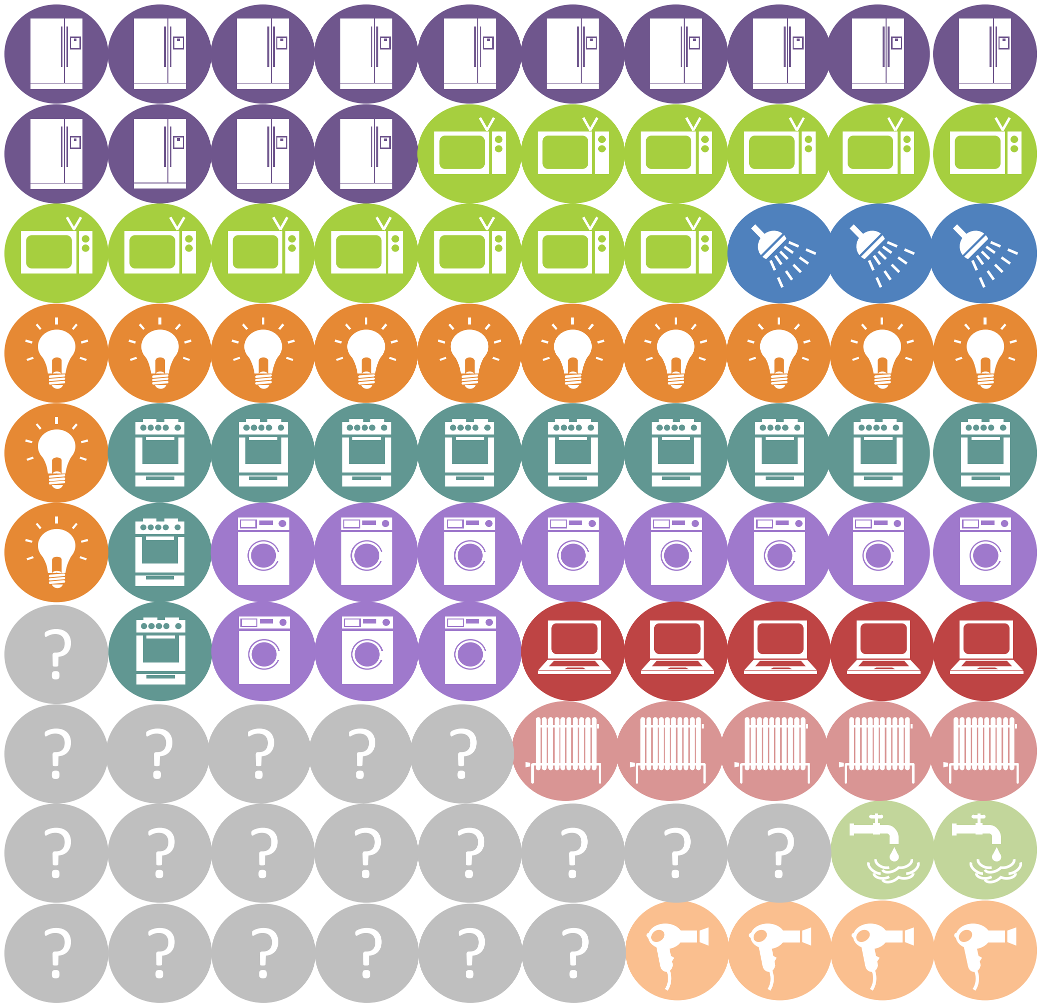
Further Analysis of the Household Electricity Use Survey

Electrical appliances at home: tuning in to energy saving

29 November 2013



Reference 475/09/2012

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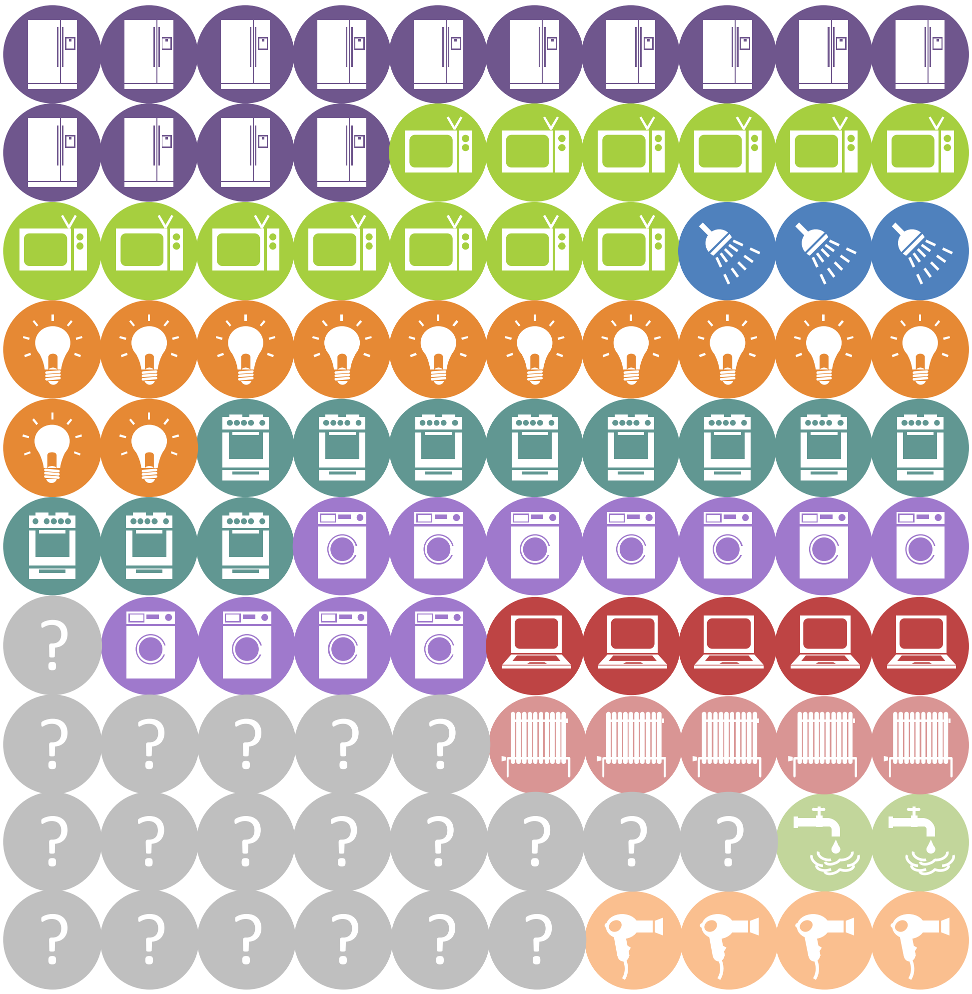
Average electricity breakdown over year



Cold Appliances
13.8% (566 kWh)

Audio/Visual
13.1% (537 kWh)

Showers
2.7% (112 kWh)

Lighting
11.8% (483 kWh)

Cooking
10.9% (448 kWh)

Washing Appliances
10.7% (437 kWh)

ICT
5.1% (207 kWh)

Space Heating
5.5% (227 kWh)

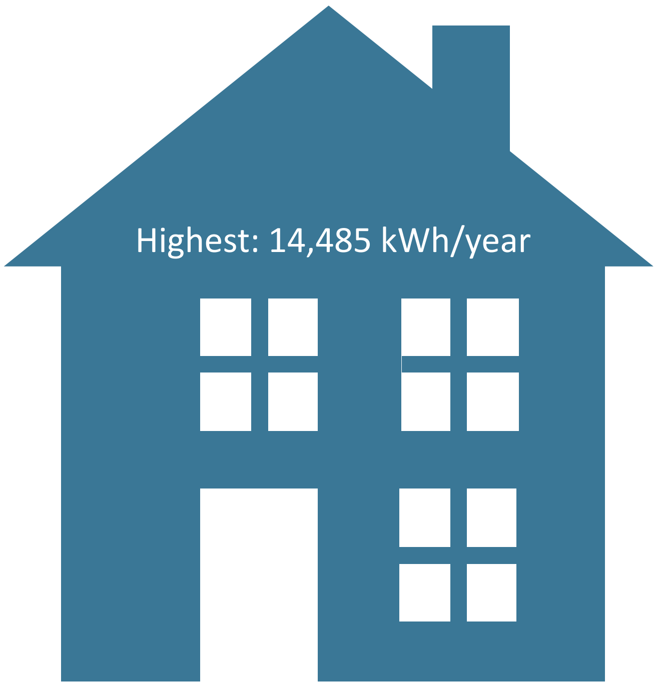
Water Heating
2.1% (85 kWh)

Other
4.2% (173 kWh)

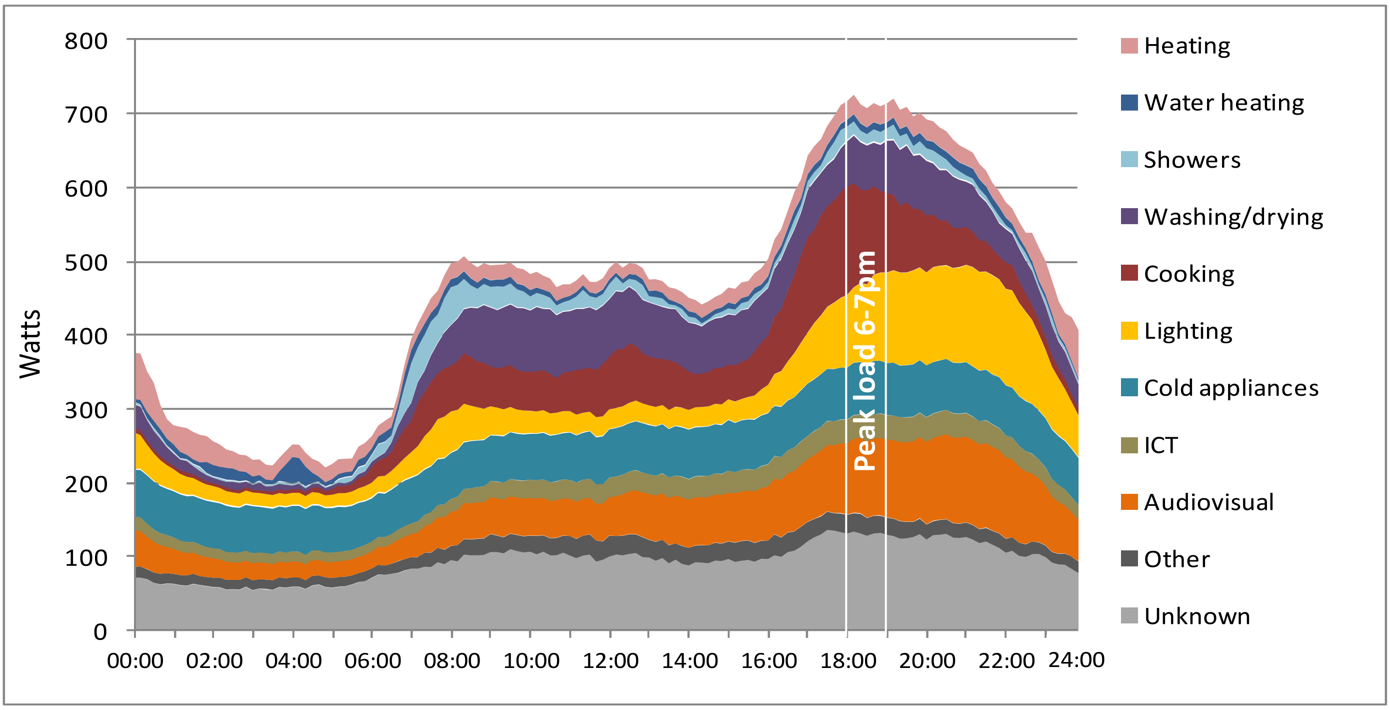
Unknown
20.0% (204,776 kWh)

Highest and lowest users

Lowest:
562 kWh/year



Average 24-hour profile for 250 homes



Average peak load breakdown

(Area shows proportion)

Savings from smaller appliances

(Slices show proportions, see p92)

Contents

Executive summary

Overview

The Household Electricity Survey monitored a total of 250 owner-occupier households across England from 2010 to 2011. It was the most detailed survey of electricity use in English homes ever undertaken. This is the second research report written by Cambridge Architectural Research, Loughborough University and Element Energy presenting further analysis of the Household Electricity Survey.

This report presents our findings on ownership patterns for appliances, and how these appliances are used. The material is more detailed and more complex than our Early Findings report, responding to more difficult questions drawn up by DECC and DEFRA. The report covers the following 14 topics:

1. Do different households own more appliances, or older ones?
2. Annual purchase and replacement rates
3. Energy ratings and socio-demographic indicators
4. HES energy ratings and national sales data
5. Cluster analysis and consumer archetypes
6. Electricity use in single-person households
7. Appliance use associations
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9. Electricity demand for products with high agency
10. Savings from smaller, simpler appliances
11. Data on the use of washing machines
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13. Appliances left on when not in use
14. Direct rebound effects of more efficient products

Do different households own more appliances, or older ones?

■ There is enormous variation in the ages of appliances owned. One fridge-freezer was reported to be 41 years old, and pensioners tend to have older appliances. However, mean appliance age across all households varied from 3.8 years for kettles to 8.4 years for fridge-freezers.

■ Some appliances are more likely to be owned by certain social demographic groups. For example, people in social grade A are more likely to have a dishwasher and tumble dryer, and older people are likely to own significantly older cold appliances, washing machines and televisions.

Annual purchase and replacement rates

■ Only 2.7% of these households purchased a new fridge each year – the lowest mean 'purchase rate' of all appliances. At the other end of the spectrum, 21.4% of these households bought new televisions (the highest mean purchase rate). The high purchase rate for TVs was driven partly by the Digital Switchover between 2008 and 2012.

■ Purchasing TVs appears to be different from other appliances, which are usually replaced when they break. It appears to be more common to retain old TVs and continue using them after buying a new one, which means the 'replacement rate' for new energy efficient TVs is lower than sales data suggests.

Compare energy ratings and socio-demographic indicators

■ At least 70% of dishwashers and cold appliances in these households had A-rated Energy Labels when purchased. However, 68% of washing machines in the sample were B-rated, and 75% of tumble dryers had only a C rating. There was no significant trend linking energy ratings to socio-demographic groups.

■ For nearly all appliances, there was no significant trend linking the environmental attitudes households expressed in a survey to the energy ratings of their appliances. The only exception was cold appliances, where all owners of A+ rated machines were 'Very concerned' about the environment.

Comparing HES energy ratings with national sales data

■ Most appliances sold are getting more efficient over time – at least partly due to Energy Labelling and minimum efficiency standards. However, tumble dryers did not get any more efficient from 2008 to 2010. 16% of tumble dryers in the sample were only D- or E-rated.

■ The penetration of fridges and freezers rated A+ and better is very low, and uptake is very slow. We recommend clearer information about running costs to make it easier for purchasers to justify the higher initial cost of more efficient cold appliances, possibly linked to a scrappage scheme for old inefficient fridges and freezers.

Cluster analysis and consumer archetypes

■ We have identified seven discrete clusters of household behaviour and other characteristics: 'Profligate Potential', 'Thrifty Values', 'Lavish Lifestyles', 'Modern Living', 'Practical Considerations', 'Off-Peak Users', and 'Peak-Time Users'. Each cluster offers different potential electricity savings, and each needs a different intervention strategy.

■ 'Profligate Potential' households offer the largest potential for saving electricity by switching to more efficient appliances, with an average opportunity of 1,546 kWh/year per household – more than twice the next-highest cluster. This translates to around 2.4 TWh/year when scaled to the whole of England.

■ The 'Peak-Time Users' cluster offers a high potential for shifting peak demand, with an average possible saving of 341 W per household during the 6-7pm peak (approximately 0.8 GW when scaled to England). This cluster also offers the highest electricity savings from optimising or switching heating fuel (on average 1,049 kWh/year per household – about 2.3 TWh/year for England).

Electricity use in single-person households

■ Single-person households owned significantly fewer cold appliances and TVs than larger households. They also watched significantly fewer hours of TV (average 5.5 hours/day for singles, and 7.8 hours/day for couples).

■ Single-person households also use the washing machine less than other groups (76 times a year, on average, compared to 130 times a year for couples, with single pensioners running fewest washing cycles).

■ Single person households could save 78 kWh/year by using a half-size dishwasher (six place settings instead of 12). However, as with washing machines, all households would save energy by running dishwashers at lower temperatures, and running at 55°C instead of 70°C could save 31 to 96 kWh/year for each household that makes the change.

Appliance use associations

■ Sophisticated analysis using 'association rules' and the 'apriori principle' found a strong link between cooking and watching TV: when households were using cooking appliances there was as much as a 74% chance that the TV would be on. This analysis also uncovered links between TV use while ICT, audiovisual and washing appliances were on.

■ Predictably, we found strong correlations between use of related ICT appliances (computers, monitors, printers etc.), and between audiovisual appliances (TVs, games consoles, hi-fi's etc.). This reminds us that projections for electricity consumption from TVs and ICT must include the power use of associated appliances as well as the 'primary' appliance.

■ The analysis also found that households from lower social grades were more likely to have the TV on in the background while performing other tasks. It is very common for households of all grades to use TV as a background activity, and new TVs with programmable auto-off periods (which switch off when there is no interaction with the remote control) should bring significant savings as penetration rises.

Seasonality trends in non-heating appliances

■ We identified a large seasonal variation in tumble dryer use, with average energy use of 1.7 kWh/day in winter compared to only 0.8 kWh/day in summer for households with tumble dryers. However, there was very little seasonal variation in energy use for dishwashers or washing machines.

■ The seasonal trend for cold appliances was the reverse: greater energy use in summer and less in winter, because of the variation in external temperature. Fridges are more susceptible to seasonal variations than freezers, and four of the fridges in the sample used 50% more energy in summer than in winter.

■ We found hardly any seasonal variation in the use of most electric cooking equipment: ovens, cookers (oven and hob) and microwaves had very consistent use through the year. Conversely, kettles showed a much larger variation through the seasons – an average of 0.4 kWh/day in summer, rising towards 0.6 kWh/day in winter.

Assess electricity demand for products with high agency

■ Here we tried to estimate possible savings by changing the way households use appliances where they have more discretion about how they use them – entertainment devices, washing appliances, and some forms of lighting. We found strong links between demographic factors (like the number of people in a household) and energy use for these appliances.

■ However, the work identified worthwhile potential savings – if high-use households could be persuaded to reduce appliance use to the average for similar households. For lighting, audio-visual, tumble dryers and ICT, this might save 330-445 kWh/year per dwelling, on average.

Assess savings from smaller, simpler appliances

■ Televisions are getting gradually larger over time, and using more energy as a result. Screen size is undermining the efficiency gains achieved in new TVs. If a household that has yet to buy a new TV today bought a TV the same size as they had 10 years ago instead of today's mean size, they could save 50 W, or about 47% of the energy to run their TV when it is on.

■ The equivalent saving for a washing machine is much smaller – only 25 Wh per load, or 5% of the energy used per load. This is because the increase in average size over time is less dramatic.

■ For fridges, if a household that needed to replace its fridge bought one the same size as they did 10 years ago, they might save 14 kWh/year, or 9.5% of the fridge's annual energy use.

Unpack the data on use of washing machines

■ New washing machines and washing powders designed for low temperature washes have been relatively successful in encouraging more energy efficient low temperature wash modes.

■ However, new washing machines are not demonstrably more energy efficient than older models. On average, machines purchased in 2010-11 used about 35% more electricity per cycle than machines bought in 1997-98. Balanced against this is the increased volume of newer machines, allowing more clothes per wash, and average volume increased about 20% between these years.

Investigate electric heating in conservatories

■ Only five of the HES homes had conservatories with electric heating, and three of them also had radiators linked to the central heating in the conservatory. Three of the five showed evidence of very limited electric heating in the conservatories in cold weather: this heating was used with restraint. However, the other two had average electric heating of the conservatories of between 500 and 1200 W during the day – all peak rate electricity.

■ If the HES households are representative (uncertain because of the tiny sample of homes with conservatories), and if *all* English homes refrained from using electric heating in their conservatories, 1.6 GW could be saved from the evening peak load.

Appliances left on when not in use

■ Nearly 80 of the 250 households in the survey left some lights on overnight, and this lighting used an average of 11.8 W, equivalent to 23-37 kWh per year for each household. If 1 million households could be persuaded to turn off all lights overnight, this would save from 9 to 14.5 MW, or 23-37 GWh over the year.

■ At least 18 households left appliances on in empty rooms for more than one hour/day. These households appear to be wasting from 62 to 250 kWh/year each, and TVs and computers are the most common appliances left on when not in use. Looking across all homes, we estimate that switching off unused appliances would achieve typical savings in the range from 10 to 44 kWh/year per home.

Rebound effects from more efficient products

■ We could not find any significant evidence of a rebound effect (where improved efficiency leads to increased use) for TVs, dishwashers, washing machines, tumble dryers or washer-dryers.

