us by how much total energy use varies with a 1% variation in the input parameter.)

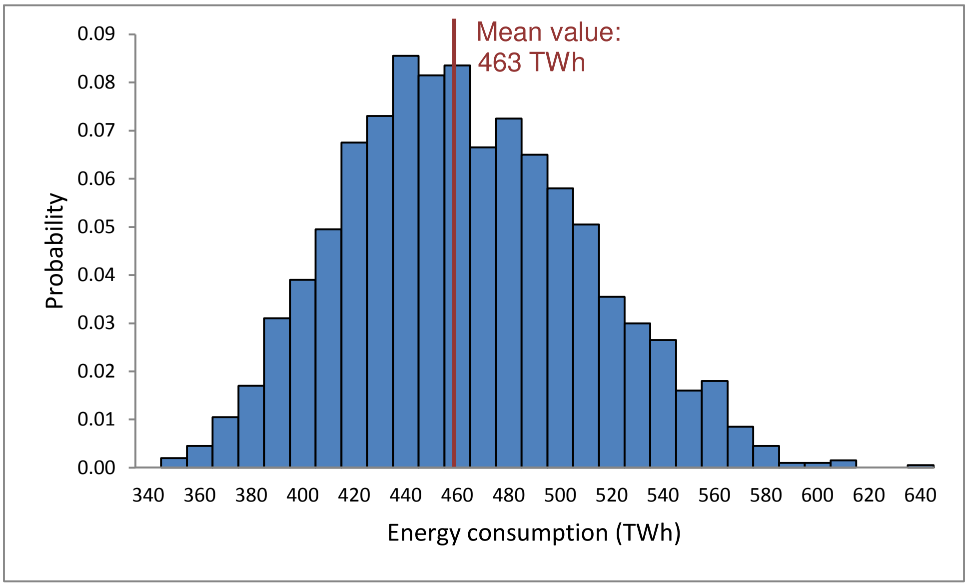
Unsurprisingly, the table shows that internal (thermostat) and external (winter) temperature are among the most significant parameters, which is consistent with the overall finding from this research that thermostat settings are key determinants of energy consumption.

Sensitivity tests for CHM parameters

Input parameter		Initial set value x_i	Normalised sensitivity coefficient S_i
1	Internal demand temperature (°C)	19.0	1.54
2	Main heating system efficiency (%)	80.5	-0.66
3	External temperature (°C)	7.5	-0.59
4	Total floor area (m^2)	96.4	0.53
5	Storey height (m)	2.5	0.46
6	Daily heating hours (hrs)	11.0	0.27
7	Hot water system efficiency (%)	76.6	-0.19
8	Wall U-value (W/m^2K)	1.2	0.18
9	Effective air change rate (air changes/hour)	1.0	0.18
10	Wind factor parameter	4.0	-0.17
11	Wind speed (m/s)	4.8	0.17
12	Infiltration rate (ach)	0.8	0.17
13	Shelter factor	0.9	0.16

[11] Hughes M. et al (forthcoming) Sensitivity and Uncertainty Analysis of the UK's Housing Energy Model. Cambridge: CAR.

The second aspect of our CHM uncertainty work that is relevant here is the Monte Carlo simulation we have applied to the model. This involves identifying and quantifying all possible sources of uncertainty in the model, and varying each one in combination with all others, randomly. The variation was chosen according to the distributions of each of the input parameters, and followed established techniques for this sort of Monte Carlo simulation[12]. We ran the model 2,000 times, varying all input parameters within their range of values, and generated the plot below of total energy consumption. Effectively, this shows the spread of values generated by the model on varying all input parameters together.



Our analysis showed that the variation from the single point estimate from the model ranged from -15% to +26% for 95% of the Monte Carlo outputs. These are the factors we used to estimate ‘low’ and ‘high’ energy savings generated using the model. For example, in the ‘Heating Assumptions+Calcs’ worksheet, Cell D7 shows the estimate of ‘likely’ space heating calculated from the model. B7 estimates a ‘low’ mean space heating per home at (1-0.15) x likely space heating. C7 estimates a ‘high’ mean space heating per home at (1+0.26) x mean.