Introduction

The Household Electricity Survey monitored a total of 250 owner-occupier households across England from 2010 to 2011. Twenty-six of these households were monitored for a full year. The remaining 224 were monitored for one month, on a rolling basis throughout the trial. There were no private rented homes or homes owned by registered social landlords or local authorities – to avoid the extra procedures necessary in getting agreement from both tenants and landlords to participate.

The study had four broad objectives at the outset[1]:

1. To identify and catalogue the range and quantity of electrically powered appliances, products and gadgets found in the typical home.
2. To understand their patterns of use - in particular, their impact on peak electricity demand.
3. To monitor total electricity consumption of the home as well as individually monitoring the majority of appliances in the household.
4. To collect 'user habit' data when using a range of appliances through the use of diaries.

Participants kept detailed diaries of how they used certain appliances, which can be matched against actual energy use monitoring for their homes. They had between 13 and 85 appliances in their homes, with about a third of households owning between 30 and 40 appliances.

Seasonal adjustments

Most of the households in the survey were only monitored for a month, and these figures were unduly affected by the time of year when they were monitored. As a result, for some of the Department's questions we had to adjust the data for these homes to account for seasonal differences. For example, fridges and freezers use more energy in the summer, but lighting is used more in the winter.

We used data from the 26 households monitored over a whole year to generate seasonality factors for each appliance type – cold appliances, electric cooking, lighting, washing, AV, ICT, water heating and space heating. (For water heating there was no significant difference between the seasons.)

We calculated the electricity use on each day for each appliance type, averaging over the total usage for the 26 households. Then we normalised this by dividing by the total use over the year, times 365 to get a factor for each day.

The results were very noisy, so we used regression analysis and least squares to find a best fit curve, based on sine and cosine functions. We generated a separate adjustment curve for each of the eight appliance types where there was a link between energy use and the time of year.

[1] DECC/EST/DEFRA (2012) Powering the Nation. London: DECC/EST/DEFRA.

The adjustments result in increased uncertainty, which is hard to quantify, particularly for heating due to the small sample. (None of the households monitored for a year used electricity for their main heating.) For heating we avoid using the adjusted figures where possible.

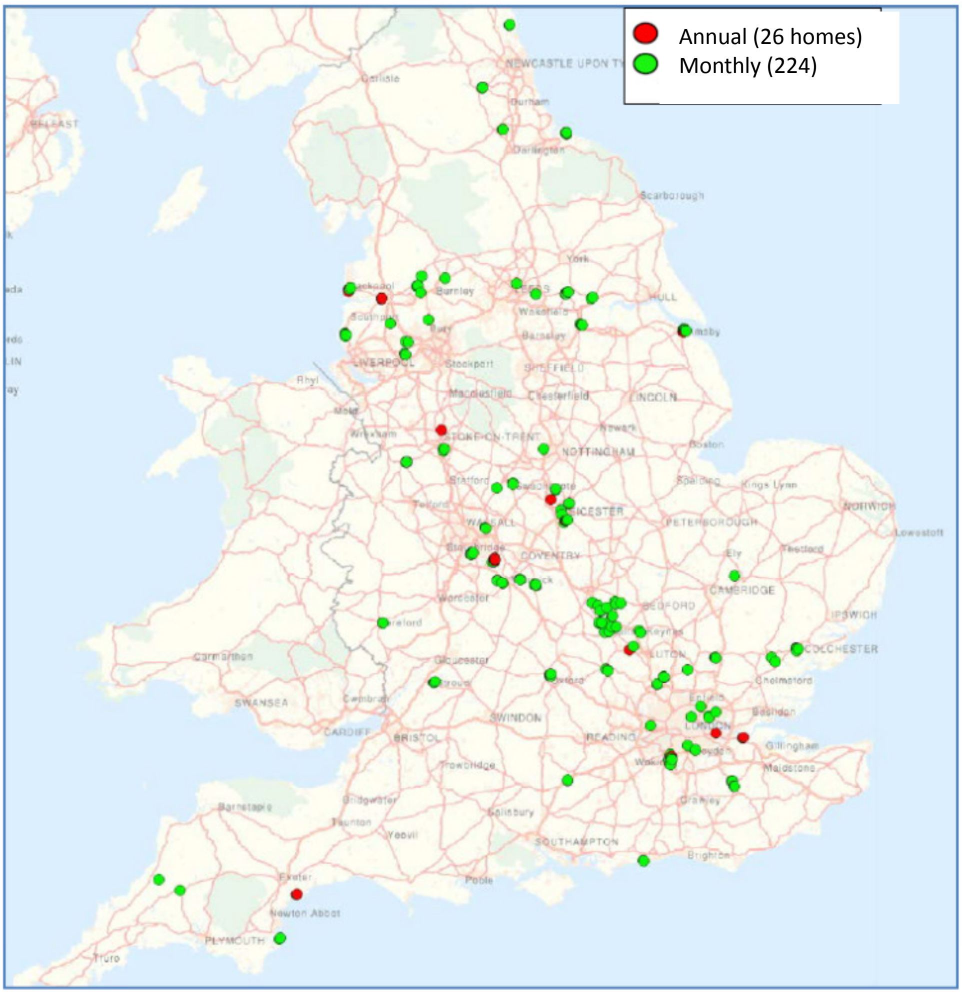
The sample of homes was not perfectly representative – partly because only homeowners were included and partly because they were more energy-conscious than average households. However they were fairly typical in terms of social grade, number of residents, life stage, and property age[2]. Average (mean) electricity use across homes in the sample was 4,093 kWh/year, against a mean of 4,154 kWh across all UK homes[3]. The location of households that participated is shown on the map below.

This data offers an unparalleled source of very detailed electricity profiles. It has already provided unmatched insights into the way electricity is used in English homes. However, there remains considerable potential for doing more with the data – notably in understanding the scope for demand shifting, baseload electricity demand, changes in the size and efficiency of appliances, and how different socio-economic groups and ages use electricity. It also provides a rich seam of data we can mine to inform the National Monitoring Survey using smart meters, to support or challenge DECC's existing understanding of power use, and to support or challenge the Department's current statistics and modelling of electricity use in homes.

This report, by Cambridge Architectural Research Ltd, Loughborough University and Element Energy, is the second in a series of five reports that investigate different questions drawn up by DECC and DEFRA. These questions were unexplored, or not explored in full, in the original analysis of the Household Electricity Survey[3] (HES).

[2] Zimmerman et al (2012) Household Electricity Survey: A study of domestic electrical product usage. Milton Keynes: Intertek/EST/DECC/DEFRA.

[3] DECC (2012) Energy Consumption in the UK. London: DECC. (Tables 3.1 and 3.3.)



Participants came from most parts of England, although they were not perfectly representative – the south-west is under-represented and the north is over-represented. Source: Zimmermann et al, 2012[4].

Working closely together, we scrutinised and analysed the data in a variety of different ways to explore specific questions. We have established a secure database for the data, and used tools including SPSS, R (both specialist statistics packages), Excel and SQL (structured query language) for analysis. Where necessary we used programming for functions that were not supported in these packages. We carried out standard statistical tests (t-tests and others), and we focused quite explicitly on uncertainty in the data and the analysis.

We are writing five detailed reports over the 13 months of this project:

- One on 'Demand side management and grids'[5]
- This report, on 'Appliances ownership and usage patterns'

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[4] Zimmerman et al (2012) Household Electricity Survey: A study of domestic electrical product usage. Milton Keynes: Intertek/EST/DECC/DEFRA.

[5] Palmer J, Terry N, Kane T (2013) Further Analysis of the Household Electricity Use Survey: Early findings – demand side management. London: DECC/DEFRA.

- One report on ‘Extreme users’, ‘Updating modelling’, and ‘Updating electricity use statistics by appliance’
- One report on ‘Social studies and Policy’, and
- The Final Report – giving an overview of the whole project and summarising the main findings to emerge.

Limitations of the data

Studies like the Household Electricity Survey are unusual because they are complex to organise, and very expensive. Inevitably, there are some compromises in assembling such a rich set of data – largely linked to the modest sample size. Ideally, there would have been thousands, or perhaps tens of thousands of households participating in the study, including both rented and privately-owned homes. Ideally, all homes would have been monitored for the full 12 months rather than having some of them monitored for just one month. Some commentators hold that gender is an important determinant of energy use at home, and ideally we would have data on the gender makeup of households and/or individual participants, but this data was not collected.

It is possible that people living in rented property use electric appliances differently from owner occupiers, although we know of no empirical work in the UK that demonstrates this.

The Departments asked us to draw out policy recommendations from the work where possible. They and we recognise that policy recommendations would be more robust if based on a larger sample – especially for work focused on subsets of the homes in the study (e.g. homes with electric heating, or pensioners). The small sample makes it impossible to extrapolate reliably to all homes, but it is a starting point, and where possible we combine with other sources of empirical data.

In many parts of this work we see associations (or the absence of associations) between demographic profiles and patterns of energy use. We suggest explanations for these patterns where appropriate, with caveats, but we would not claim that our interpretations are categorical or definitive, and it is very seldom possible to infer unambiguous causality from the correlations.

Do different households own more appliances, or older ones?

The Departments wished to find out about the relationship between appliance ownership, appliance age and socio-demographic indicators. On ownership, they wanted to know whether households have one or more of certain appliances, while on appliance age, they wanted to know how long ago the appliance was originally purchased. The presence of appliances and their age was recorded in 251 HES households through an appliance survey and questions to the householders. Socio-demographic data were also captured for each household.

(This section of the report, and the three sections that follow, have data for 251 households, whereas all other sections report 250 households. This is because although 251 households started the survey and completed the initial questions about their appliances, one later dropped out, so there is no electricity use data for this household.)

Approach

Ten appliance types are included in this analysis. An appliance type was included if it was covered by energy label legislation or where there was sales data available for comparison. The exception to this rule was ovens, which are not included as the sample size was too small (n=19). An appliance type of 'All cold appliances' was also included. The ten appliance types are:

- Dishwashers
- Washing machines
- Tumble dryers
- All cold appliances
- Refrigerators
- Freezers
- Fridge-freezers
- Televisions
- Microwaves, and
- Kettles.

The percentage ownership of the appliances (how many homes owned one or more of a particular appliance type) was calculated according to different socio-demographic groups. The breakdown of groups included social grade, employment status, the age of the household reference person, household size, household type and environmental concern. The percentage ownership values are given for all homes in the HES sample, and for sub-samples according to the socio-demographic groups. 95% confidence intervals are also calculated for the percentage ownership values. To test for the impact of socio-demographic indicators on appliance ownership, Chi square tests (statistical tests that compare how well a theoretical distribution fits observations) within each socio-demographic group are used to establish whether differences in appliance ownership relate to socio-demographics.

Similar statistics are calculated for the mean appliance age. Here the significance tests used are Analysis of Variance (ANOVA) tests, to identify if there are any statistically significant relationships between mean appliance age and socio-demographic groups. (Refer to the

'Significance tests' box on p82 for more information about this.)

The results of this analysis are shown in a series of tables in the 'Evidence' section below.

Findings

In the HES sample, 99% of homes owned at least one television, cold appliance and kettle (see summary table below). 91% of homes owned a washing machine and 91% also owned a microwave. The remaining appliance types were owned in from 48% to 74% of homes. In comparison with ONS national ownership statistics, the HES sample had slightly lower ownership values in all appliance types, except for dishwashers, which were slightly higher.

Summary statistics of appliance ownership and age

	HES sample				Comparison data	
Appliance type	Percentage appliance ownership in HES* (%)	Mean appliance age (years)	Estimated lifespan (years)	Age of oldest appliance	National ownership (%)[6]	Appliance lifespan[7] (results from two previous studies)
Dishwasher	59	5.5	11	18	40	8 and 13
Washing machine	91	5.7	11	22	96	12 and 14
Tumble dryer	53	6.7	13	26	57	13 and 17
All cold appliances	100	7.4	15	41	97	-
Refrigerator	50	6.8	14	21	-	16 and 19
Freezer	48	6.8	14	30	-	11 and 19
Fridge-freezer	74	8.4	17	41	-	-
Television	99	5.3	11	27	99	-
Microwave	91	6.2	12	31	92	-
Kettle	99	3.8	8	26	-	-

** The data for this column is from a survey that the householders completed. However, we have limited information about these appliances. Later tables are based on the number of appliances monitored, where we have energy use data. Since this data is not complete the ownership figures should be considered as a lower bound.*

The mean appliance age varied between 3.8 years (kettles) and 8.4 years (fridge-freezers). Mean appliance age can be used as an indication of the lifespan of an appliance, defined as the length of time before an appliance is replaced. Here we estimate that the approximate average lifespan of a product is twice the average age of the stock of appliances. For the HES sample the estimated lifespans of dishwashers, washing machines, tumble dryers,

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[6] ONS (2011) Ownership of consumer durables increases into 2010 http://www.ons.gov.uk/ons/rel/family-spending/family-spending/family-spending-2011-edition/sum-consumer-durables-nugget.html (accessed 2nd October 2013)

[7] Young, D. (2008) When do energy-efficient appliances generate energy savings? Some evidence from Canada. Energy Policy, 36(1), 34–46

refrigerators and freezers are comparable with appliance lifespans reported in the academic literature. There were also some very old appliances within the sample, including a fridge-freezer reported to be 41 years old.

There is detailed analysis in the tables in the Evidence section below, and this points to a number of significant relationships between appliance ownership, appliance age and the socio-demographic groups:

Social grade: Households classified as the old National Readership Survey social grade A are more likely to own a dishwasher (93% of households in social grade A, P<0.05) than the average ownership (59% of the whole HES sample). Conversely, those in social grade D are less likely to own a dishwasher (35%, P<0.05). Households in social grade A are also more likely to own a tumble dryer (86%, P<0.05) than the average ownership (55% of the whole HES sample). Viewed logically, those in social grade A have professional jobs and this could mean they are more likely to have expendable income to spend on items sometimes perceived as 'luxuries'.

Employment status: People in part time employment were more likely to own a dishwasher (80%, P<0.05), while retired people were less likely to own a dishwasher (42%, P<0.05).

Age of Household Representative Person: People aged between 45-54 years are more likely to own a dishwasher (78%, P<0.05), compared to 59% for the whole sample, while those aged 65-74 (40%, P<0.05) and 75+ (32%, P<0.05) are less likely to own a dishwasher. Those aged between 65 and 75 years own older washing machines, on average (mean appliance age 7.5 years old). On the other hand, people aged between 19 and 34 have washing machines that are newer, on average (mean appliance age 3.5 years old). We found similar results for cold appliances and televisions.

Household size: The most consistent results are related to household size. Households with one person are less likely to own dishwashers (34% compared to 59% for all homes, P<0.05), tumble dryers (31% compared to 55%), refrigerators (40% against 51%) and microwaves (86% compared to 91%). Conversely, households with 4 or more people are more likely to own dishwashers, tumble dryers and refrigerators.

Household type: Older tumble dryers were owned by households with single (10.1 years compared to 2.4 years for single non pensioners) and multiple pensioners (11.3 years). We found a similar trend for cold appliances, with people aged between 65-74 (9.4 years) and those 75+ (10.1 years) having older fridge-freezers than people aged between 35-44 years old (5.1 years).

We also found a number of other statistically significant relationships, and these are highlighted in blue in the Evidence tables below.

Recommendations

■ Some appliances are more likely to be purchased by individuals from certain social demographic groups. Consequently energy use information could be targeted more directly to these people.

- People in social grade A are more likely to own a dishwasher.
- Households classified as social grade A are more likely to own a tumble dryer.

■ Households reporting a high level of environmental concern were more likely to own certain appliance types. We recommend that information is provided to environmentally-concerned households about the value of upgrading to more efficient appliances in terms of saving energy and CO_2 emissions.

■ Cold appliances, tumble dryers, washing machines and televisions owned by older or retired people were found to be significantly older. This suggests that there may be merit in targetting information promoting the benefits of purchasing newer, energy efficient appliances at older people.

Evidence - Ownership and age according to social demographic descriptors

Dishwashers

Socio-demographic descriptor		Number of households	Dishwasher ownership			Dishwasher age		
			n	Percentage within socio-demographic category		n	Reported value within socio-demographic category (years)	
				Value	(95% CI)		Mean	(95% CI)
	All	251	147	59%	(52% to 65%)	92	5.5	(4.7 to 6.2)
Social Grade	A	14	13	93%**	(79% to 106%)	7	4.3	(1.2 to 7.4)
	B	68	48	71%**	(60% to 81%)	27	5.9	(4.3 to 7.5)
	C1	93	53	57%	(47% to 67%)	33	5.1	(4.0 to 6.2)
	C2	42	21	50%	(35% to 65%)	16	5.5	(4.0 to 7.0)
	D	23	8	35%**	(15% to 54%)	5	6.4	(0 to 14.7)
	E	11	4	36%	(8% to 65%)	4	6.0	(0.3 to 11.7)
Employment status	Full-time paid work	81	51	63%	(52% to 73%)	26	5.4	(4.1 to 6.6)
	Part-time paid work	44	35	80%**	(52% to 73%)	27	5.0	(3.6 to 6.4)
	Unemployed	10	5	50%	(68% to 91%)	2	6.5	(0 to 51)
	Retired	95	40	42%**	(19% to 81%)	28	5.9	(4.3 to 7.5)
	Not in paid employment	18	13	72%	(32% to 52%)	8	5.0	(2.3 to 7.7)
	Full time higher education	3	3	100%	(52% to 93%)	1	10.0	N/A
Age HRP	19-34	20	11	55%	(100% to 100%)	6	4.8	(2.7 to 7.0)
	35-44	54	36	67%	(54% to 79%)	22	4.5	(3.2 to 5.9)
	45-54	50	39	78%**	(33% to 77%)	23	6.0	(4.3 to 7.6)
	55-64	55	34	62%	(54% to 79%)	23	5.6	(4.3 to 6.8)
	65-74	47	19	40%**	(67% to 89%)	14	6.3	(3.2 to 9.3)
	75+	25	8	32%**	(49% to 75%)	4	5.0	(0.7 to 9.3)
Household size	1 person	70	24	34%**	(23% to 45%)	25	6.6	(4.7 to 8.4)
	2 people	87	53	61%	(51% to 71%)	26	5.5	(4.5 to 6.5)
	3 people	30	20	67%	(50% to 84%)	11	4.8	(2.5 to 7.1)
	4 people	49	37	76%**	(63% to 88%)	24	5.0	(3.5 to 6.6)
	5 people	8	7	88%*	(65% to 110%)	2	3.0	(3.0 to 3.0)
	6 or more people	7	6	86%	(60% to 112%)	4	3.8	(1.0 to 6.5)
Household type	Single Pensioner	34	7	21%*	(49% to 75%)	5	3.0	(0.4 to 5.6)
	Single Non Pensioner	35	16	46%	(26% to 54%)	7	6.3	(2.7 to 9.9)
	Multiple Pensioner	29	13	45%	(14% to 50%)	7	7.1	(2.2 to 12.1)
	Household With Children	78	55	71%**	(60% to 81%)	36	4.9	(3.9 to 6.0)
	Multiple With No Dependent Children	75	56	75%**	(7% to 34%)	37	5.8	(4.6 to 7.0)
Environmental concern	Very concerned	69	46	67%	(29% to 62%)	32	4.7	(3.5 to 5.9)
	Fairly concerned	116	70	60%	(27% to 63%)	40	6.2	(5.0 to 7.3)
	Not very concerned	46	23	50%	(60% to 81%)	15	5.7	(3.4 to 8.0)
	Not at all concerned	15	5	33%*	(65% to 85%)	3	5.7	(0 to 11.9)
	No opinion	2	1	50%	(0% to 119%)	0	-	N/A
	Did not answer	3	2	67%	(56% to 78%)	2	1.5	(0 to 7.9)

*Statistically significant at the 90% level, **Statistically significant at the 95% level

Washing machine

Socio-demographic descriptor		Number of households	Washing machine ownership			Washing machine age		
			n	Percentage within socio-demographic category		n	Reported value within socio-demographic category (years)	
				Value	(95% CI)[1]		Mean	(95% CI)[1]
	All	251	247	98%	(97% to 100%)	202	5.7	(5.1 to 6.3)
Social Grade	A	14	14	100%	(100% to 100%)	12	5.9	(3.4 to 8.5)
	B	68	66	97%	(93% to 101%)	54	5.3	(4.3 to 6.3)
	C1	93	93	100%	(100% to 100%)	74	5.8	(4.8 to 6.9)
	C2	42	41	98%	(93% to 102%)	34	5.3	(3.7 to 6.9)
	D	23	22	96%	(87% to 104%)	19	5.9	(4.2 to 7.6)
	E	11	11	100%	(100% to 100%)	9	7.4	(2.5 to 12.4)
Employment status	Full-time paid work	81	79	98%	(94% to 101%)	**62**	**4.5**[a]	**(3.7 to 5.3)**
	Part-time paid work	44	44	100%	(100% to 100%)	39	5.4	(3.9 to 6.8)
	Unemployed	10	10	100%	(100% to 100%)	7	4.7	(1.3 to 8.2)
	Retired	95	93	98%	(95% to 101%)	**76**	**6.9**[a]	**(5.7 to 8.0)**
	Not in paid employment	18	18	100%	(100% to 100%)	17	6.1	(4.5 to 7.8)
	Full time higher education	3	3	100%	(100% to 100%)	1	2.0	N/A
Age HRP	19-34	20	20	100%	(100% to 100%)	16	3.5	(1.9 to 5.1)
	35-44	54	54	100%	(100% to 100%)	45	5.2	(4.0 to 6.3)
	45-54	50	50	100%	(100% to 100%)	35	5.1	(3.9 to 6.3)
	55-64	55	53	96%	(91% to 101%)	50	6.0	(4.7 to 7.2)
	65-74	47	45	96%	(90% to 102%)	37	7.5	(5.9 to 9.2)
	75+	25	25	100%	(100% to 100%)	19	5.6	(3.2 to 7.9)
Household size	1 person	70	68	97%	(93% to 101%)	59	5.9	(4.7 to 7.2)
	2 people	87	85	98%	(95% to 101%)	67	6.1	(4.9 to 7.2)
	3 people	30	30	100%	(100% to 100%)	26	5.2	(4.0 to 6.4)
	4 people	49	49	100%	(100% to 100%)	39	5.5	(4.3 to 6.6)
	5 people	8	8	100%	(100% to 100%)	4	3.0	(0.1 to 5.9)
	6 or more people	7	7	100%	(100% to 100%)	7	4.4	(2.4 to 6.5)
Household type	Single Pensioner	**34**	**32**	**94%****	**(86% to 102%)**	29	6.6	(5.0 to 8.2)
	Single Non Pensioner	35	35	100%	(100% to 100%)	28	6.6	(4.9 to 8.4)
	Multiple Pensioner	29	29	100%	(100% to 100%)	20	6.6	(4.4 to 8.8)
	Household With Children	78	78	100%	(100% to 100%)	66	4.9	(4.0 to 5.8)
	Multiple With No Dependent Children	75	73	97%	(94% to 101%)	59	5.3	(4.1 to 6.5)
Environmental Concern	Very concerned	69	69	100%	(100% to 100%)	62	5.4	(4.5 to 6.4)
	Fairly concerned	116	115	99%	(97% to 101%)	87	5.8	(4.9 to 6.7)
	Not very concerned	46	44	96%	(90% to 102%)	37	5.8	(4.2 to 7.4)
	Not at all concerned	15	14	93%	(81% to 106%)	12	6.8	(2.8 to 10.8)
	No opinion	2	2	100%	(100% to 100%)	1	4.0	N/A
	Did not answer	3	3	100%	(100% to 100%)	3	3.3	(0 to 11.3)

[1] Confidence Interval.