[12] Hughes M et al (forthcoming) Sensitivity and Uncertainty Analysis of the UK’s Housing Energy Model. Cambridge: CAR.

Ranked estimates

		Energy saving per household (kWh/y)*			GB Households able to adopt (indicative)		Indicative take-up (millions of households)		Total potential saving (GWh/y)		
	Behaviour	Low	High	Most likely	Proportion	Number (millions)	50% take-up	75% take-up	Low	High	**Most likely**
	Example	Extreme low estimate	Extreme low estimate	Single estimate from evidence, modelling or calculation.	Percentage of all households	Number of households	Millions of households if 50% adopt	Millions of households if 75% adopt	Low energy saving x 50% take-up	High energy saving x 75% take-up	'Most likely' saving x mean of 50 & 75% take-up
1	Turn thermostat down by 2 degrees from 20℃ to 18℃ (modelled)	2,630	3,900	3,090	100%	25.36	12.7	19.0	33,340	74,120	**49,020**
2	Turn thermostat down by 1 degree from 19℃ to 18℃ (modelled)	1,300	1,930	1,530	100%	25.36	12.7	19.0	16,470	36,620	**24,220**
3	Delay start of heating from October to November (modelled)	570	840	670	100%	25.36	12.7	19.0	7,190	15,980	**10,570**

		Energy saving per household (kWh/y)*			GB Households able to adopt (indicative)		Indicative take-up (millions of households)		Total potential saving (GWh/y)		
	Behaviour	Low	High	Most likely	Proportion	Number (millions)	50% take-up	75% take-up	Low	High	**Most likely**
4	Wear a thick jumper at home in the heating season (modelled) [13]	760	3,090	1,530	25%	6.3	3.2	4.8	2,420	14,710	**6,060**
5	Install water efficient shower head and use twice every day	410	4,530	810	40%	10.1	5.1	7.6	2,090	34,470	**5,140**
6	Use radiator valves to turn off heating in unused rooms (modelled)	150	1,650	530	50%	12.7	6.3	9.5	970	15,660	**4,200**

[13] CAR's estimate of the effect of wearing a thick jumper is that, where wearing jumpers makes any difference, it results in a range of changes to thermostat settings - from 0.5C to 2ºC lower. In the absence of any more reliable data, we further estimate that half of households would not make any change to thermostat settings after putting on jumpers, and of the remaining half, a quarter already wear thick jumpers in the heating season. This translates into a 'maximum uptake' for this behaviour of 25% of households.

		Energy saving per household (kWh/y)*			GB Households able to adopt (indicative)		Indicative take-up (millions of households)		Total potential saving (GWh/y)		
	Behaviour	Low	High	Most likely	Proportion	Number (millions)	50% take-up	75% take-up	Low	High	**Most likely**
7	Regularly maintain heating system: use chemical inhibitor and bleed radiators	-760	920	390	44%	11.2	5.6	8.4	-4,250	7,680	**2,710**
8	Turn off lights when not in use	27	540	130	100%	25.4	12.7	19.0	340	10,210	**2,130**
9	Insulate hot water pipework (primary circuit, modelled)	220	310	260	51%	12.9	6.5	9.7	1,430	3,010	**2,120**
10	Take 2 showers lasting 7 minutes each instead of 2 baths per week	-130	500	160	65%	16.5	8.20	12.4	-1,060	6,190	**1,670**

		Energy saving per household (kWh/y)*			GB Households able to adopt (indicative)		Indicative take-up (millions of households)		Total potential saving (GWh/y)		
	Behaviour	Low	High	Most likely	Proportion	Number (millions)	50% take-up	75% take-up	Low	High	**Most likely**
11	Take showers lasting 5 minutes, not 7 minutes, 4 times a week	47	350	130	80%	20.3	10.1	15.2	480	6,194	**1,670**
12	Air dry laundry instead of using the tumble drier	21	2,700	360	29%	7.4	3.7	5.5	76	14,920	**1,670**
13	Install sensors and use to turn off lights	-61	520	100	100%	25.4	12.7	19.0	-770	9,800	**1,640**
14	Work from home 2 days/week [14]	-2180	7,600	690	14%	3.6	1.8	2.7	-3,870	20,220	**1,530**

[14] Based on transport energy saved.