*Statistically significant at the 90% level. **Statistically significant at the 95% level.

[a] ANOVA statistics show statistically different average appliance age between groups.

Tumble dryer

Socio-demographic descriptor		Number of households	Tumble dryer ownership			Tumble dryer age		
			n	Percentage within socio-demographic category		n	Reported value within socio-demographic category (years)	
				Value	(95% CI)		Mean	(95% CI)
	All	251	138	55%	(49% to 61%)	96	6.7	(5.5 to 7.8)
Social Grade	A	**14**	**12**	**86%****	**(67% to 104%)**	10	9.0	(4.4 to 13.6)
	B	68	34	50%	(38% to 62%)	25	5.9	(4.1 to 7.7)
	C1	93	49	53%	(43% to 63%)	35	5.7	(4.0 to 7.4)
	C2	42	24	57%	(42% to 72%)	16	7.7	(3.9 to 11.4)
	D	23	13	57%	(36% to 77%)	9	8.6	(2.9 to 14.2)
	E	11	6	55%	(25% to 84%)	1	1.0	N/A
Employment status	Full-time paid work	81	48	59%	(49% to 70%)	**35**	**4.7 [a]**	**(3.4 to 6.1)**
	Part-time paid work	44	24	55%	(40% to 69%)	20	6.0	(4.3 to 7.6)
	Unemployed	10	5	50%	(19% to 81%)	**2**	**6.0 [a]**	**(0 to 44.1)**
	Retired	95	49	52%	(42% to 62%)	30	9.9	(7.0 to 12.7)
	Not in paid employment	18	11	61%	(39% to 84%)	8	5.5	(2.6 to 8.4)
	Full time higher education	3	1	33%	(0% to 87%)	1	3.0	N/A
Age HRP	19-34	20	9	45%	(23% to 67%)	**6**	**3.3 [a]**	**(0.4 to 6.3)**
	35-44	**54**	**37**	**69%****	**(56% to 81%)**	**27**	**5.0 [a]**	**(3.7 to 6.2)**
	45-54	50	28	56%	(42% to 70%)	**19**	**5.3 [a]**	**(3.7 to 6.9)**
	55-64	55	29	53%	(40% to 66%)	22	7.6	(4.5 to 10.7)
	65-74	47	25	53%	(39% to 67%)	**16**	**10.3 [a]**	**(6.3 to 14.2)**
	75+	25	10	40%	(21% to 59%)	6	9.2	(2.0 to 16.4)
Household size	1 person	**70**	**22**	**31%****	**(21% to 42%)**	24	7.2	(4.3 to 10.1)
	2 people	87	51	59%	(48% to 69%)	36	6.3	(4.6 to 8.1)
	3 people	30	19	63%	(46% to 81%)	14	6.6	(3.8 to 9.5)
	4 people	**49**	**37**	**76%****	**(63% to 88%)**	18	7.3	(4.3 to 10.3)
	5 people	8	6	75%	(45% to 105%)	1	3.0	(0 to 0)
	6 or more people	7	3	43%	(6% to 80%)	3	4.0	(0 to 10.6)
Household type	Single Pensioner	**34**	**10**	**29%****	**(14% to 45%)**	**6**	**10.2 [a]**	**(3.3 to 17)**
	Single Non Pensioner	**35**	**12**	**34%****	**(19% to 50%)**	**7**	**2.4 [a]**	**(1.3 to 3.6)**
	Multiple Pensioner	29	15	52%	(34% to 70%)	**10**	**11.3 [a]**	**(5.9 to 16.7)**
	Household With Children	**78**	**52**	**67%****	**(56% to 77%)**	**38**	**5.1 [a]**	**(4.1 to 6.1)**
	Multiple With No Dependent Children	**75**	**49**	**65%****	**(55% to 76%)**	35	7.3	(5.1 to 9.5)
Environmental concern	Very concerned	69	37	54%	(42% to 65%)	26	6.4	(4.6 to 8.2)
	Fairly concerned	116	70	60%	(51% to 69%)	46	6.4	(4.9 to 8.0)
	Not very concerned	46	22	48%	(33% to 62%)	19	6.8	(3.2 to 10.5)
	Not at all concerned	15	7	47%	(21% to 72%)	4	8.8	(0 to 21.6)
	No opinion	2	1	50%	(0% to 119%)	0	-	N/A
	Did not answer	3	1	33%	(0% to 87%)	1	12.0	N/A

*Statistically significant at the 90% level **Statistically significant at the 95% level

[a] ANOVA statistics show statistically different average appliance age between groups

Refrigerators

Socio-demographic descriptor		Number of households (ave no. appliance per home)	Refrigerator ownership			Refrigerator age		
			n	Percentage within socio-demographic category		n	Reported value within socio-demographic category (years)	
				Value	(95% CI)[1]		Mean	(95% CI)[1]
	All	251	127	51%	(32% to 44%)	87	6.8	(5.9 to 7.7)
Social Grade	A	14	10	71%	(39% to 89%)	10	6.7	(4.7 to 8.7)
Social Grade	B	68	35	51%	(29% to 53%)	21	7.5	(5.0 to 10.1)
Social Grade	C1	93	51	55%	(25% to 44%)	30	6.4	(4.9 to 7.8)
Social Grade	C2	42	19	45%	(23% to 53%)	15	7.4	(5.2 to 9.6)
Social Grade	D	23	6	26%**	(8% to 44%)	6	4.3	(1.0 to 7.7)
Social Grade	E	11	6	55%	(16% to 75%)	5	8.0	(1.5 to 14.5)
Employment status	Full-time paid work	81	43	53%	(26% to 47%)	28	6.4	(5.2 to 7.6)
Employment status	Part-time paid work	44	22	50%	(24% to 54%)	19	8.5	(5.7 to 11.3)
Employment status	Unemployed	10	6	60%	(2% to 58%)	2	6.0	(0 to 69.5)
Employment status	Retired	95	45	47%	(33% to 53%)	34	6.3	(4.9 to 7.7)
Employment status	Not in paid employment	18	10	56%	(0% to 36%)	4	6.5	(1.6 to 11.4)
Employment status	Full time higher education	3	1	33%	(10% to 90%)	0	-	N/A
Age HRP	19-34	20	8	40%	(0% to 34%)	2	10.0	(0 to 86.2)
Age HRP	35-44	54	27	50%	(29% to 56%)	20	6.4	(4.6 to 8.2)
Age HRP	45-54	50	26	52%	(25% to 51%)	15	7.2	(5.1 to 9.3)
Age HRP	55-64	55	35	64%	(36% to 62%)	29	6.3	(4.6 to 8.0)
Age HRP	65-74	47	20	43%**	(19% to 45%)	14	8.4	(5.7 to 11.2)
Age HRP	75+	25	11	44%	(16% to 51%)	7	5.3	(2.3 to 8.2)
Household size	1 person	70	28	40%**	(29% to 51%)	24	8.2	(5.7 to 10.8)
Household size	2 people	87	41	47%	(37% to 58%)	30	6.4	(5.2 to 7.6)
Household size	3 people	30	18	60%	(42% to 78%)	13	6.0	(4.0 to 8.0)
Household size	4 people	49	30	61%*	(48% to 75%)	15	5.3	(3.8 to 6.8)
Household size	5 people	8	4	50%	(15% to 85%)	3	8.3	(2.1 to 14.6)
Household size	6 or more people	7	6	86%*	(60% to 112%)	2	10.5	(0 to 80.4)
Household type	Single Pensioner	34	15	44%**	(19% to 51%)	10	7.8	(3.8 to 11.8)
Household type	Single Non Pensioner	35	12	34%	(21% to 53%)	13	7.5	(4.7 to 10.2)
Household type	Multiple Pensioner	29	10	34%*	(27% to 63%)	7	6.0	(3.2 to 8.8)
Household type	Household With Children	78	44	56%	(28% to 49%)	27	6.8	(5.2 to 8.3)
Household type	Multiple With No Dependent Children	75	46	61%**	(26% to 48%)	30	6.4	(4.8 to 8.1)
Environmental concern	Very concerned	69	34	49%	(25% to 48%)	24	7.2	(5.0 to 9.3)
Environmental concern	Fairly concerned	116	58	50%	(30% to 48%)	36	6.9	(5.4 to 8.4)
Environmental concern	Not very concerned	46	22	48%	(23% to 51%)	18	5.7	(4.7 to 6.8)
Environmental concern	Not at all concerned	15	9	60%	(21% to 72%)	7	7.9	(4 to 11.7)
Environmental concern	No opinion	2	2	100%	(0% to 119%)	1	13.0	N/A
Environmental concern	Did not answer	3	2	67%	(0% to 87%)	1	2.0	N/A

[1] Confidence Interval

*Statistically significant at the 90% level **Statistically significant at the 95% level

Freezers

Socio-demographic descriptor		Number of households (mean no. appliances per home)	Freezer ownership			Freezer age		
			n	Percentage within socio-demographic category		n	Reported value within socio-demographic category (years)	
				Value	(95% CI)		Mean	(95% CI)
	All	251	117	47%	(40% to 53%)	122	8.4	(7.2 to 9.6)
Social Grade	A	14	7	50%	(24% to 76%)	12	8.9	(5.8 to 12.1)
	B	68	30	44%	(32% to 56%)	28	8.7	(5.9 to 11.5)
	C1	93	46	49%	(39% to 60%)	38	8.8	(5.9 to 11.7)
	C2	42	18	43%	(28% to 58%)	22	8.5	(5.7 to 11.3)
	D	23	11	48%	(27% to 68%)	12	7.1	(4.4 to 9.7)
	E	11	5	45%	(16% to 75%)	10	6.9	(3.9 to 9.9)
Employment status	Full-time paid work	81	38	47%	(36% to 58%)	37	7.9	(6.2 to 9.5)
	Part-time paid work	44	19	43%	(29% to 58%)	20	8.2	(6.0 to 10.4)
	Unemployed	10	5	50%	(19% to 81%)	6	6.5	(2.6 to 10.4)
	Retired	95	47	49%	(39% to 60%)	52	8.8	(6.4 to 11.2)
	Not in paid employment	18	8	44%	(21% to 67%)	7	10.7	(1.7 to 19.7)
	Full time higher education	3	0	0%	(0% to 0%)	0	N/A	
Age HRP	19-34	20	4	20%**	(2% to 38%)	1	16	N/A
	35-44	54	20	37%	(24% to 50%)	24	7.8	(5.1 to 10.5)
	45-54	50	27	54%	(40% to 68%)	26	8.8	(6.7 to 11.0)
	55-64	55	30	55%	(41% to 68%)	34	7.9	(5.6 to 10.2)
	65-74	47	25	53%	(39% to 67%)	27	9.9	(6.2 to 13.6)
	75+	25	11	44%	(25% to 63%)	10	5.5	(2.3 to 8.7)
Household size	1 person	70	26	37%*	(26% to 48%)	36	8.1	(6.1 to 10.2)
	2 people	87	42	48%	(38% to 59%)	43	9.1	(6.4 to 11.9)
	3 people	30	16	53%	(35% to 71%)	16	6.1	(4.0 to 8.1)
	4 people	49	25	51%	(37% to 65%)	21	8.4	(5.7 to 11.1)
	5 people	8	4	50%	(15% to 85%)	3	12	(0 to 25.8)
	6 or more people	7	4	57%	(20% to 94%)	3	10.7	(0 to 23.2)
Household type	Single Pensioner	34	15	44%	(27% to 61%)	12	6.5	(3.1 to 9.9)
	Single Non Pensioner	35	10	29%**	(14% to 44%)	12	10.0	(3.9 to 16.1)
	Multiple Pensioner	29	17	59%	(41% to 77%)	15	5.7	(3.8 to 7.7)
	Household With Children	78	37	47%	(36% to 59%)	37	8.5	(6.8 to 10.3)
	Multiple With No Dependent Children	75	38	51%	(39% to 62%)	46	9.3	(6.8 to 11.7)
Environmental concern	Very concerned	69	33	48%	(36% to 60%)	36	7.7	(5.0 to 10.3)
	Fairly concerned	116	47	41%*	(32% to 49%)	43	8.2	(6.6 to 9.8)
	Not very concerned	46	26	57%	(42% to 71%)	28	8.1	(5.2 to 11.1)
	Not at all concerned	15	8	53%	(28% to 79%)	12	9.5	(5.4 to 13.6)
	No opinion	2	1	50%	(0% to 119%)	1	13	N/A
	Did not answer	3	2	67%	(13% to 120%)	2	21	(0 to 148.1)

*Statistically significant at the 90% level **Statistically significant at the 95% level

Fridge-freezers

Socio-demographic descriptor		Number of households	Fridge-freezer ownership			Fridge-freezer age		
			n	Percentage within socio-demographic category		n	Reported value within socio-demographic category (years)	
				Value	(95% CI)		Mean	(95% CI)
	All	251	186	74%	(69% to 80%)	125	6.8	(5.7 to 7.8)
Social Grade	**A**	14	9	64%	(39% to 89%)	4	7.8	(0 to 18.9)
	B	68	50	74%	(63% to 84%)	30	6.7	(4.5 to 9.0)
	C1	93	68	73%	(64% to 82%)	51	6.6	(4.9 to 8.2)
	C2	42	31	74%	(61% to 87%)	19	6.3	(4.3 to 8.4)
	D	23	19	83%	(67% to 98%)	16	7.9	(4.1 to 11.8)
	E	11	9	82%	(59% to 105%)	5	5.6	(0 to 13)
Employment status	**Full-time paid work**	81	58	72%	(62% to 81%)	34	5.5	(3.9 to 7.1)
	Part-time paid work	44	34	77%	(65% to 90%)	25	6.0	(4.8 to 7.1)
	Unemployed	10	8	80%	(55% to 105%)	5	3.4	(1.1 to 5.7)
	Retired	95	68	72%	(63% to 81%)	50	8.7	(6.5 to 10.9)
	Not in paid employment	18	15	83%	(66% to 101%)	9	5.4	(2.9 to 8.0)
	Full time higher education	3	3	100%	(100% to 100%)	2	4.0	(0 to 29.4)
Age HRP	**19-34**	20	17	85%	(69% to 101%)	14	4.7	(2.8 to 6.6)
	35-44	54	41	76%	(65% to 87%)	24	**5.1** [a]	**(3.8 to 6.4)**
	45-54	50	38	76%	(64% to 88%)	20	6.3	(4.1 to 8.4)
	55-64	55	38	69%	(57% to 81%)	27	5.4	(3.9 to 6.9)
	65-74	47	35	74%	(62% to 87%)	25	**9.4** [a]	**(6.1 to 12.6)**
	75+	25	17	68%	(50% to 86%)	15	**10.1** [a]	**(5.2 to 14.9)**
Household size	**1 person**	70	50	71%	(61% to 82%)	34	7.1	(4.7 to 9.4)
	2 people	87	65	75%	(66% to 84%)	45	7.6	(5.8 to 9.4)
	3 people	30	23	77%	(62% to 92%)	12	7.5	(4.9 to 10.1)
	4 people	49	37	76%	(63% to 88%)	24	4.6	(2.6 to 6.6)
	5 people	8	7	88%	(65% to 110%)	4	6.5	(0 to 19.8)
	6 or more people	7	4	57%	(20% to 94%)	6	6.0	(4.0 to 8)
Household type	**Single Pensioner**	34	24	71%	(55% to 86%)	**21**	**6.6** [a]	**(4.0 to 9.3)**
	Single Non Pensioner	35	26	74%	(60% to 89%)	**18**	**5.2** [a]	**(2.7 to 7.6)**
	Multiple Pensioner	29	21	72%	(56% to 89%)	**15**	**12.9** [a]	**(7.7 to 18)**
	Household With Children	78	59	76%	(66% to 85%)	**39**	**5.7** [a]	**(4.6 to 6.7)**
	Multiple With No Dependent Children	75	56	75%	(65% to 85%)	**32**	**6.2**	**(4.3 to 8.1)**
Environmental concern	**Very concerned**	69	52	75%	(65% to 86%)	32	4.9	(3.8 to 6.0)
	Fairly concerned	116	89	77%	(69% to 84%)	56	7	(5.3 to 8.6)
	Not very concerned	46	32	70%	(56% to 83%)	26	7.5	(4.7 to 10.2)
	Not at all concerned	15	9	60%	(35% to 85%)	7	8.9	(1.5 to 16.2)
	No opinion	2	1	50%	(0% to 119%)	0	-	N/A
	Did not answer	3	3	100%	(100% to 100%)	4	9.8	(0 to 19.8)

*Statistically significant at the 90% level **Statistically significant at the 95% level

[a] ANOVA statistics show statistically different average appliance age between groups