		Energy saving per household (kWh/y)*			GB Households able to adopt (indicative)		Indicative take-up (millions of households)		Total potential saving (GWh/y)		
	Behaviour	Low	High	Most likely	Proportion	Number (millions)	50% take-up	75% take-up	Low	High	**Most likely**
15	Only fill kettle to the level required	20	350	83	91%	23.1	11.6	17.4	230	6,020	**1,200**
16	Always use the dishwasher on eco settings	0	780	180	39%	9.9	5.0	7.4	0	5,790	**1,130**
17	Fill oven when on	16	142	64	98%	24.9	12.4	18.6	200	2,650	**1000**
18	Install cylinder thermostat and use to control tank temperature (modelled)	310	460	370	17%	4.3	2.1	3.2	670	1,490	**980**
19	Defrost freezer regularly	14	260	68	75%	19.0	9.5	14.3	131	3,730	**810**

		Energy saving per household (kWh/y)*			GB Households able to adopt (indicative)		Indicative take-up (millions of households)		Total potential saving (GWh/y)		
	Behaviour	Low	High	Most likely	Proportion	Number (millions)	50% take-up	75% take-up	Low	High	**Most likely**
20	Switch televisions off when not being watched instead of leaving on in the background	16	100	50	97%	24.6	12.3	18.5	200	1,910	**760**
21	Close bedroom window at night instead of leaving a little open (modelled)	350	490	420	10%	2.5	1.3	1.9	450	940	**660**
22	Refitting old and damaged seals on refrigerators and freezers	52	260	130	30%	7.6	3.8	5.7	200	1,480	**610**
23	Put lids on saucepans	13	580	124	30%	7.6	3.8	5.7	49	3,310	**590**

		Energy saving per household (kWh/y)*			GB Households able to adopt (indicative)		Indicative take-up (millions of households)		Total potential saving (GWh/y)		
	Behaviour	Low	High	Most likely	Proportion	Number (millions)	50% take-up	75% take-up	Low	High	**Most likely**
24	Maintain fridge well (de-ice, clean coils)	8	100	37	90%	22.8	11.4	17.1	91	1,770	**520**
25	Put cold appliance in cool place with enough room for ventilation	40	860	220	14%	3.7	1.8	2.8	74	2,360	**490**
26	Insulate water tank using a thermal jacket (modelled)	2,450	3,640	2,890	1%	0.2	0.1	0.2	300	670	**440**
27	Buying less food more frequently to reduce the fridge capacity	13	140	24	111%	28.2	14.1	21.1	180	2,980	**420**
28	Avoid 'fast freeze' setting on freezer	35	270	96	22%	5.6	2.8	4.2	98	1,130	**340**

		Energy saving per household (kWh/y)*			GB Households able to adopt (indicative)		Indicative take-up (millions of households)		Total potential saving (GWh/y)		
	Behaviour	Low	High	Most likely	Proportion	Number (millions)	50% take-up	75% take-up	Low	High	**Most likely**
29	Cook with the microwave not oven	1	133	18	93%	23.6	11.8	17.7	17	2,350	**270**
30	Wash clothes at 40 degrees or less	21	364	70	23%	5.8	2.9	4.4	61	1,590	**260**
31	Simmer rather than boiling food when cooking	1.7	139	28	50%	12.67	6.3	9.5	11	1,320	**220**
32	Install sensor in hallway and use to turn off lights	-24	165	13	100%	25.4	12.7	19.02	-305	3,140	**210**
33	Repair leaks in hot water system (i.e. dripping hot water taps)	11	480	130	10%	2.5	1.3	1.90	14	910	**200**