Televisions

Socio-demographic descriptor		Number of households (Ave no. appliance per home)	Television ownership			Television age		
			n	Percentage within socio-demographic category		n	Reported value within socio-demographic category (years)	
				Value	(95% CI)[1]		Mean	(95% CI)[1]
	All	251 (2.1)	249	99%	(98% to 100%)	397	5.3	(4.9 to 5.8)
Social Grade	A	14 (2.4)	14	100%	(100% to 100%)	21	5.4	(3.4 to 7.4)
	B	68 (2.1)	67	99%	(96% to 101%)	104	4.8	(3.9 to 5.7)
	C1	93 (2.0)	92	99%	(97% to 101%)	130	5.5	(4.7 to 6.4)
	C2	42 (2.5)	42	100%	(100% to 100%)	73	4.8	(3.7 to 5.9)
	D	23 (2.3)	23	100%	(100% to 100%)	45	5.7	(4.1 to 7.3)
	E	11 (2.5)	11	100%	(100% to 100%)	24	7.5	(4.9 to 10.2)
Employment status	Full-time paid work	81 (2.3)	80	99%	(96% to 101%)	129	4.9	(4.1 to 5.7)
	Part-time paid work	44 (2.4)	43	98%	(93% to 102%)	85	5.2	(4.2 to 6.1)
	Unemployed	10 (2.7)	10	100%	(100% to 100%)	21	5.9	(3.3 to 8.4)
	Retired	95 (1.9)	95	100%	(100% to 100%)	130	5.5	(4.6 to 6.4)
	Not in paid employment	18 (2.2)	18	100%	(100% to 100%)	29	6.6	(4.4 to 8.7)
	Full time higher education	3 (1.0)	3	100%	(100% to 100%)	3	9.3	(0 to 21.1)
Age HRP	19-34	20 (1.8)	19	95%	(85% to 105%)	**27**	**3.7** [a]	**(2.5 to 4.9)**
	35-44	54 (2.3)	53	98%	(95% to 102%)	100	5.3	(4.4 to 6.1)
	45-54	50 (2.5)	50	100%	(100% to 100%)	**82**	**6.7** [a]	**(5.4 to 8.0)**
	55-64	55 (2.3)	55	100%	(100% to 100%)	**89**	**4.2** [a]	**(3.4 to 5.0)**
	65-74	47 (2.0)	47	100%	(100% to 100%)	70	5.3	(4.2 to 6.5)
	75+	25 (1.6)	25	100%	(100% to 100%)	29	6.9	(4.6 to 9.2)
Household size	1 person	70 (1.8)	68	97%	(93% to 101%)	117	4.9	(4.0 to 5.8)
	2 people	87 (2.3)	87	100%	(100% to 100%)	135	5.4	(4.6 to 6.3)
	3 people	30 (2.5)	30	100%	(100% to 100%)	42	5.3	(3.6 to 7.0)
	4 people	49 (2.3)	49	100%	(100% to 100%)	78	5.4	(4.4 to 6.3)
	5 people	8 (2)	8	100%	(100% to 100%)	12	9.0	(5.1 to 12.9)
	6 or more people	7 (1.6)	7	100%	(100% to 100%)	13	5.2	(2.8 to 7.7)
Household type	Single Pensioner	34 (1.6)	34	100%	(100% to 100%)	41	5.9	(4.4 to 7.4)
	Single Non Pensioner	35 (1.6)	33	94%	(87% to 102%)	38	5.8	(4.1 to 7.5)
	Multiple Pensioner	29 (1.9)	29	100%	(100% to 100%)	41	6.0	(4.2 to 7.7)
	Household With Children	78 (2.5)	78	100%	(100% to 100%)	159	5.5	(4.7 to 6.3)
	Multiple With No Dependent Children	75 (2.4)	75	100%	(100% to 100%)	118	4.5	(3.7 to 5.4)
Environmental concern	Very concerned	69 (2.1)	69	100%	(100% to 100%)	113	5.6	(4.6 to 6.6)
	Fairly concerned	116 (2.3)	114	98%	(96% to 101%)	173	5.3	(4.7 to 6.0)
	Not very concerned	46 (2.1)	46	100%	(100% to 100%)	81	4.6	(3.7 to 5.6)
	Not at all concerned	15 (1.9)	15	100%	(100% to 100%)	22	5.8	(3.2 to 8.5)
	No opinion	2 (1.0)	2	100%	(100% to 100%)	2	2	(2.0 to 2.0)
	Did not answer	3 (2.0)	3	100%	(100% to 100%)	6	8.7	(0 to 18.7)

[1] Confidence Interval

[a] ANOVA statistics show statistically different average appliance age between groups

Microwaves

Socio-demographic descriptor		Number of households	Microwave ownership			Microwave age		
			n	Percentage within socio-demographic category		n	Reported value within socio-demographic category (years)	
				Value	(95% CI)		Mean	(95% CI)
	All	251	229	91%	(88% to 95%)	185	6.2	(5.4 to 7.0)
Social Grade	A	14	14	100%	(100% to 100%)	8	6.5	(1.5 to 11.5)
	B	68	61	90%	(82% to 97%)	48	6.3	(4.7 to 8.0)
	C1	93	82	88%	(82% to 95%)	64	6.7	(5.2 to 8.3)
	C2	42	39	93%	(85% to 101%)	33	5.2	(3.6 to 6.9)
	D	23	22	96%	(87% to 104%)	22	6.1	(3.7 to 8.6)
	E	11	11	100%	(100% to 100%)	10	5.1	(2.7 to 7.5)
Employment status	Full-time paid work	81	71	88%	(80% to 95%)	56	4.7	(3.5 to 6.0)
	Part-time paid work	44	41	93%	(86% to 101%)	34	6.1	(4.2 to 7.9)
	Unemployed	10	10	100%	(100% to 100%)	8	5.5	(2.6 to 8.4)
	Retired	95	87	92%	(86% to 97%)	72	7.4	(5.9 to 8.9)
	Not in paid employment	18	18	100%	(100% to 100%)	14	6.9	(3.4 to 10.3)
	Full time higher education	3	2	67%	(13% to 120%)	1	2.0	N/A
Age HRP	19-34	20	18	90%	(77% to 103%)	14	4.0	(2.7 to 5.3)
	35-44	54	48	89%	(81% to 97%)	40	5.6	(4.0 to 7.2)
	45-54	50	46	92%	(84% to 100%)	35	4.7	(3.3 to 6.1)
	55-64	55	51	93%	(86% to 100%)	41	7.2	(5.0 to 9.4)
	65-74	47	43	91%	(84% to 99%)	36	7.6	(5.3 to 9.8)
	75+	25	23	92%	(81% to 103%)	19	6.9	(4.9 to 8.9)
Household size	1 person	70	60	86%*	(78% to 94%)	54	7.9	(6.0 to 9.9)
	2 people	87	81	93%	(88% to 98%)	61	5.9	(4.6 to 7.2)
	3 people	30	28	93%	(84% to 102%)	22	4.9	(3.0 to 6.8)
	4 people	49	46	94%	(87% to 101%)	35	4.9	(3.8 to 6.0)
	5 people	8	7	88%	(65% to 110%)	6	5.0	(1.6 to 8.4)
	6 or more people	7	7	100%	(100% to 100%)	7	6.7	(0.3 to 13.1)
Household type	Single Pensioner	34	31	91%**	(82% to 101%)	29	6.5	(4.9 to 8.1)
	Single Non Pensioner	35	28	80%	(67% to 93%)	27	6.8	(4.5 to 9.1)
	Multiple Pensioner	29	25	86%	(74% to 99%)	18	8.0	(5.0 to 11.0)
	Household With Children	78	72	92%	(86% to 98%)	59	5.3	(3.9 to 6.6)
	Multiple With No Dependent Children	75	73	97%**	(94% to 101%)	52	6.2	(4.4 to 7.9)
Environmental concern	Very concerned	69	59	86%**	(77% to 94%)	48	5.4	(4.2 to 6.7)
	Fairly concerned	116	106	91%	(86% to 96%)	81	6.4	(5.1 to 7.8)
	Not very concerned	46	44	96%	(90% to 102%)	38	6.9	(4.9 to 9.0)
	Not at all concerned	15	15	100%	(100% to 100%)	14	6.1	(4.4 to 7.8)
	No opinion	2	2	100%	(100% to 100%)	1	1	N/A
	Did not answer	3	3	100%	(100% to 100%)	3	5.3	(0 to 19.9)

*Statistically significant at the 90% level **Statistically significant at the 95% level

Electric kettles

Socio-demographic descriptor		Number of households	Electric kettle ownership			Electric kettle age		
			n	Percentage within socio-demographic category		n	Reported value within socio-demographic category (years)	
				Value	(95% CI)		Mean	(95% CI)
	All	251	245	98%	(96% to 99%)	208	3.8	(3.3 to 4.3)
Social Grade	A	14	13	93%	(79% to 106%)	10	3.3	(1.3 to 5.4)
	B	68	67	99%	(96% to 101%)	56	4.5	(3.2 to 5.8)
	C1	93	92	99%	(97% to 101%)	79	3.7	(3.0 to 4.4)
	C2	42	39	93%	(85% to 101%)	33	3.5	(2.3 to 4.7)
	D	23	23	100%	(100% to 100%)	18	3.7	(2.3 to 5.1)
	E	11	11	100%	(100% to 100%)	9	2.7	(0.9 to 4.4)
Employment status	Full-time paid work	81	78	96%	(92% to 100%)	62	3.2	(2.7 to 3.8)
	Part-time paid work	44	43	98%	(93% to 102%)	38	4.1	(2.8 to 5.3)
	Unemployed	10	10	100%	(100% to 100%)	7	3.1	(1.3 to 4.9)
	Retired	95	93	98%	(95% to 101%)	79	4.1	(3.2 to 5.0)
	Not in paid employment	18	18	100%	(100% to 100%)	17	4.5	(1.5 to 7.5)
	Full time higher education	3	3	100%	(100% to 100%)	2	1.5	(0 to 7.9)
Age HRP	19-34	20	20	100%	(100% to 100%)	17	3.5	(1.8 to 5.3)
	35-44	54	51	94%	(88% to 101%)	45	3.4	(2.6 to 4.1)
	45-54	50	49	98%	(94% to 102%)	35	4.3	(2.6 to 6.1)
	55-64	55	55	100%	(100% to 100%)	49	3.6	(2.9 to 4.2)
	65-74	47	46	98%	(94% to 102%)	40	3.7	(2.3 to 5.0)
	75+	25	24	96%	(88% to 104%)	19	5.1	(2.8 to 7.4)
Household size	1 person	70	70	100%	(100% to 100%)	61	4.0	(2.8 to 5.1)
	2 people	87	85	98%	(95% to 101%)	72	4.0	(3.2 to 4.3)
	3 people	30	29	97%	(90% to 103%)	23	4.0	(2.1 to 5.6)
	4 people	49	46	94%	(87% to 101%)	36	4.0	(2.3 to 5.4)
	5 people	8	8	100%	(100% to 100%)	7	2.0	(0.8 to 3.5)
	6 or more people	7	7	100%	(100% to 100%)	6	4.0	(1.5 to 7.2)
Household type	Single Pensioner	34	34	100%	(100% to 100%)	30	4.8	(3.0 to 6.6)
	Single Non Pensioner	35	35	100%	(100% to 100%)	30	4.5	(3.0 to 6.0)
	Multiple Pensioner	29	28	97%	(90% to 103%)	23	4.7	(2.0 to 7.3)
	Household With Children	78	76	97%	(94% to 101%)	64	3.1	(2.6 to 3.7)
	Multiple With No Dependent Children	75	72	96%	(92% to 100%)	58	3.3	(2.7 to 3.9)
Environmental Concern	Very concerned	69	68	99%	(96% to 101%)	61	3.9	(2.9 to 4.8)
	Fairly concerned	116	112	97%	(93% to 100%)	85	3.9	(3.0 to 4.8)
	Not very concerned	46	46	100%	(100% to 100%)	42	3.6	(2.7 to 4.4)
	Not at all concerned	15	14	93%	(81% to 106%)	13	3.5	(1.8 to 5.1)
	No opinion	2	2	100%	(100% to 100%)	1	6.0	(0 to 0)
	Did not answer	3	3	100%	(100% to 100%)	3	3.3	(0 to 11.3)

*Statistically significant at the 90% level **Statistically significant at the 95% level

Annual purchase and replacement rates

The Departments are interested in the 'replacement rate' of appliances: the rate at which appliances in homes are replaced by new models. This provides an indication of the penetration times for new, more efficient appliances and the time taken for advances in energy efficiency in appliances to have an impact on energy consumption in the housing stock. In the 251 households where data was available, the age of appliances was recorded and, using this age data, we derived an 'annual purchase rate' for each of the main appliance types and calculated the percentage of appliances purchased over a five year period.

Approach

The ten appliance types described in the previous section are studied in this analysis. Using the HES appliance age data, we estimated an 'annual purchase rate', defined as the percentage of new appliance purchases to the number of households in the sample[8]. This provided an indication of the proportion of households that purchase a new appliance each year. This assumes that the recorded age of an appliance indicates the time when the household purchased the appliance (i.e. no second-hand purchases). Mean annual purchase rates for each appliance types are calculated from the annual purchase rates for the last five complete years (2006 to 2010).

We compared the results against national sales data provided by GFK[9]. GFK data was available for 2003-2010 for dishwashers and for 2008-2010 for other appliance types, except for televisions where no sales data was provided. The GFK data included the total number of appliances sold in Great Britain. By comparing this to the number dwellings in the Great Britain housing stock, a 'national annual purchase rate' was calculated.

The percentage of appliances purchased in the last five years was also calculated as a further indicator of replacement rates. This was defined as the percentage of appliances aged five years or less compared to the total number of appliances in the sample.

Graphs showing the frequency distribution and cumulative frequency of appliance ages are shown for each appliance type in the Evidence section below.

Findings

The lowest mean annual purchase rate for the HES households was for refrigerators (2.7%), suggesting that only 2.7% of households purchase a new refrigerator each year. The highest mean annual purchase rate was for televisions (21.4%). The purchase rate is influenced by the level of appliance ownership, the appliance lifespan, and the rate at which new improved models become available on the market. For televisions the high purchase rate was also likely to be driven by the nationwide 'Digital Switchover' during the period 2008-12,

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[8] It was not possible to derive replacement rates, rather than purchase rates, as information about whether appliances were purchased for the first time or to replace an old product was not recorded.

[9] GFK sales hit-list by GFK retail, provided for research purposes by DEFRA.

which overlapped with the HES survey (2010-11), and which obliged many households to replace their TVs. On top of this, additional televisions are often purchased by households, rather than replacement purchases to replace existing, out-of-date or broken appliances.

In the HES households 28% of freezers and 29% of refrigerators were purchased in the last five years, the lowest observations in the sample. Conversely, kettles were purchased most, with 77% of households buying new kettles. This provides a good indication of the rate at which the appliances already present in the HES sample may be replaced over the coming years. Some appliances had low annual purchase rates but a high percentage of appliances purchased over the last five years. Taking dishwashers as an example, the low annual purchase rate of dishwashers (3.6%) was largely due to the fact that only 44% of the households owned a dishwasher. However, for the dishwashers present in the sample, 50% were purchased in the last five years, suggesting a relatively high replacement rate.

Summary of purchase and replacement rates

Appliance type	HES mean annual purchase rate (%)	GFK National purchase rate* (%)	HES - Percentage of appliances purchased in the last five years (%)
Television	21.4	-	62
Kettle	13.0	11.0	77
All cold appliances	11.6	4.4	34
Washing machine	9.2	5.8	51
Microwave	8.4	2.5	46
Fridge-freezer	5.3	3.3	43
Freezer	4.3	1.2	28
Tumble dryer	4.3	3.1	49
Dishwasher	3.6	2.4	50
Refrigerator	2.7	1.1	29

*Calculated using GFK data for the years available[10].

[10] GfK sales data supplied by DEFRA.

Recommendations

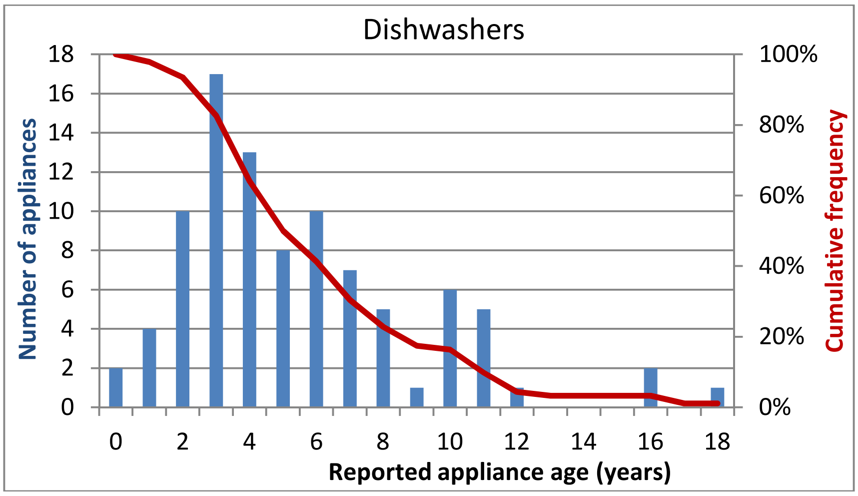
■ Televisions had a high annual purchase rate. This is partly because many older televisions were kept and moved to other rooms of the house as second and third televisions. This behaviour differs significantly to that of the other appliances studied, which appeared to be replaced because they broke, and may have been partially related to rate of technology change for TVs (e.g. the Digital Switchover, High Definition, and larger LCD, LED and plasma screens). Where households do purchase additional appliances, rather than replacing an appliance and disposing of the old model, information could be provided to highlight the implications for additional energy consumption of second and third TVs – especially when left on standby mode.

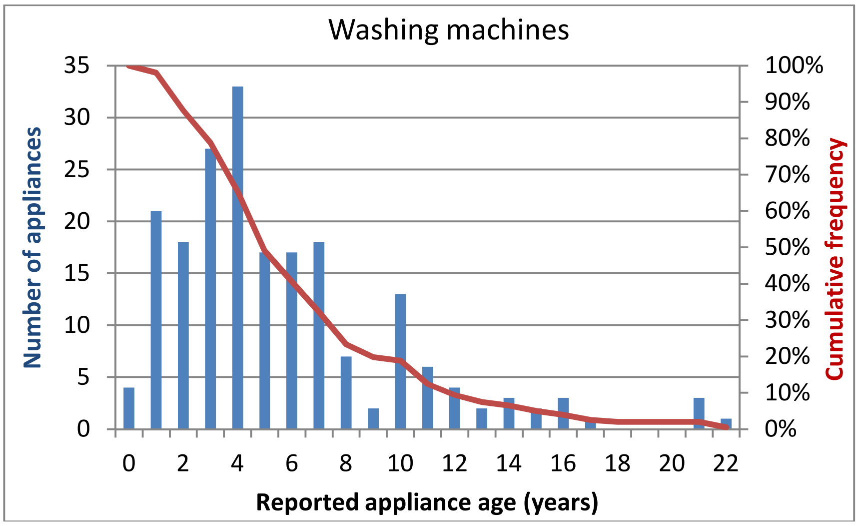
■ Annual purchase rates of appliances and replacement rates (apart from televisions) are partly related to the expected lifespan of the appliance. Appliances with a longer lifespan had a lower purchase rate because the majority of new purchases are the result of replacing an old or broken appliance. This means the penetration of energy efficient models is quicker for appliances with shorter lifespans.

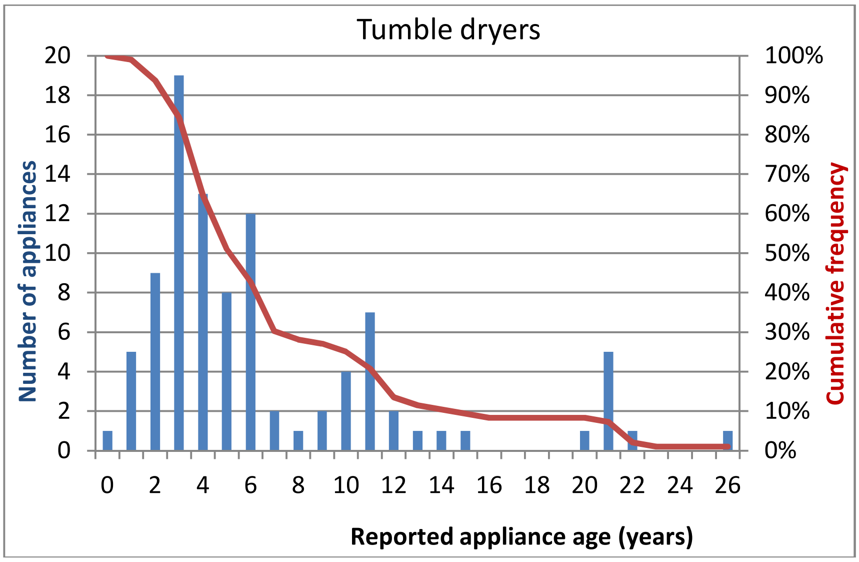
■ This study cannot explore the motives for appliance purchase. It would be useful to know which purchases are prompted by the need to replace failed appliances, and which are prompted for other reasons. Length of tenure of the household may also be a factor prompting some purchases – anecdotally households often buy new when they move to new homes – especially white goods. This information was not collected in the HES survey and could form part of a future study of appliance replacement rates.

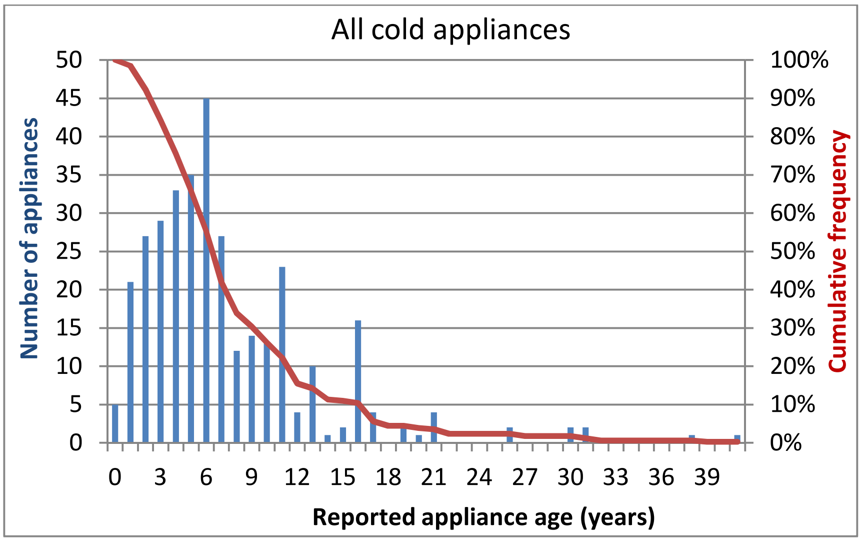
■ Product lifecycles should also be considered in future research. The high turnover of kettles, for example, is likely to be partly related to the low unit cost of some models, which are not designed to last. When products are replaced frequently the embodied energy in product manufacture becomes more important.

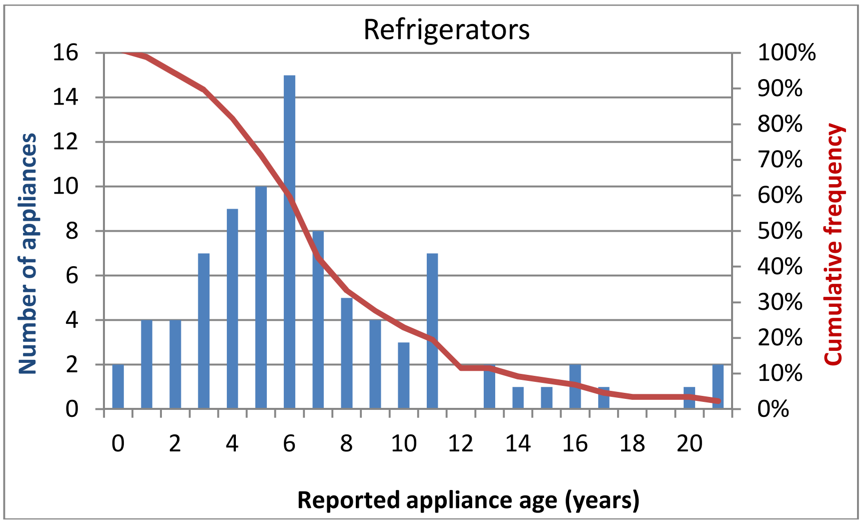
Evidence - Frequency of reported appliance age in the HES sample

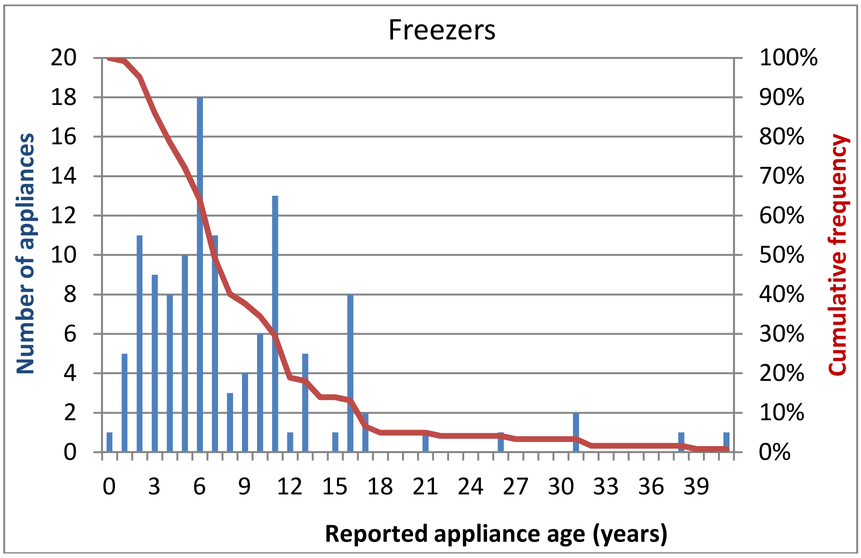


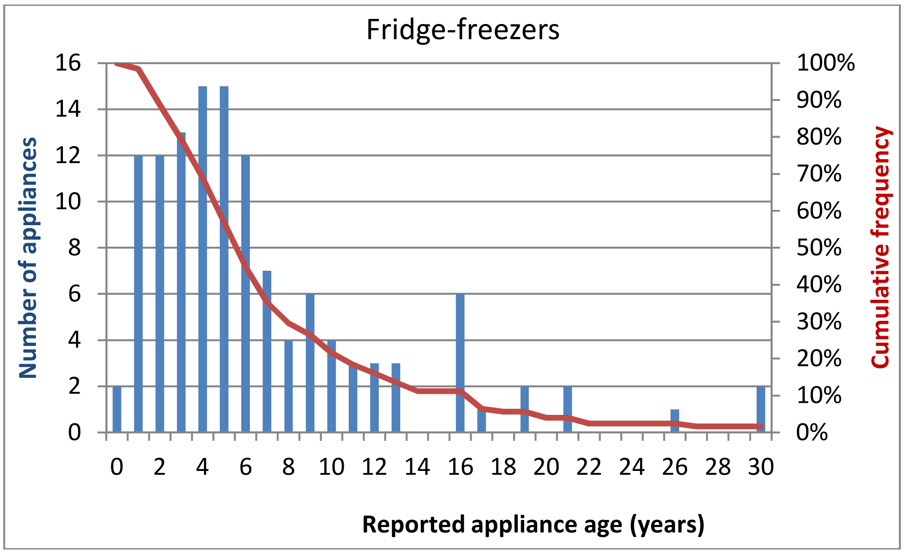


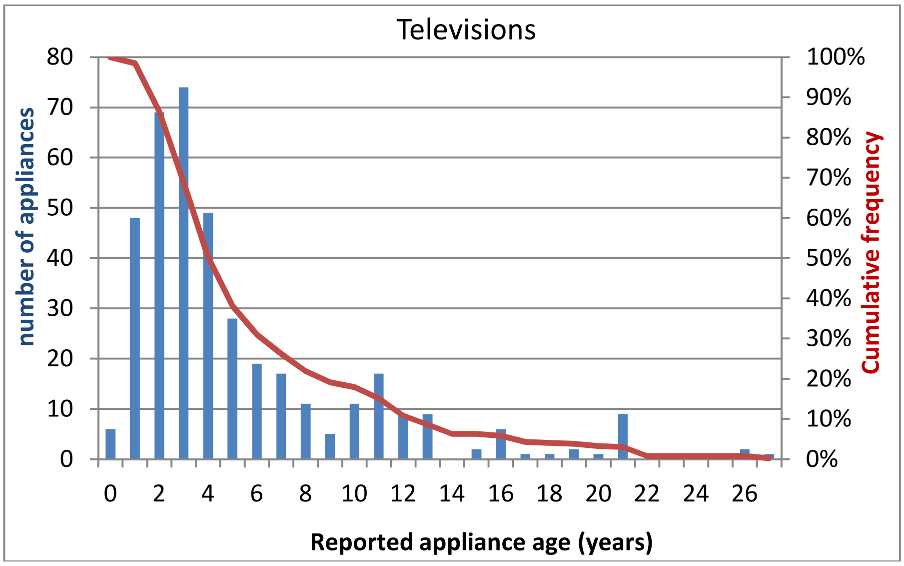


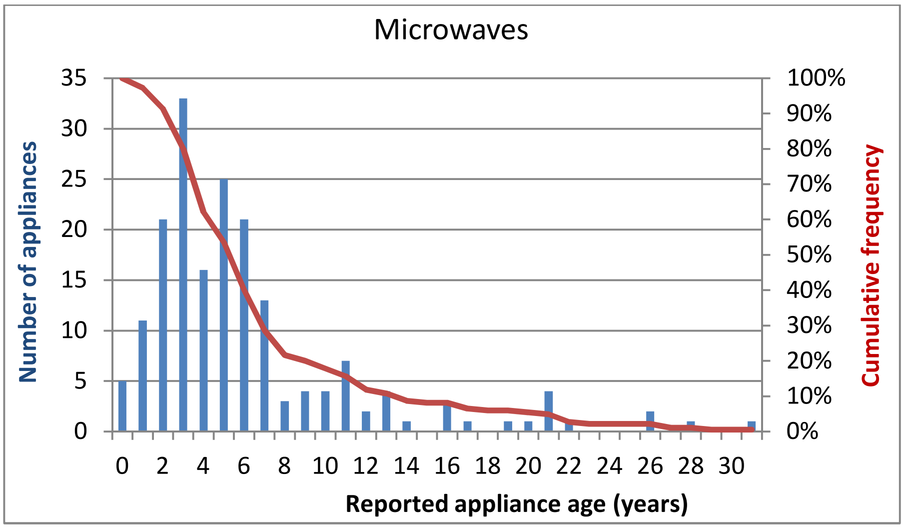

All cold appliances
Number of appliances
Cumulative frequency
50
45
40
35
30
25
20
15
10
5
0
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0 3 6 9 12 15 18 21 24 27 30 33 36 39
Reported appliance age (years)

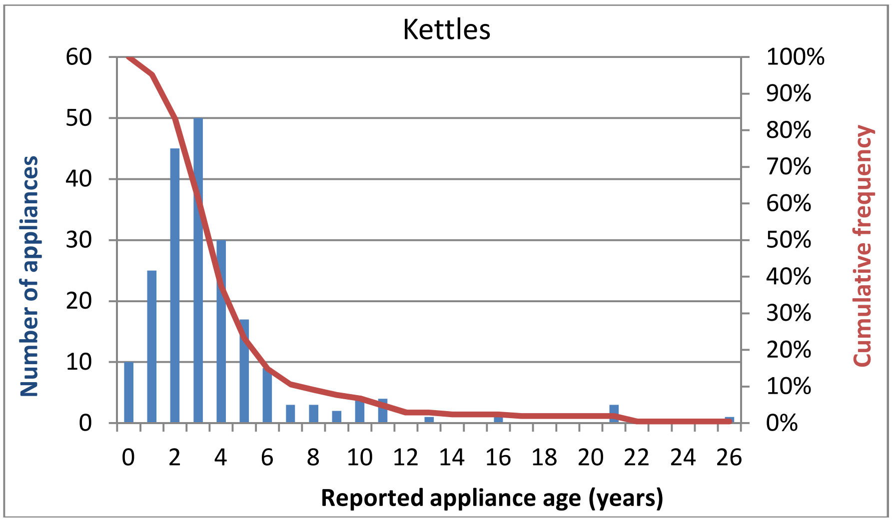

Refrigerators
Number of appliances
Cumulative frequency
16
14
12
10
8
6
4
2
0
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0 2 4 6 8 10 12 14 16 18 20
Reported appliance age (years)


Freezers
Number of appliances
Cumulative frequency
20
18
16
14
12
10
8
6
4
2
0
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0 3 6 9 12 15 18 21 24 27 30 33 36 39
Reported appliance age (years)


Fridge-freezers
Number of appliances
Cumulative frequency
Reported appliance age (years)


Televisions
number of appliances
Cumulative frequency
Reported appliance age (years)


Microwaves
Number of appliances
Cumulative frequency
Reported appliance age (years)


Kettles
Number of appliances
Cumulative frequency
Reported appliance age (years)
0
10
20
30
40
50
60
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
0 2 4 6 8 10 12 14 16 18 20 22 24 26

Comparing energy ratings and socio-demographic indicators

The Departments wished to find out about the relationship between appliance energy ratings (given on Energy Labels) and socio-demographic indicators. Appliance energy labels were recorded in the 251 HES households through the appliance survey, either directly during the survey itself or afterwards, using the appliance make and model number. In all cases, the ratings in this report were relevant when the appliance was purchased.

Approach

We included seven appliance types in this analysis. An appliance type was included if it was covered by Energy Label legislation. The appliance types are:

- Dishwashers
- Washing machines
- Tumble dryers
- All cold appliances
- Refrigerators
- Freezers, and
- Fridge-freezers.

The appliance energy ratings varied between ‘A+’ (high efficiency), ‘A’, ‘B’, ‘C’, ‘D’ and ‘E’ (low efficiency). Not all appliance types had the ‘A+’, ‘D’ or ‘E’ categories. Not all energy ratings could be determined for all appliances, and appliances with an unknown energy rating were excluded from the analysis. The percentage of appliances with each energy rating was calculated according to different socio-demographic groups including social grade, employment status, age of the household reference person, household size, household type and environmental concern. We also included a further group, ‘Appliance age’, in the analysis.

The results are shown in the tables in the Evidence section below. For each category of socio-demographic indicator (e.g. ‘Social grade A’) the number of appliances in the sample is given and, for each energy rating, the percentage of appliances with this rating compared to the total number of appliances in the socio-demographic group (e.g. ‘Social grade’). Within each socio-demographic group (‘All’, ‘Appliance age’, ‘Social grade’, etc) the sum of all the percentage values is 100%.

Findings

High ownership of A-rated or better appliances was observed in the sample for all appliances studied, except for washing machines, where 68% of appliance in the sample were B-rated, and tumble dryers, where 75% of the appliances were C-rated. There were very few trends linking energy labels and socio-demographic groups. This may be related to the dominance of a single energy rating for each appliance type (a single energy rating accounts for at least 65% of the machines in each appliance type).

Summary statistics of appliance energy ratings

Appliance type	Number of appliances in HES sample	Number of appliances with an energy rating	Percentage of appliances in each energy efficiency rating according to energy label					
			A+	A	B	C	D	E
Dishwashers	111	61	3%	74%	7%	13%	3%	-
Washing machines	227	149	1%	15%	68%	9%	7%	-
Tumble dryers	111	64	-	2%	8%	75%	13%	3%
All cold appliances	398	122	2%	75%	18%	4%	-	-
Refrigerators	106	44	5%	70%	23%	2%	-	-
Freezers	143	46	2%	65%	17%	9%	2%	4%
Fridge-freezers	149	77	1%	79%	14%	5%	-	-

The analysis showed little evidence that householders' environmental concern had any bearing on the energy efficiency of their appliances – except that all the owners of A+ rated refrigerators were 'Very concerned' about the environment. This absence of a trend suggests that other factors, such as price or features, are stronger drivers of purchase behaviour.

Recommendations

■ There are few A+ or A-rated washing machines and tumble dryers in HES households, suggesting that encouraging households to purchase more efficient models would lead to energy savings.

■ Other factors appear to be stronger drivers for purchases than energy rating, since households that are concerned about the environment often do not purchase the most efficient model available. (Cost and volume of the appliance, and what models were available at the time of purchase, may be more important.) Clear information comparing initial cost against typical running costs may help provide an incentive to spend a little more up front in return for energy savings in use. It is also possible that environmentally aware households perceive higher environmental costs from replacing and disposing of older appliances (where the 'waste' is visible and tangible) than they do from continuing to use inefficient appliances (where 'waste', in the form of higher energy use, is invisible).

■ Financial incentives could be used to increase the penetration rate of the most efficient products (perhaps like the boiler take-back scheme). Incentives could be used to reduce the cost of A+ and higher rated products so they can compete with other products on cost. Increased sales of these appliances could help reduce manufactures' costs, so when incentives finish the high efficiency models remain competitive.

Evidence - HES appliance energy label by socio-demographic group

Dishwashers

	Socio-demographic descriptor	Number of dishwashers	Percentage of dishwashers in each socio-demographic group according to energy label				
			A+	A	B	C	D
	All	61	3%	74%	7%	13%	3%
Appliance age	2 years old or less	10	2%	13%	0%	0%	2%
	3 to 4 years old	32	0%	33%	0%	2%	0%
	5 or more years old	19	0%	18%	5%	7%	2%
	No age data available	11	2%	10%	2%	5%	0%
Social Grade	A	6	0%	7%	2%	2%	0%
	B	18	2%	23%	2%	3%	0%
	C1	24	2%	26%	3%	7%	2%
	C2	7	0%	11%	0%	0%	0%
	D	4	0%	5%	0%	0%	2%
	E	2	0%	2%	0%	2%	0%
Employment status	Full-time paid work	18	0%	21%	0%	5%	3%
	Part-time paid work	16	3%	23%	0%	0%	0%
	Unemployed	2	0%	3%	0%	0%	0%
	Retired	17	0%	18%	5%	5%	0%
	Not in paid employment	7	0%	8%	2%	2%	0%
	Full time higher education	1	0%	0%	0%	2%	0%
Age HRP	19-34	8	0%	10%	0%	3%	0%
	35-44	15	2%	20%	2%	2%	0%
	45-54	15	2%	20%	0%	3%	0%
	55-64	12	0%	11%	3%	2%	3%
	65-74	9	0%	11%	2%	2%	0%
	75+	2	0%	2%	0%	2%	0%
Household size	1 person	5	0%	5%	0%	3%	0%
	2 people	29	2%	33%	5%	5%	3%
	3 people	8	2%	10%	0%	2%	0%
	4 people	11	0%	15%	2%	2%	0%
	5 people	5	0%	7%	0%	2%	0%
	6 or more people	3	0%	5%	0%	0%	0%
Household type	Single Pensioner	4	0%	5%	0%	2%	0%
	Single Non Pensioner	1	0%	0%	0%	2%	0%
	Multiple Pensioner	3	0%	3%	0%	2%	0%
	Household With Children	21	2%	30%	2%	2%	0%
	Multiple With No Dependent Children	32	2%	36%	5%	7%	3%
Environmental concern	Very concerned	28	2%	36%	3%	5%	0%
	Fairly concerned	21	0%	25%	0%	8%	2%
	Not very concerned	10	2%	10%	3%	0%	2%
	Not at all concerned	1	0%	2%	0%	0%	0%
	No opinion	1	0%	2%	0%	0%	0%
	Did not answer	0	N/A	N/A	N/A	N/A	N/A

(Note that the 'Environmental concern' rows in these tables are based on a single respondent answering on behalf of the household. It is likely that views differ between household members for households of more than one person.)