		Energy saving per household (kWh/y)*			GB Households able to adopt (indicative)		Indicative take-up (millions of households)		Total potential saving (GWh/y)		
	Behaviour	Low	High	Most likely	Proportion	Number (millions)	50% take-up	75% take-up	Low	High	**Most likely**
34	Avoid setting fridge thermostat too cold	17	68	39	30%	7.6	3.8	5.7	64	390	**190**
35	Avoid use of second freezers	27	365	109.5	10%	2.5	1.3	1.9	34	690	**170**
36	Not refrigerating / freezing items unnecessarily	2	60	10	100%	25.4	12.7	19.0	23	1,140	**160**
37	Use dishwasher only when full	9	347	104	9%	2.3	1.1	1.7	10	590	**150**
38	Avoid opening fridge door unnecess-arily	1	40	5	100%	25.4	12.7	19.0	16	760	**80**

		Energy saving per household (kWh/y)*			GB Households able to adopt (indicative)		Indicative take-up (millions of households)		Total potential saving (GWh/y)		
	Behaviour	Low	High	Most likely	Proportion	Number (millions)	50% take-up	75% take-up	Low	High	**Most likely**
39	Check oven seals, and replacing if necessary	1.3	34	9.6	29%	7.5	3.7	5.6	5	190	**45**
40	When designing the kitchen, site fridge away from oven	0	39	4	30%	7.6	3.8	5.7	2	220	**20**
41	Put cold items back in the fridge as soon as possible	0.6	6.8	1.4	80%	20.3	10.1	15.2	6	104	**17**
42	Defrost food in the fridge	0.6	16.9	3.4	30%	7.6	3.8	5.7	2	97	**16**
43	Avoid cooling hot food in the fridge	0.4	11.9	1.9	20%	5.1	2.5	3.8	1	45	**6**

		Energy saving per household (kWh/y)*			GB Households able to adopt (indicative)		Indicative take-up (millions of households)		Total potential saving (GWh/y)		
	Behaviour	Low	High	Most likely	Proportion	Number (millions)	50% take-up	75% take-up	Low	High	**Most likely**
44	Avoid leaving fridges empty	1.7	53	6.9	5%	1.3	0.6	1.0	1	50	**5**
45	Install program-mer or time switch to control space heating, and use (modelled)[15]	0	0	0	13%	3.3	1.6	2.5	0	0	**0**

*Household figures are for Great Britain, from DCLG's Table 401.

[15] The Standard Assessment Procedure, SAP, and empirical studies suggest programmers and timers do not save any energy.

Triangulating estimates of largest savings

The table above and the Excel spreadsheet show that the top six energy-saving behaviours to emerge from this work were:

1. Turn thermostat down by 2 degrees from 20°C to 18°C (49 TWh)
2. Turn thermostat down by 1 degree from 19°C to 18°C (24 TWh)
3. Delay start of heating from October to November (11 TWh)
4. Wear a thick jumper at home in the heating season (6 TWh)
5. Replace ordinary with a water efficient shower head and use twice every day (5TWh)
6. Use radiator valves to turn off heating in unused rooms (4TWh)

Given that these are the behaviours we expect to deliver biggest savings, they merit additional scrutiny, so we have also used different approaches to 'triangulate' or validate these savings estimates. We have also carried out limited sensitivity and uncertainty analysis on these estimates. This work is described in this section.

Turn thermostat down by 1 degree from 19 to 18ºC

Our original estimate of the energy saving from this behaviour, based on modelling using the CHM, was a 'most likely' value of 1,530 kWh per household per year, or 13% of space heating energy.

An alternative way to calculate savings from turning a thermostat down by 1°C is to consider average achieved temperatures and degree days[16].

In most homes the average temperature is lower than the thermostat temperature by several degrees, because the heating is off overnight, and also part of the day. Typically, some rooms are also heated less than others, although bedrooms are not necessarily cooler than other rooms. Shipworth et al (2009)[17] shows a typical heating pattern with the living room dropping in temperature by approximately 4°C overnight in winter and the bedroom 1-2°C cooler than the living room.