Washing machines

	Socio-demographic descriptor	Number of washing machines	Percentage of washing machines in each socio-demographic group according to energy label				
			A+	A	B	C	D
	All	149	1%	15%	68%	9%	7%
Appliance age	2 years old or less	34	1%	6%	13%	2%	1%
	3 to 4 years old	46	0%	5%	23%	1%	1%
	5 or more years old	56	0%	2%	26%	5%	5%
	No age data available	13	0%	2%	6%	1%	0%
Social Grade	A	9	0%	0%	5%	1%	0%
	B	41	0%	4%	19%	3%	1%
	C1	58	0%	8%	24%	3%	3%
	C2	22	0%	3%	10%	1%	1%
	D	13	0%	0%	7%	1%	1%
	E	6	1%	1%	3%	0%	0%
Employment status	Full-time paid work	47	0%	4%	22%	3%	3%
	Part-time paid work	30	0%	6%	11%	1%	2%
	Unemployed	7	0%	0%	4%	1%	0%
	Retired	52	1%	5%	22%	5%	2%
	Not in paid employment	12	0%	1%	7%	0%	0%
	Full time higher education	1	0%	0%	1%	0%	0%
Age HRP	19-34	17	0%	3%	7%	2%	0%
	35-44	33	0%	4%	15%	1%	2%
	45-54	29	0%	3%	15%	1%	1%
	55-64	27	0%	3%	13%	1%	1%
	65-74	29	1%	1%	14%	2%	1%
	75+	14	0%	2%	4%	2%	1%
Household size	1 person	36	0%	3%	15%	5%	2%
	2 people	51	1%	5%	23%	3%	2%
	3 people	23	0%	2%	11%	1%	2%
	4 people	27	0%	5%	11%	1%	1%
	5 people	7	0%	0%	5%	0%	0%
	6 or more people	5	0%	0%	3%	1%	0%
Household type	Single Pensioner	20	0%	2%	8%	3%	1%
	Single Non Pensioner	16	0%	1%	7%	2%	1%
	Multiple Pensioner	16	1%	1%	7%	1%	1%
	Household With Children	51	0%	7%	23%	2%	2%
	Multiple With No Dependent Children	46	0%	5%	23%	2%	1%
Environmental concern	Very concerned	45	0%	5%	20%	3%	2%
	Fairly concerned	68	0%	7%	31%	5%	3%
	Not very concerned	25	1%	3%	11%	1%	1%
	Not at all concerned	9	0%	1%	5%	0%	1%
	No opinion	1	0%	0%	1%	0%	0%
	Did not answer	1	0%	0%	1%	0%	0%

Tumble dryers

	Socio-demographic descriptor	Number of tumble dryers	Percentage of tumble dryers in each socio-demographic group according to energy label				
			A	B	C	D	E
	All	64	2%	8%	75%	13%	3%
Appliance age	2 years old or less	12	2%	3%	14%	0%	0%
	3 to 4 years old	23	0%	3%	30%	2%	2%
	5 or more years old	22	0%	2%	23%	8%	2%
	No age data available	7	0%	0%	8%	3%	0%
Social Grade	A	6	0%	0%	9%	0%	0%
	B	22	2%	0%	25%	6%	2%
	C1	23	0%	5%	28%	2%	2%
	C2	8	0%	2%	8%	3%	0%
	D	3	0%	0%	5%	0%	0%
	E	2	0%	2%	0%	2%	0%
Employment status	Full-time paid work	27	2%	5%	31%	3%	2%
	Part-time paid work	13	0%	0%	14%	6%	0%
	Unemployed	2	0%	0%	3%	0%	0%
	Retired	17	0%	2%	22%	2%	2%
	Not in paid employment	5	0%	2%	5%	2%	0%
	Full time higher education	0	0%	0%	0%	0%	0%
Age HRP	19-34	6	0%	2%	8%	0%	0%
	35-44	22	2%	3%	25%	5%	0%
	45-54	11	0%	2%	14%	2%	0%
	55-64	11	0%	0%	11%	5%	2%
	65-74	11	0%	2%	14%	0%	2%
	75+	3	0%	0%	3%	2%	0%
Household size	1 person	7	0%	3%	8%	0%	0%
	2 people	24	0%	2%	30%	3%	3%
	3 people	10	0%	0%	14%	2%	0%
	4 people	19	2%	3%	19%	6%	0%
	5 people	3	0%	0%	3%	2%	0%
	6 or more people	1	0%	0%	2%	0%	0%
Household type	Single Pensioner	3	0%	2%	3%	0%	0%
	Single Non Pensioner	4	0%	2%	5%	0%	0%
	Multiple Pensioner	6	0%	0%	8%	0%	2%
	Household With Children	26	2%	3%	31%	5%	0%
	Multiple With No Dependent Children	25	0%	2%	28%	8%	2%
Environmental concern	Very concerned	20	0%	2%	28%	2%	0%
	Fairly concerned	31	2%	3%	33%	8%	3%
	Not very concerned	10	0%	3%	9%	3%	0%
	Not at all concerned	3	0%	0%	5%	0%	0%
	No opinion	0	0%	0%	0%	0%	0%
	Did not answer	0	0%	0%	0%	0%	0%

All cold appliances

Socio-demographic descriptor		Number of cold appliances	Percentage of cold appliances in each socio-demographic group according to energy label			
			A+	A	B	C
	All	122	2%	75%	18%	4%
Appliance Age	2 Years old Or Less	27	1%	21%	0%	0%
	3 to 4 Years Old	30	1%	23%	1%	0%
	5 or More Years Old	52	0%	25%	16%	2%
	No Age Data Available	13	1%	7%	2%	2%
Social Grade	A	9	2%	4%	2%	0%
	B	29	1%	18%	5%	0%
	C1	53	0%	35%	7%	2%
	C2	16	0%	10%	2%	1%
	D	12	0%	7%	2%	1%
	E	3	0%	1%	1%	1%
Employment status	Full-time paid work	38	0%	25%	5%	2%
	Part-time paid work	25	2%	13%	6%	0%
	Unemployed	5	1%	3%	0%	0%
	Retired	45	0%	29%	6%	2%
	Not in paid employment	8	0%	5%	2%	0%
	Full time higher education	1	0%	1%	0%	0%
Age HRP	19-34	12	1%	7%	2%	0%
	35-44	33	1%	21%	5%	0%
	45-54	17	1%	11%	2%	1%
	55-64	25	0%	16%	3%	1%
	65-74	21	0%	11%	5%	2%
	75+	14	0%	10%	1%	1%
Household size	1 person	33	0%	23%	4%	0%
	2 people	38	0%	23%	5%	3%
	3 people	14	2%	7%	3%	0%
	4 people	30	1%	18%	5%	1%
	5 people	4	0%	3%	0%	0%
	6 or more people	3	0%	2%	1%	0%
Household type	Single Pensioner	18	0%	11%	3%	0%
	Single Non Pensioner	15	0%	11%	1%	0%
	Multiple Pensioner	12	0%	7%	3%	0%
	Household With Children	42	2%	24%	9%	0%
	Multiple With No Dependent Children	35	1%	22%	2%	4%
Environmental concern	Very concerned	39	2%	22%	7%	0%
	Fairly concerned	50	0%	31%	8%	2%
	Not very concerned	24	0%	16%	2%	2%
	Not at all concerned	6	0%	5%	0%	0%
	No opinion	0	0%	0%	0%	0%
	Did not answer	3	0%	2%	0%	1%

Refrigerators

Socio-demographic descriptor		Number of refrigerators	Percentage of refrigerators in each socio-demographic group according to energy label			
			A+	A	B	C
	All	44	5%	70%	23%	2%
Appliance Age	2 Years old Or Less	8	2%	16%	0%	0%
	3 to 4 Years Old	9	0%	18%	2%	0%
	5 or More Years Old	21	0%	27%	18%	2%
	No Age Data Available	6	2%	9%	2%	0%
Social Grade	A	7	2%	9%	5%	0%
	B	7	2%	9%	5%	0%
	C1	20	0%	36%	7%	2%
	C2	6	0%	11%	2%	0%
	D	3	0%	5%	2%	0%
	E	1	0%	0%	2%	0%
Employment status	Full-time paid work	15	0%	30%	2%	2%
	Part-time paid work	9	2%	9%	9%	0%
	Unemployed	1	2%	0%	0%	0%
	Retired	18	0%	30%	11%	0%
	Not in paid employment	1	0%	2%	0%	0%
	Full time higher education	0	0%	0%	0%	0%
Age HRP	19-34	2	2%	2%	0%	0%
	35-44	13	2%	20%	7%	0%
	45-54	6	0%	14%	0%	0%
	55-64	10	0%	16%	5%	2%
	65-74	9	0%	9%	11%	0%
	75+	4	0%	9%	0%	0%
Household size	1 person	11	0%	20%	5%	0%
	2 people	13	0%	20%	9%	0%
	3 people	4	2%	5%	2%	0%
	4 people	14	2%	20%	7%	2%
	5 people	1	0%	2%	0%	0%
	6 or more people	1	0%	2%	0%	0%
Household type	Single Pensioner	6	0%	9%	5%	0%
	Single Non Pensioner	5	0%	11%	0%	0%
	Multiple Pensioner	6	0%	5%	9%	0%
	Household With Children	14	2%	20%	9%	0%
	Multiple With No Dependent Children	13	2%	25%	0%	2%
Environmental concern	Very concerned	14	5%	16%	11%	0%
	Fairly concerned	19	0%	36%	7%	0%
	Not very concerned	8	0%	11%	5%	2%
	Not at all concerned	2	0%	5%	0%	0%
	No opinion	0	0%	0%	0%	0%
	Did not answer	1	0%	2%	0%	0%

Freezers

Socio-demographic descriptor		Number of freezers	Percentage of freezers in each socio-demographic group according to energy label					
			A+	A	B	C	D	E
	All	46	2%	65%	17%	9%	2%	4%
Appliance Age	**2 Years old Or Less**	11	0%	22%	0%	0%	0%	2%
	3 to 4 Years Old	10	0%	13%	9%	0%	0%	0%
	5 or More Years Old	17	2%	20%	4%	7%	2%	2%
	No Age Data Available	8	0%	11%	4%	2%	0%	0%
Social Grade	**A**	6	0%	11%	2%	0%	0%	0%
	B	9	2%	11%	2%	2%	0%	2%
	C1	17	0%	22%	7%	7%	0%	2%
	C2	8	0%	15%	2%	0%	0%	0%
	D	3	0%	4%	2%	0%	0%	0%
	E	3	0%	2%	2%	0%	2%	0%
Employment status	**Full-time paid work**	11	0%	20%	2%	2%	0%	0%
	Part-time paid work	5	0%	4%	4%	2%	0%	0%
	Unemployed	3	0%	4%	2%	0%	0%	0%
	Retired	25	2%	33%	9%	4%	2%	4%
	Not in paid employment	2	0%	4%	0%	0%	0%	0%
	Full time higher education		0%	0%	0%	0%	0%	0%
Age HRP	**19-34**	1	0%	2%	0%	0%	0%	0%
	35-44	9	0%	15%	2%	2%	0%	0%
	45-54	7	0%	9%	7%	0%	0%	0%
	55-64	9	0%	13%	4%	2%	0%	0%
	65-74	12	0%	17%	2%	2%	2%	2%
	75+	8	2%	9%	2%	2%	0%	2%
Household size	**1 person**	12	2%	11%	9%	0%	0%	4%
	2 people	20	0%	33%	4%	4%	2%	0%
	3 people	3	0%	4%	2%	0%	0%	0%
	4 people	9	0%	15%	0%	4%	0%	0%
	5 people	1	0%	0%	2%	0%	0%	0%
	6 or more people	1	0%	2%	0%	0%	0%	0%
Household type	**Single Pensioner**	9	2%	9%	4%	0%	0%	4%
	Single Non Pensioner	3	0%	2%	4%	0%	0%	0%
	Multiple Pensioner	11	0%	17%	2%	2%	2%	0%
	Household With Children	9	0%	11%	4%	4%	0%	0%
	Multiple With No Dependent Children	14	0%	26%	2%	2%	0%	0%
Environmental concern	**Very concerned**	16	2%	22%	4%	4%	0%	2%
	Fairly concerned	15	0%	24%	4%	4%	0%	0%
	Not very concerned	12	0%	15%	9%	0%	2%	0%
	Not at all concerned	3	0%	4%	0%	0%	0%	2%
	No opinion	0	0%	4%	0%	0%	0%	2%
	Did not answer	0	0%	0%	0%	0%	0%	0%

Fridge-freezers

Socio-demographic descriptor		Number of fridge-freezers	Percentage of fridge-freezers in each socio-demographic group according to energy label			
			A+	A	B	C
	All	77	1%	79%	14%	5%
Appliance Age	2 Years old Or Less	19	0%	25%	0%	0%
	3 to 4 Years Old	20	1%	25%	0%	0%
	5 or More Years Old	30	0%	23%	13%	3%
	No Age Data Available	8	0%	6%	1%	3%
Social Grade	A	2	1%	1%	0%	0%
	B	22	0%	23%	5%	0%
	C1	32	0%	35%	5%	1%
	C2	10	0%	9%	3%	1%
	D	9	0%	9%	1%	1%
	E	2	0%	1%	0%	1%
Employment status	Full-time paid work	22	0%	22%	5%	1%
	Part-time paid work	16	1%	16%	4%	0%
	Unemployed	4	0%	5%	0%	0%
	Retired	27	0%	29%	3%	4%
	Not in paid employment	7	0%	6%	3%	0%
	Full time higher education	1	0%	1%	0%	0%
Age HRP	19-34	10	0%	9%	4%	0%
	35-44	20	0%	22%	4%	0%
	45-54	11	1%	9%	3%	1%
	55-64	14	0%	17%	1%	0%
	65-74	12	0%	12%	1%	3%
	75+	10	0%	10%	1%	1%
Household size	1 person	22	0%	25%	4%	0%
	2 people	24	0%	25%	1%	5%
	3 people	10	1%	8%	4%	0%
	4 people	16	0%	17%	4%	0%
	5 people	3	0%	4%	0%	0%
	6 or more people	2	0%	1%	1%	0%
Household type	Single Pensioner	12	0%	13%	3%	0%
	Single Non Pensioner	10	0%	12%	1%	0%
	Multiple Pensioner	6	0%	8%	0%	0%
	Household With Children	28	1%	26%	9%	0%
	Multiple With No Dependent Children	21	0%	21%	1%	5%
Environmental concern	Very concerned	25	1%	26%	5%	0%
	Fairly concerned	30	0%	29%	8%	3%
	Not very concerned	16	0%	18%	1%	1%
	Not at all concerned	4	0%	5%	0%	0%
	No opinion		0%	0%	0%	0%
	Did not answer	2	0%	1%	0%	1%

Comparing HES energy ratings with national sales data

The Departments were interested in comparing the energy ratings of appliances found in the HES study with recent national sales data. It was hoped this would provide an insight into recent trends in sales and their impact on appliance energy ratings across all households.

Approach

Six appliance types were studied in this analysis. An appliance type was included if it was covered by energy label legislation and there was a GFK datasheet available. The appliance types were:

- Dishwashers
- Washing machines
- Tumble dryers
- Refrigerators
- Freezers, and
- Fridge-freezers

We compared the results with national sales data provided by GFK[11]. The GFK datasets included the numbers of appliances sold and the energy ratings of those appliances. For dishwashers, the GFK data was available for 2003 to 2011, excluding 2005. For the other appliance types, the GKF data was only available for 2008 to 2011.

The results are shown in the bar charts in the Evidence section below. For each appliance type, the proportion of appliances sold by energy rating is given for each year of the GFK data. The bar charts also show the proportion of appliances in HES households broken down by energy rating.

Findings

Analysing the data shows that over time most appliances sold are becoming increasingly efficient. This is partially driven by policy changes, because the Energy Labelling system introduced in 2010 required minimum efficiency standards for a number of appliances. For example, all dishwashers had to have an A-rated cleaning cycle and all washing machines with a capacity greater than 3kg had to have an A-class washing performance [12].

Unlike the other wet appliances (dishwashers and washing machines), tumble dryers did not achieve a significant improvement in the three years before the survey. 75% of tumble dryers in HES households were C-rated, and a further 16% were D or E-rated. Analysis of GFK sales data from 2008 to 2010 suggested that C-rated machines still dominated the market, accounting for around 80% of sales. The proportion of differently-rated tumble dryers sold in

[11] GFK sales hit-list by GFK Retail, and provided by DEFRA.
[12] http://www.newenergylabel.eu/

the three years before the survey was similar to the survey results, suggesting that the average energy label of tumble dryers was not improving.

The proportion of refrigerators and freezers sold, broken down by energy rating, showed a slow trend towards appliances with higher efficiency, but there was a remarkably slow penetration of refrigerators and freezers rated A+ and higher. This may have been partially related to these high-efficiency appliances being more expensive.

Other Evidence on Appliance Energy Ratings

A study[13] into the electricity use in residential buildings monitored the energy consumption of 1300 households across 12 countries in Europe (unfortunately the UK was not included). Analysis estimated that a reduction of almost 50% in household electricity consumption should be feasible by replacing existing appliances and lighting with Best Available Technologies, and improving their use. Cold appliances and desktop PCs were found to have particularly large potential savings.

Research used by the Market Transformation Programme team[14] found significant differences in uptake of energy efficient appliances across Europe, even between countries with similar policies and approaches. The study, based on market data up to 2008 and existing literature for eight countries, shows that the uptake of A+ and A++ rated cold appliances (as a percentage of total sales) is particularly low in the UK. It also suggests that sales of A-rated tumble dryers (approximately twice as efficient as C-rated driers) are generally poor across Europe, but that this is particularly relevant to the UK, which has considerably higher sales per year than the other countries considered.

Recommendations

■ The evidence suggests that minimum energy efficiency standards, linked to energy labels, have helped to encourage the uptake of more efficient appliances over time. The energy labels for appliances in this sample of households show an increasing proportion of efficient machines being purchased. We therefore recommend that energy labelling and mandatory minimum energy efficiency standards are rolled out to other appliance groups not currently covered by legislation. Minimum efficiency standards would be particularly beneficial for tumble dryers, where relatively inefficient C-rated machines have by far the greatest market share, and they may help to counteract the higher prices of more efficient dryers.

■ The market penetration of cold appliances rated A+ and higher is remarkably slow – there have been numerous models on the market in each category since 2008 but A-rated models still dominate sales. Cold appliances do have a low replacement rate but this does not fully explain the small numbers of A+ and higher rated appliance being purchased. It may be related to the additional cost of higher-rated models, so we recommend providing better information so that consumers can easily compare higher initial costs against ongoing savings in running costs. It may also be partly due to purchasers being unaware that A is no longer the top energy rating for these appliances.

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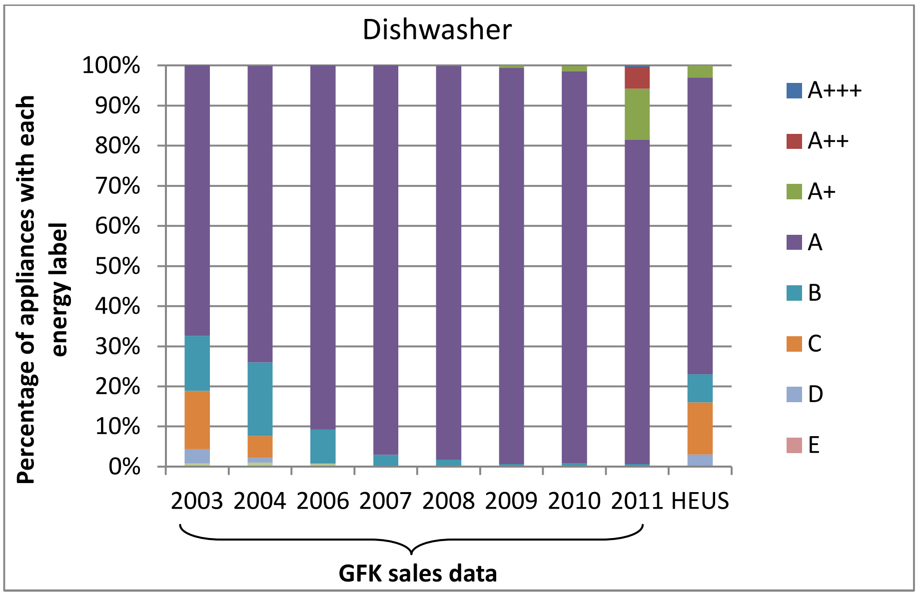
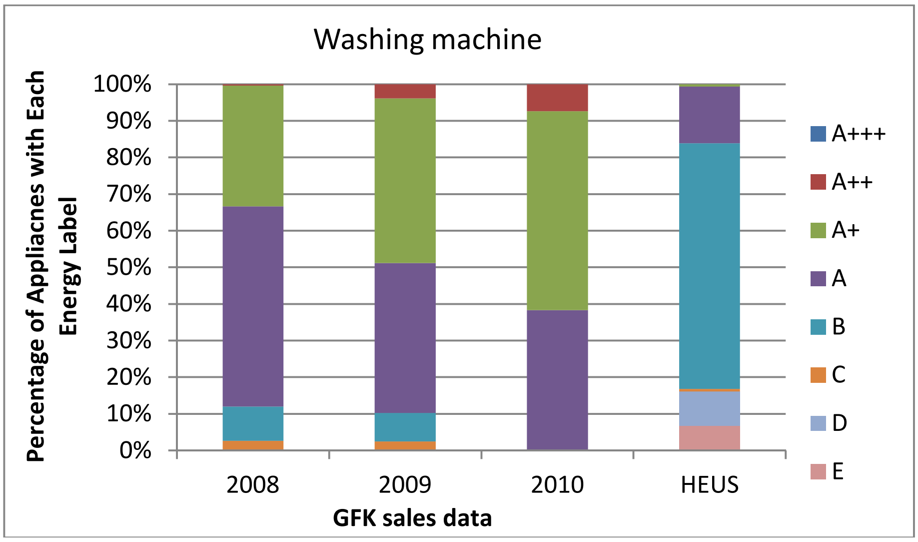
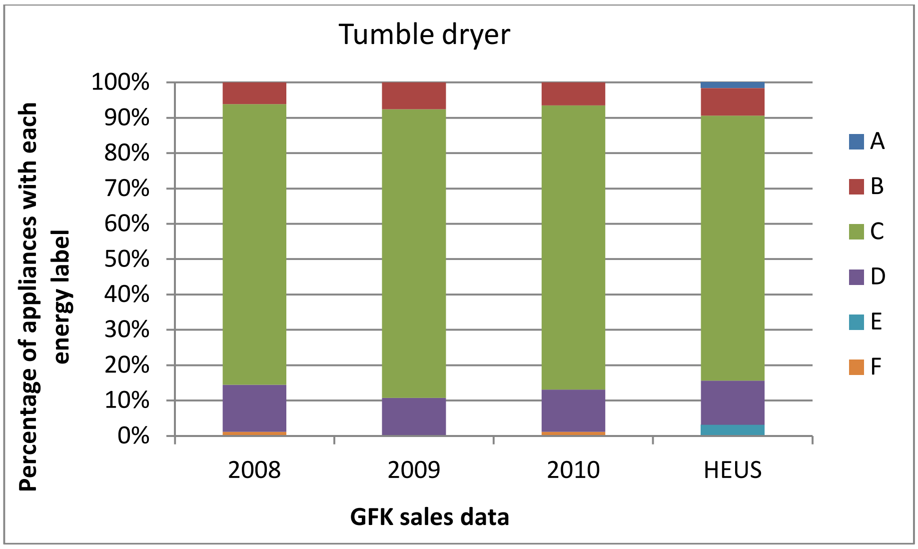
[13] de Almeida, A., et al. (2008) REMODECE-Residential monitoring to decrease energy use and carbon emissions in Europe: Final Report. Coimbra, Portugal: University of Coimbra.

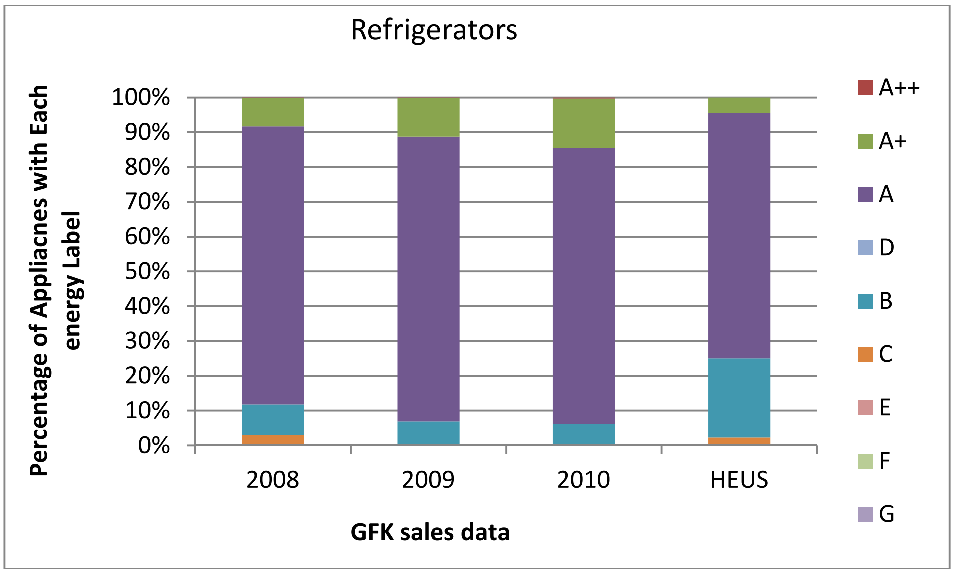
[14] Attali, Sophie, Eric Bush, and Anette Michel (2009) Factors influencing the market penetration of energy efficient electrical appliances into national markets in Europe. Paris: SoWATT/Bush Energie Gmbh.

Evidence - Proportion of appliances sold according to energy label, HES vs. total GB sales








Refrigerators
Percentage of Appliacnes with Each energy Label
100%
90%
80%
70%
60%
50%
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20%
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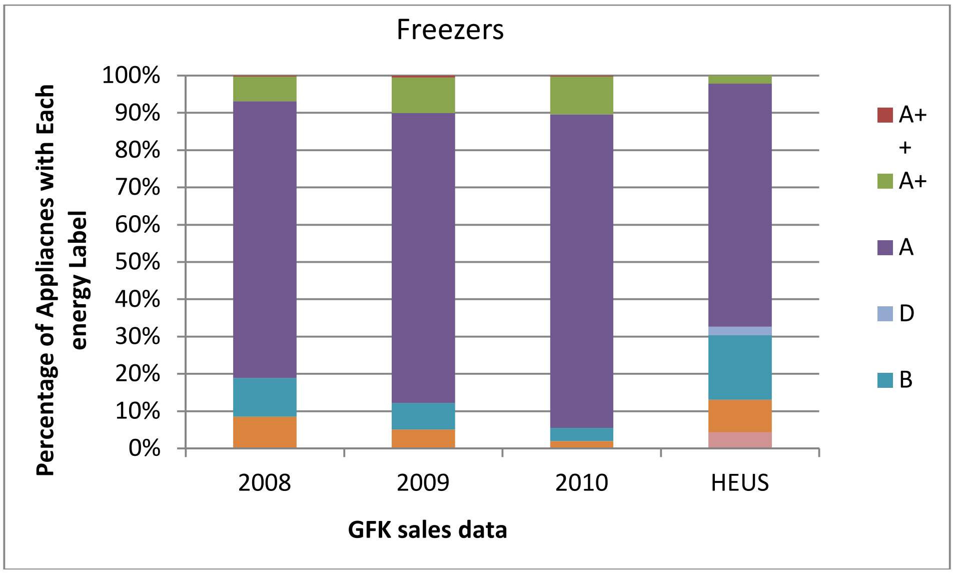
Freezers
Percentage of Appliacnes with Each energy Label
100%
90%
80%
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60%
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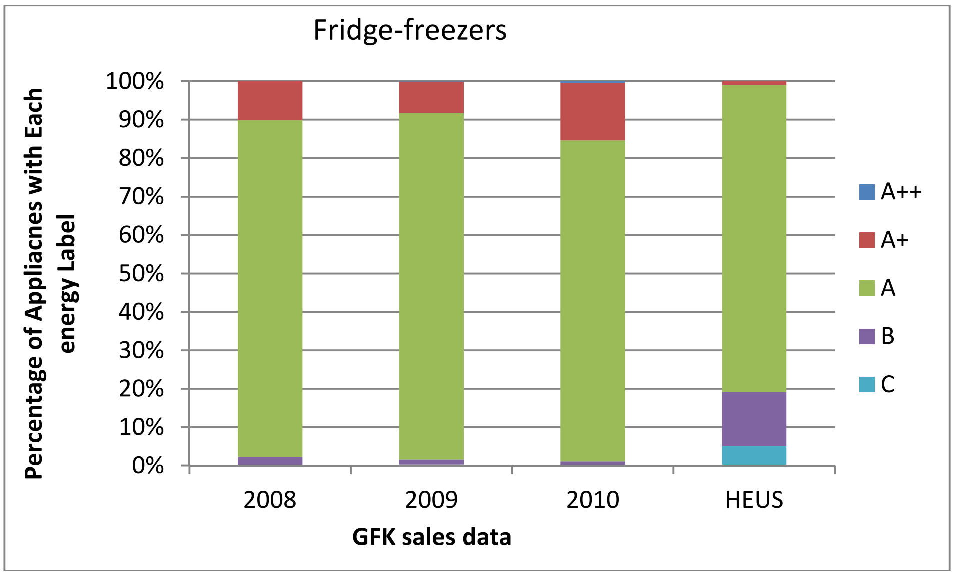
Fridge-freezers
Percentage of Appliacnes with Each energy Label
100%
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2008
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GFK sales data
A++
A+
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B
C

Cluster analysis and consumer archetypes

The diversity and variation in electricity consumption between different households across the UK is a significant barrier to understanding energy use. It also makes it harder to assess policy impacts at anything but highly aggregated levels, where most of the detail is lost. Sorting households into several well-resolved and characterised groups makes it possible to explore national electricity use trends at more disaggregated levels, revealing consumption patterns and policy opportunities for different consumer 'archetypes'. Using such groups, the drivers and implications of consumption trends can be better understood, bringing new insights into electricity use and offering opportunities to target policies and interventions that represent the needs of population sub-groups, as well as the UK as a whole.

Cluster analysis is a statistical technique that allows households to be grouped on the basis of attributes such as demographics, attitudes and behaviour, where the differences in these attributes are minimised within each group and maximised between groups. This technique makes it possible to define categories of consumer archetypes based on multiple household characteristics, extending the scope of analysis beyond the limitations imposed by exploring each of these household metrics in isolation.

Element Energy carried out a comprehensive cluster analysis on the Household Electricity Survey dataset. It is described in more detail elsewhere[15], and a summary of the approach, findings and recommendations is presented here.

Attitude survey: caveats

The attitude survey was intended to assess the attitudes of the whole household towards energy and environmental issues. However, the postal questionnaire that was used for this part of the survey was completed by just one person from each household – likely to be the same person who answered the telephone when the household was first recruited. The questionnaire did not ask for 'household attitudes', and instead asked 'How concerned are **you** about climate change', for example [bold added].

For single-person households it is reasonable to take the attitudes of the respondent as representing the whole household. However, this is dubious for multiple-occupant households, where different members are likely to hold different views – at least for some of the 29 questions.

Exactly who in each household responded to the questionnaire in each household is not documented in the data available to us, although it is reasonable to assume only adults completed the questionnaire.

We advocate caution when interpreting data from the attitude part of the survey, and readers should bear in mind that in many cases the expressed attitudes are those of just one adult in the households with more than one adult. Other adults may be more or less aware of energy and environmental issues.

[15] Element Energy (2013) Further Analysis of Data from the Household Electricity Usage Study, Lot II: Consumer Archetypes. Cambridge: Element Energy.

Approach

As part of the Household Electricity Survey, participants completed a survey including 29 questions on household attitudes and behaviours in relation to the environment, climate change and energy use. Factor analysis, which identifies the common themes underlying the survey questions, was used to condense the 29 survey questions into three factors on climate change and the environment:

- Current beliefs
- Current actions, and
- Beliefs about the future

These three factors were then combined with nine further variables on household demographics, building characteristics and electricity use to complete the full set of clustering variables. These additional nine variables were:

- National Readership Survey (NRS) social grade
- Household occupancy (i.e. the number of people living in each house)
- Building age
- Building floor area
- Number of electrical appliances
- Total electricity use per annum
- Percentage of electricity used in the 6-7pm peak period
- Appliance efficiency improvement potential (i.e. the electricity that could be saved by switching to modern energy efficient appliances such as those with classes of A+ or A++ and low standby power)
- Peak shift potential (i.e. the amount of electricity use that could feasibly be shifted out of the 6-7pm peak period)

Clustering analysis was performed using the software package, SPSS, via a multi-stage procedure involving hierarchical analysis (using Ward's method) and k-means analysis.[16,17] The clustering methodology involves an iterative procedure to group the households so that the differences in attributes between groups are maximised and the differences within each group are minimised. The optimal variance between and within clusters was found to occur for a seven-cluster solution.[18,19]

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[16] Ketchen, D. J. & Shook, C. L. (1996), "The application of cluster analysis in strategic management research: an analysis and critique", *Strategic Management Journal*, 17(6), 441–458.

[17] Punj, G. & Stewart, D.W (1983), "Cluster Analysis in Marketing Research: Review and Suggestions", *Journal of Marketing Research*, 20, 134–148.

[18] Calinski, T. and Harabasz, J. (1974), "A dendrite method for cluster analysis" *Commun Stat Theory Methods,* 3(1):1–27.

[19] Milligan, G. W. and Cooper, M. C.(1985), "An examination of procedures for determining the number of clusters in a data set", *Psychometrika*, 50, 159–179.

Analysis

The seven household archetypes/clusters can be summarised as shown in the box below, which also indicates the proportion of the 250 households allocated to each group. A more detailed profile of the specific characteristics of each cluster is provided in the table beneath. This includes the twelve variables used for the cluster analysis, and an additional variable describing the potential savings from switching heating fuel (or to a more efficient electric heating system) in each of the clusters. This additional variable could not be included in the clustering variables used for the cluster analysis because not all households were monitored in the November to March period when space heating is generally used.

Summary of the seven household archetypes.

1. Profligate Potential (7%) – these are high occupancy, low social grade households with the highest levels of electricity consumption and large numbers of inefficient appliances. While their beliefs may be relatively green, they are failing to put these into action and exhibit, by far, the greatest scope for appliance efficiency improvement.

2. Thrifty Values (25%) – this cluster consists of small, relatively low social grade households with few appliances and low levels of electricity use. Conservative electricity consumption is accompanied by non-green attitudes, indicating that the frugal focus of these households derives from cost-conscious values rather than environmental conservation.

3. Lavish Lifestyles (9%) – these are affluent households with the highest social grades and largest building floor areas. While they possess green beliefs, this is not reflected in their actions which are characterised by high electricity use and many appliances.

4. Modern Living (10%) – the small, predominately single occupant households in this cluster live in newly built homes and have medium to high social grades. These households use low levels of electricity which is well-aligned with their green actions and small household sizes.

5. Practical Considerations (20%) – these medium to high social grade households have the highest occupancy levels, yet still manage to constrain their total electricity usage to medium levels. These households have the lowest electricity use per person, reflecting the judicious use of electricity in densely occupied (i.e. lowest floor area per occupant) households with relatively green beliefs.

6. Off-Peak Users (19%) – these medium social grade households consume a small fraction of their total electricity use during the peak-time period. These households possess predominately retired respondents, which is linked to their off-peak electricity usage patterns.

7. Peak-Time Users (10%) – this cluster exhibits high electricity use with a high fraction of this occurring during the peak-time period. These households have by far the highest peak shifting and fuel switching potential savings available, though their relatively non-green actions appear to inhibit the extent to which these are currently being realised.

Characterising the seven household clusters. All quantities shown in brackets reflect the average value for the cluster.

		1. Profligate Potential	2. Thrifty Values	3. Lavish Lifestyles	4. Modern Living	5. Practical Considerations	6. Off-Peak Users	7. Peak-Time Users
Occupant Characteristics	Current beliefs (z-score)[20]	Very Green (0.36)	Not Green (-0.68)	Very Green (0.56)	Moderately Green (0.16)	Very Green (0.79)	Not Green (-0.35)	Moderately Green (-0.19)
	Current actions (z-score)[20]	Moderately Green (0.01)	Moderately Green (0.11)	Not Green (-1.25)	Very Green (0.65)	Moderately Green (0.00)	Very Green (0.22)	Not Green (-0.22)
	Beliefs about the future (z-score)[20]	Moderately Green (0.07)	Very Green (0.43)	Moderately Green (0.18)	Not Green (-0.41)	Very Green (0.27)	Not Green (-0.66)	Moderately Green (-0.15)
	Social grade (average NRS grade)	Low (C2)	Low (C2)	High (B)	High-Medium (B-C1)	High-Medium (B-C1)	Medium (C1)	Medium (C1)
	Household occupancy (average no. of people)	High (3.4)	Low (1.7)	High (3.3)	Low (1.2)	High (3.6)	Medium (1.9)	Medium (3.0)
Building Details	Building age (average age band)	Older (1930-1949)	Older (1930-1949)	Medium (1967-1975)	Newer (1983-1990)	Older (1930-1949)	Medium (1950-1966)	Medium (1967-1975)
	Building floor area (average m^2)	Medium (112)	Small (78)	Large (169)	Small (77)	Medium (107)	Medium (111)	Medium (97)
Electricity Usage	Electrical appliances (average no. of devices)	Many (53)	Few (27)	Many (53)	Few (31)	Medium (43)	Medium (48)	Medium (47)
	Total electricity use (kWh/year)	Very High (7839)	Low (2254)	High (5567)	Low (1868)	Medium (4084)	Medium (3491)	High (5871)
	Percentage of electricity used in the 6-7pm peak	Low (5.6)	Medium (6.3)	High (6.9)	Medium (5.8)	Medium (6.2)	Low (5.5)	High (7.1)
Technical Potential	Efficiency potential (kWh/year)	Very High (1546)	Low (344)	High (719)	Low (323)	Medium (652)	Medium (516)	High (791)
	Peak shift potential (kWh/year)	Medium (31)	Low (11)	High (36)	Low (8)	Medium (24)	Low (14)	Very High (124)
	Fuel switch potential (kWh/year)	Medium (483)	Low (243)	High (530)	Very Low (62)	Low (321)	Medium (425)	Very High (1,049)

[20] The three factors are presented as z-scores (i.e. standardised scores) which indicate the number of standard deviations each household response differed from the mean response (which has a z-score of 0).

Recommendations

The unique characteristics of each of the seven household clusters make it possible to identify where different interventions (relating to energy efficiency, peak shifting and heating fuel switching or optimisation) could be best focused. The savings potentials shown below are technical potentials – i.e. the maximum potential savings that could be achieved.

- Profligate Potential households offer by far the greatest technical potential for appliance efficiency savings with an average opportunity of 1,546 kWh/year per household (about double that of any other cluster), or approximately 2.9 TWh/year nationally. When considered alongside the very green current beliefs of Profligate Potential households, there appears to be scope for uptake of appropriately-targeted interventions. We recommend that this household archetype be targeted for awareness raising and other policy interventions relating to energy efficiency.

- The medium levels of appliance efficiency savings potential per household (652 kWh/year) of the Practical Considerations cluster, when combined with their strong representation in the English population (20%), yields a large potential for efficiency savings at the national level (2.9 TWh/year for England). Practical Considerations households also have very green current beliefs that may predispose them favourably towards appliance efficiency interventions. As such, this cluster should be considered a high priority group, alongside the Profligate Potential cluster, for energy efficiency interventions.

- The Peak-Time Users cluster offers by far the highest technical potential for shifting electricity use out of the evening peak demand period, with a per household average capacity of 341 W during the 6-7pm peak (more than triple the next highest cluster) which equates to approximately 0.8 GW for England. The Peak-Time Users cluster also offers the highest electricity savings for switching heating fuel (or to a more efficient electric heating system) – on average 1,049 kWh/year per household and about 2.3 TWh/year nationally. However, these high technical potentials are combined with non-green current actions and only moderately green beliefs in this cluster, indicating there may be limited willingness or motivation to address these areas at present. We recommend that further work be conducted to investigate the drivers and incentives that could motivate households in the Peak-Time Users cluster to realise the high technical potentials of this group, particularly in the context of future demand-side response strategies.

- The Lavish Lifestyles cluster also offers high heating fuel switching potential per household (530 kWh/year, which scales to about 1.1 TWh/year for England), the majority of which (82%), was from secondary electric space heating devices supporting a non-electric central heating system (i.e. natural gas or heating oil). This indicates significant potential for electricity savings, by optimising use of the primary central heating system in this cluster (approximately 0.9 TWh/year across England). We recommend that awareness-raising and other interventions in this area be targeted at this cluster. Such interventions will need to consider the lifestyle priorities (related to high social grades) that motivate this group and currently appear to hinder the adoption of environmentally friendly behaviours in this cluster.

■ Finally, the well-defined clusters produced in this project offer excellent scope in future work for combining the household clusters with other low-carbon technology uptake and geographical mapping studies[21,22,23]. We recommend that future household studies examining low-carbon technology uptake, demand-side response strategies and policy impacts are structured so that they can be linked to the HES clusters identified in this project, thereby revealing potential synergies, which has implications for policy development and grid management.

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[21] Element Energy (2011) "Plug-in Vehicles Economics and Infrastructure: Quantifying Consumer Behaviour", for the Energy Technologies Institute.

[22] Element Energy (2009), "Strategies for the uptake of electric vehicles and associated infrastructure implications", for the Committee on Climate Change.

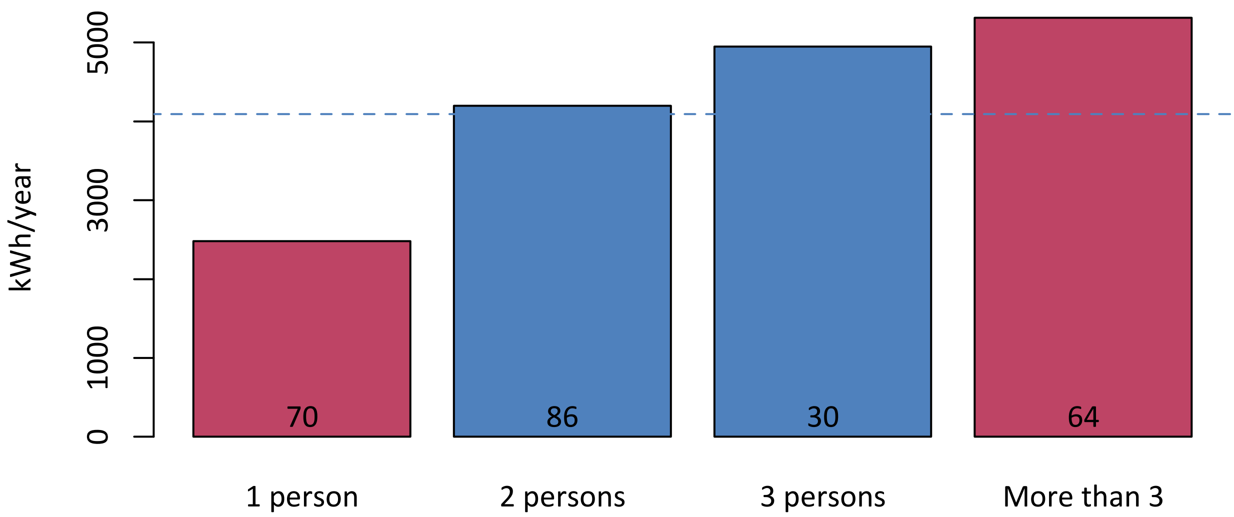
[23] Element Energy (2009), "Uptake of energy efficiency in buildings", for the Committee on Climate Change.

Electricity Use in Single-Person Households

Between 1970 and 2010 the number of people living alone in the UK increased from 6% to 13% of the population, although this percentage has been stable since 1998[24]. Single-person households use above-average energy per person, as single person households use more than half as much as couples. In this study couples used 2100 kWh/year/person, whereas single people used 2480 kWh/year: 18% more. A comparison of total annual energy use against number of occupants is shown in the graph below.