Based on this, reducing the thermostat from 19 to 18°C might reduce the average

[16] 'Degree days' give a measure of how mild or cold it is in winter. A degree day is the number of days mean temperature is below a benchmark temperature (e.g. 15.5°C), times the temperature difference. This figure allows you to normalise space heating energy use or CO_2 emissions between years with different weather.

[17] Shipworth, Michelle, Firth, Steven K., Gentry, Michael I., Wright, Andrew J., Shipworth, David T. and Lomas, Kevin J.(2009) 'Central heating thermostat settings and timing: building demographics', Building Research & Information, 38: 1, 50-.69

dwelling temperature from 17-16C, which would reduce the heating requirements based from 2490 - 2250 degree days (DECC, 2009, 2010)[18][19], a reduction of 10%. However, some of the heating requirements are provided by internal heat gains due to lights and appliances, hot water distribution losses, body heat and solar gain through windows. The balance of heating energy required, the net energy supplied, is smaller than the number of degree days would suggest, and the savings are therefore more than 10% in relative terms. This is consistent with our modelled estimate for relative savings of around 13%.

(We have not triangulated the 2℃ thermostat change or wearing thick jumpers – these are both very similar to the 1℃ change described above.)

Delay start of heating from October to November

Our original estimate of the energy saving from this behaviour, again based on modelling using the CHM, was a 'most likely' value of 670 kWh/year/household, or 5.5% of space heating energy.

Using a similar algorithm, assuming an average dwelling temperature of 17℃ and an average external temperature in October of 10.8℃ (BRE, 2009), the number of degree days in October is 31*(17-10.8) = 192, which is 8% of the overall degree days for 17C (2490, as above). This is higher than the 5.5% savings generated by our model and the discrepancy could again be due to gains: in October the heating demand is relatively low and a high proportion of this is supplied by internal gains.

To compare against a totally different algorithm we looked at the variation in total gas and electricity demand through the year. Using (domestic and non-domestic) gas demand data from the National Grid[20], and subtracting the base load from the seasonally varying load (using September as a cut-off), the demand for October is 7.0-8.5% of the yearly seasonal demand.

However, domestic gas use is only about one third of total gas demand, so the 8% figure is only a rough indication of heating demand. The variation in electricity demand is similar[21], with October accounting for around 8% of the seasonally varying load. However, some of the seasonal electricity use is for lighting and so the variation due to heating must be less than 8%. Again, this appears consistent with the original estimate.

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[18] DECC, 2009, The Government's Standard Assessment Produced for Energy Rating of Dwellings 2005 edition, Revision 3, BRE, Watford

[19] DECC, 2010, The Government's Standard Assessment Produced for Energy Rating of Dwellings 2009 edition, BRE, Watford.

[20] National Grid, 2012, Historic Actual NTS Demands, Actual CWV and SNT (January 1998 to December 2011) [Excel] Available from: http://www.nationalgrid.com/uk/Gas/Data/misc/ [Accessed 24 May 2012].

[21] DECC, 2012, Availability and Consumption of Electricity ET5.5 [excel] Available from: http://www.decc.gov.uk/en/content/cms/statistics/energy_stats/source/electricity/electricity.aspx [Accessed 24 May 2012].

Use radiator valves to turn off heating in unused rooms

Our original estimate of the energy saving from this behaviour was a 'most likely' value of 500 kWh/year/household, or approximately 4% of space heating energy.

An alternative calculation for the impact of not heating unused rooms assumes the unheated room has a temperature a little more than half-way between inside and outside. The average external temperature for the UK over the year is 9°C. If the average dwelling temperature is 17°C then an unheated room will be around 14°C.

If 1/6 of the home is unused and unheated, then the unheated part brings the average temperature for the whole home down to 16.5°C. This corresponds to a decrease in degree days of 2,490 down to 2,370, or 5%. This is a little higher than our model estimate of about 4%. Neither calculation allows for internal heat gains, but some of the gains are proportional to floor area in any case and the unused rooms would not contribute.

CAR also searched for existing literature on this subject and found Huber-Fauland and Ponweiser (2011)[22] describing an experiment on a test house in Vienna. Energy use with different heating regimes was compared: heating the living area and upstairs, but not the cellar; or heating the living area alone. The saving from not heating upstairs was up to 22%. Unfortunately, this study is not directly comparable with the scenario we modelled – partly due to the complicating factor from the unheated cellar, and partly also due to the test house construction materials, which were very different from UK housing.

Install water efficient shower head and use twice every day

Our original estimate of the energy saving from this behaviour was a 'most likely' value of 810 kWh/year/household, or 1.1 kWh/shower.

An alternative way to calculate savings from installing eco-showers is to look at hot water use for showers as a proportion of total hot water consumption. From ECUK[23], overall hot water consumption for all dwellings is approximately 91 GW/year or 3600 kWh/household/year. From EST's work[24], which measured hot water consumption at different points for a small sample of dwellings, the proportion of energy use in hot water used for showers is no more than 25%. Hence shower water energy is not more than 900 kWh/household/year or 2.5 kWh/day. Walker (2009)[25] reports that the

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[22] Huber-Fauland, H. and Ponweiser, K., 2011, Effects of the heating behavior of single rooms on the energy consumption and comfort in low energy and standard house in Mastorakis, N., Mladenov, V., Bojkovic, Z., Topalis, F., Psaris, K., Barbulescu, A., Karimi, H., Tsekouras, G, Salem, A., Vladereanu, L., Nikolic, A., Simian, D., Hausnerova, B., Berber, S., Bardis, N., Haraim, A., Subramaniam, C. (ed) 2011 RECENT RESEARCHES in MECHANICS, Corfu Island, WSEAS Press.

[23] DECC (2011) Energy Consumption in the UK. London: DECC.

[24] EST, 2008, Measurement of Domestic Hot Water Consumption in Dwellings [pdf] Available from: http://www.bsria.co.uk/download/est-domestic-hot-water-monitoring-report.pdf [Accessed 24 Apr 2012]

[25] Walker, G., 2009 The Water and Energy Implications of Bathing and Showering Behaviours and Technologies, Waterwise [pdf] Available from: http://www.waterwise.org.uk/data/resources/27/final-water-and-energy-implications-of-personal-bathing.pdf [Accessed 18 May 2012]

average number of showers taken per day is 1.4/household/day, albeit with considerable variation between households. This implies 1.8 kWh per shower. If an eco-shower head halves the consumption then 0.9 kWh/shower is saved. This is a little lower that our likely estimate of 1.1 kWh/shower. However, given the small sample size from EST and the wide variation shown in Walker (2009) the discrepancy is probably not significant.

Appendix: CAR's experiments

Where no other information was available, Cambridge Architectural Research carried out our own small-scale experiments. These experiments are summarised below.

Using a digital probe thermometer to measure the temperature of water:

- In a freshly prepared bath
- Collected from a shower
- Collected from a bath and shower in a second household

Measuring the gas used and water loss while simmering potatoes with the lid on the saucepan and with no lid.

The gas meter readings suggested the energy usage was doubled without the lid but the units were too large to be accurate. We calculated the energy requirement based on the heat capacity of the saucepan and lid (aluminium), potatoes and water and the latent heat of evaporation of the water. Water loss increased 400% with no lid, implying an energy increase of 60%. Dividing the measured gas use by the calculated requirement gave an efficiency of 35%-40% efficient, consistent with other sources.

Measuring a litre of water into a saucepan, simmering for 30 minutes and measuring the volume remaining. Then we repeated the experiment, this time boiling rather than simmering.

Calculating the energy requirement based on the heat capacity of the saucepan (aluminium) and lid (pyrex), potatoes and water and the latent heat of evaporation of the water. Boiling increased the water loss by 75%, implying energy use was increased 20%.

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