The Departments asked us to investigate the potential for saving energy if there were smaller appliances available, for example, smaller fridges or washing machines.

Total annual electricity usage by number in household



The dashed line shows the overall mean. Red bars are significantly different from the average. The numbers at the bottom of the bars are sample sizes.

Approach

We compared three subsets of households:

1. Single pensioners (34 cases)
2. Single non-pensioners (i.e. people under retirement age, 35 cases)
3. Couples – Households with two people (possibly pensioners) but no children (85 cases).

We distinguished between single pensioners and non-pensioners because the consumption patterns of elderly households are often different from younger people. Overall single pensioners consume somewhat less than non-pensioners: 2,240 kWh/year in this survey, compared to 2,680 kWh/year for non-pensioners.

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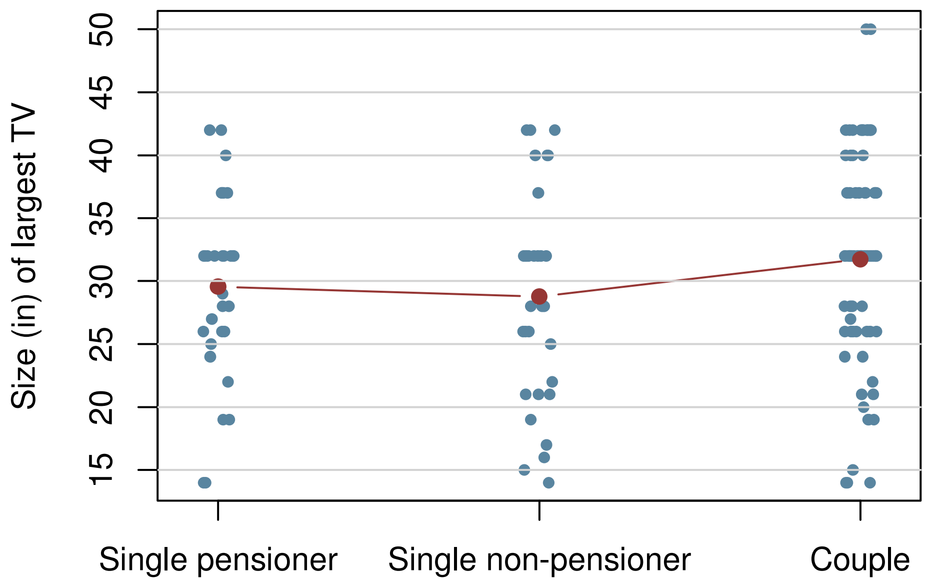
[24] ONS (2013) General Lifestyle Survey 2011. Table 3.1 Trends in household sizes 1971 to 2011. London: ONS.

We compared ownership levels between the households for each type of appliance. Then for those households possessing the appliances – where they were monitored – we compared the overall electricity use, appliance size and frequency or duration of use (where applicable).

Analysis

Televisions

TVs are already available in a range of sizes and smaller TVs use less energy because less light is needed for the screen. Single people could use smaller TVs if they wanted to, but we found little difference in TV size or age between household types.



Size of largest TV by household type (inches)

Single person households owned fewer TVs than two-person households (half a TV less, on average), watch them for less time, and use 16% less electricity for them. Single non-pensioners watched 38% less time and used less than half the electricity: single pensioners were in between.

Note that many of the households owned more TVs than were monitored (according to the list they provided of the appliances they owned). Annual use, daily hours, size and age data are based only on the appliances that were monitored. For single person households, on average 1.2 were monitored, compared to 1.6 owned. For couples, 1.8 were monitored out of 2.1 owned: a slightly higher proportion. This means that the hours watched and electricity use may be underestimated for single people.

Values that are significantly different from the total mean are shown blue.

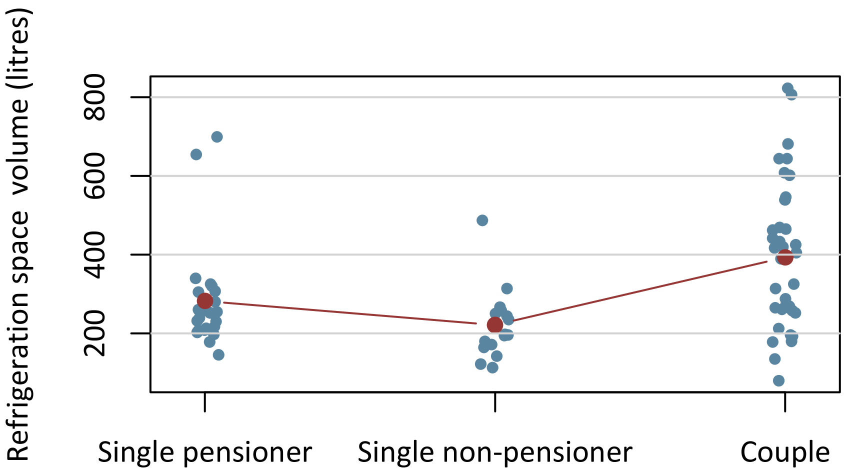
Household type	TVs per house	Annual use kWh/year (per household, all TVs)	Hours of use/day	Size of largest TV (inches)	Average year bought
Single pensioners	**1.6**	**230**	**6.5**	30	2006
Single non-pensioners	**1.6**	**137**	**4.5**	29	2006
Couples	2.1	312	7.8	32	2006
All	2.2	314	8.3	31	2006

Cold appliances

Smaller households consume less food, and potentially need less refrigerated storage space. The single person households in the survey owned fewer cold appliances than larger households, and this difference, though small, was significant ($p < 0.005$). The single non-pensioners had the least refrigerated space, then single non-pensioners, then couples.

(The size of appliances was not known in all cases, so the figures for size include only those households where the size of all their monitored appliances is known.)

Household type	Fridges/freezers household	Annual use kWh/year (per household, all cold appliances)	Total size of all cold appliances (litres) (households in sample)	Average year bought
Single pensioners	**1.6**	**431**	282 (24)	2004
Single non-pensioners	**1.4**	**384**	**221 (17)**	2004
Couples	1.9	612	**393 (37)**	2003
All	1.9	573	329 (126)	2004



Total cold appliance volume by type of household

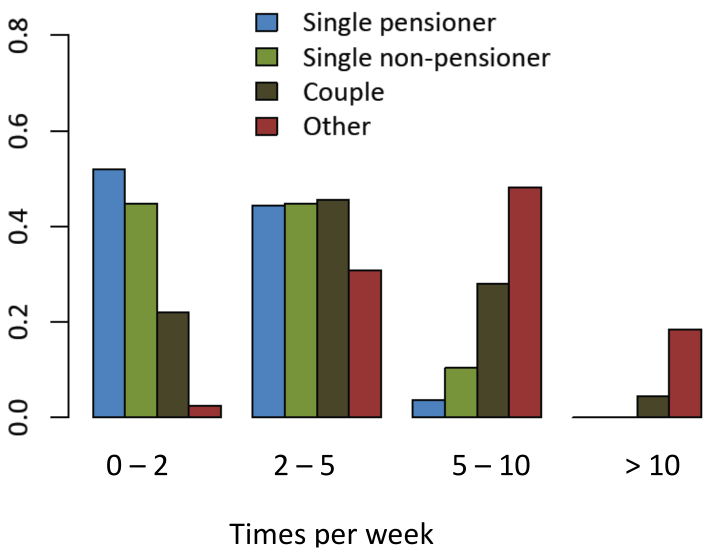
Washing machines

Single person households have less clothing to wash, which is borne out by our finding that they use the washing machine less often than couples: pensioners use it only half as often, on average, and non-pensioner singles only a little more.

There was hardly any difference in levels of ownership of washing machines between single person households and couples, but pensioners were a little more likely to have a smaller washing machine.

Household type	Washing machines/ household	Annual use kWh/year (per household, all w. machines)	Frequency of use times/week	Size (kg)	Average year bought
Single pensioners	0.88	**67**	**2.3**	**5.5**	2004
Single non-pensioners	0.89	**84**	**2.5**	5.9	2004
Couples	0.91	**130**	4.6	**5.8**	2005
All	0.94	158	5.0	6.0	2005

Washing machines, frequency of use

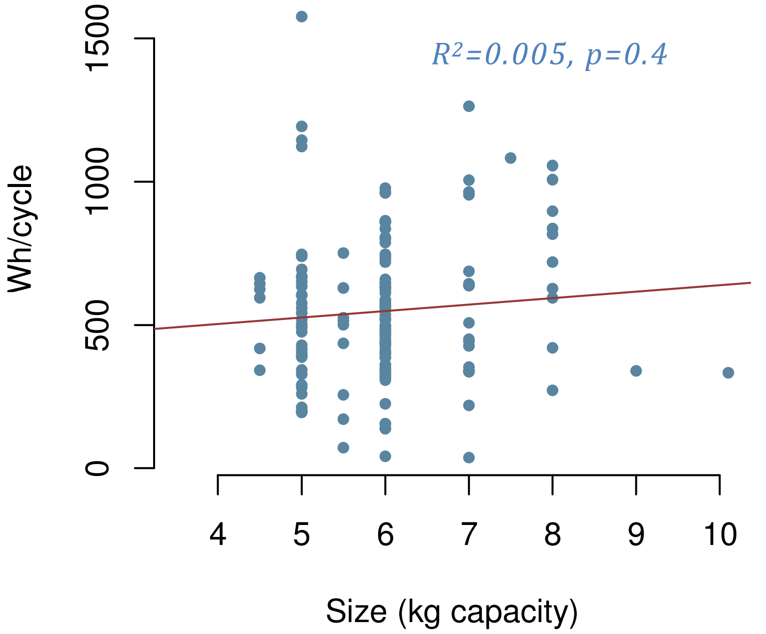


About half of single person households used their washing machines no more than twice a week, whereas 80% of couples used it more often

To evaluate the potential for using smaller washing machines we looked to see if single person households ran their washing machines on part load. We extracted fullness from diary data kept by households in the survey, and worked out the average fullness of wash for each household. We found there was hardly any difference between the groups: the average was from 77% to 89% full in all cases.

Most washing machines had a capacity of 5-6 kg, but there were a few smaller ones, and some larger appliances: up to 10kg. We determined the average energy consumption per cycle for each washing machine in the survey, and found no significant increase in cycle consumption with size, as shown in the chart below. This is counter-intuitive because the energy rating calculation for a washing machine allows for an additional 100 Wh per cycle for each additional kg capacity for an A+++ rated appliance[25]. However, the energy rating calculation is based on 5 out of 7 washes at 60°C, whereas the average wash temperature in this study (from the diary data) was only 41°C. The savings are reduced at the lower temperatures.

[25] European Commission (2010) Commission Delegated Regulation (EU) No 1061/2010 of 28 September 2010: Energy labeling of household washing machines. Brussels: EU.
The energy rating allows 47 kWh/year for each kg capacity, 220 cycles per year so 214 Wh/cycle. An A+++ machine uses no more than 46% of this, so 98 Wh/cycle.

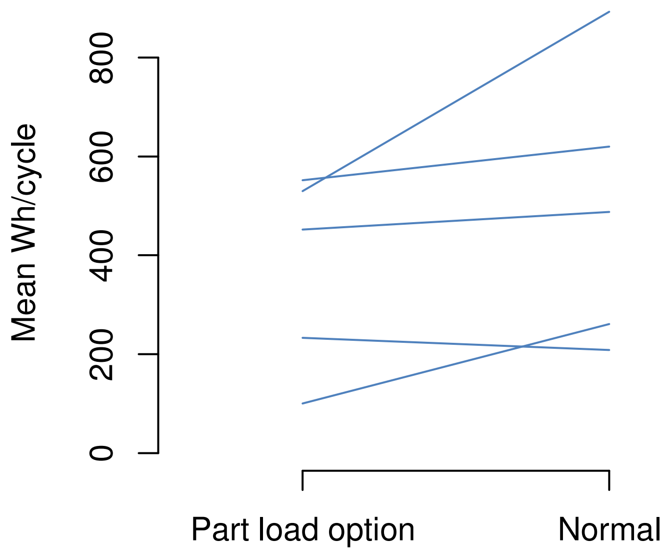


Average electricity consumption per cycle for washing machines compared to size

Each point represents the average cycle consumption for a single washing machine.

The regression line shows a very weak, non-significant relationship.

Some washing machines are able to sense a part-load or have a ‘part-load’ option that can be applied to a standard wash. To see if this option makes a difference to the energy used, we selected cases from the diary data where it had been used. We identified households that had used the option (there were six) and for each we identified sets of cycles that matched on temperature, spin speed and programme, differing only in the part load option (five pairs found). For each washing cycle in the matched sets we determined the energy use from the electricity profile data. The chart below shows energy use for the matching pairs. In two of the five cases the part-load option used considerably less than the normal load (40% and 60% of the full load energy use), whereas the other three showed little difference.



Savings using part-load option for washing cycles matched for program, spin speed and temperature.

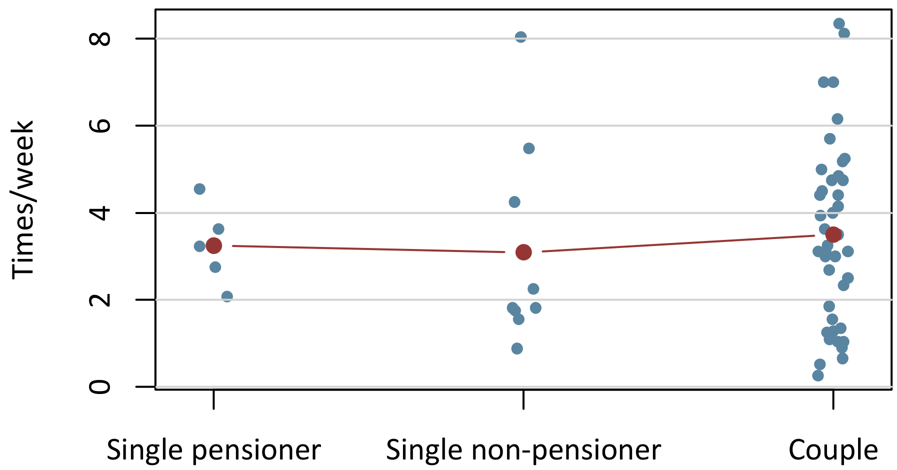
The temperature was 40°C in all cases. Spin speed varied between pairs, from 800 to 1600 rpm.

The diary data showed the average washing temperature was 41°C. However, the ‘product fiche’ (information to be included in the product brochure) for a washing machine does not allow comparisons of part and full load at that temperature. It does show energy consumption for a cotton cycle at 60°C at full and part load, but for a 40°C wash only at part load.

Dishwashers

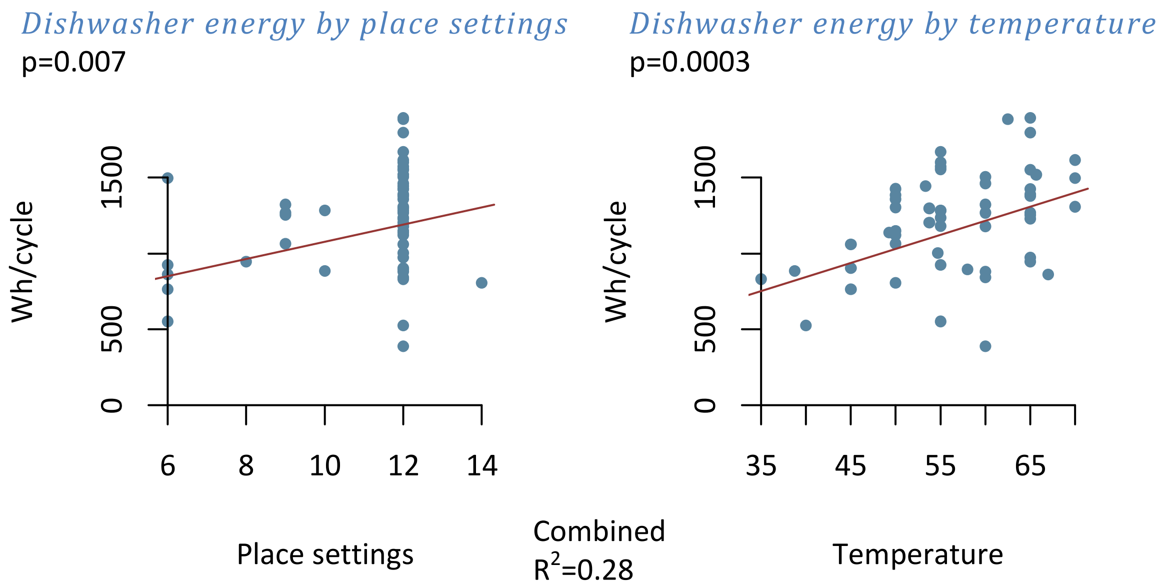
Single pensioners in the survey were only a third as likely to have a dishwasher compared to other households, see table below. Single non-pensioners in the survey were twice as likely to have one as the pensioners, but still not as likely as a couple. However, there was little difference in the frequency of use between single- and two-person households who had them.

Household type	Dishwashers/ household	Number of appliances monitored	Annual use kWh/year (per household)	Frequency of use times/week
Single pensioners	**0.21**	**6**	**170**	3.2
Single non-pensioners	0.46	9	220	3.1
Couples	0.60	41	247	**3.5**
All	0.58	112	290	4.4



Frequency of use for dishwashers

Although most dishwashers have 12 place settings, smaller versions are available: there were 11 smaller appliances in the survey. We found smaller dishwashers used significantly less energy only when we allowed for temperature as well: the combined regression found both factors significant, see plots below.



We found that a six-place setting machine uses 0.34 kWh/cycle less than the usual 12-place setting machine. (The 95% confidence interval was 0.10 to 0.58 kWh/cycle saving.) Assuming the average 4.4 cycles per week, and no increase in the number of cycles as a result of using a smaller dishwasher, this would save 78 kWh/year (95% confidence interval 23 to 133 kWh/year).

This is broadly consistent with manufacturers' guidance regarding savings to be made by size. For example, comparing two dishwashers from Indesit, the product fiche for a six-place setting machine (CD661, a table top version) states it uses 0.63 kWh/cycle, whereas the fiche for a 10-place machine (ISD105UK, slimline floor standing) uses 0.92 kWh/cycle.

Smaller dishwashers may not be acceptable simply in terms of size and shape, and the need to fit into a standard kitchen. Single person households are less likely to own a dishwasher at all, which also limits the potential savings. However, single non-pensioner households are more likely than single pensioner households to own one, and if this is a question of habit rather than need then, as the current population ages, the prevalence of dishwashers amongst pensioners will increase.

There are also considerable savings to be made from running at a lower temperature. Running at 55°C instead of 70°C, 4.4 cycles/week, saves 0.28 kWh/cycle or 64 kWh/year. (The 95% confidence interval is 0.14 to 0.42 kWh/cycle, saving 31 to 96 kWh/year.)

The diary data for dishwashers included some entries with 'Half Load' as an option, but there were only two cases where it was possible to match up cycles as with the washing machines, and these showed very little difference in energy use.

Observations and recommendations

■ Single-person households own fewer appliances than larger households, and use their TVs, washing machines and dishwashers less. They also use less energy for refrigeration. Overall, they offer less potential for achieving energy savings than larger households.

■ Single people run their washing machines half as often as couples and there is very little difference in drum fullness for these groups.

■ Some washing machines use less energy to run a part load than a full load, but not all. Product brochures for washing machines should include the energy savings by running a part load at 40°C, which is the most common wash temperature. This would allow consumers to estimate savings from running their normal wash at part load.

■ Single person households with a dishwasher use it almost as often as couples, even though they presumably have fewer articles to wash. Using a half-size dishwasher (six place settings instead of 12) could save 78 kWh/year, although smaller appliances may not fit the geometry of some kitchens. However, as with washing machines, householders should be advised to run dishwashers at lower temperatures where possible, and running at 55°C instead of 70°C can save 31 to 96 kWh/year for each household that makes the change.

Appliance Use Associations

For many UK households, lifestyle and consumption patterns mean that some appliances are frequently used at the same time as other appliances (e.g. television and cooking appliances, as people watch TV while they cook). When aggregated at the national level, these appliance associations have potential knock-on effects relating to electricity use, demand-side response potential and peak loads. To understand the coincidence of use (i.e. clustering) among the appliances monitored in the Household Electricity Survey, we performed an association rule analysis employing the 'Apriori' algorithm – a well-established technique that is capable of mining large databases for frequent itemsets and identifying product consumption associations.

To put the work into context we start this section with an introduction to association rules.

Association rule fundamentals

The technique of using association rules is commonly employed in 'market basket' analysis of large databases to understand shopping patterns. This technique is often used to investigate the purchasing behaviour of individuals (e.g. in supermarkets and online shops) to find sets of products that are frequently purchased together. In the context of the large HES dataset, this technique is well suited to finding appliances that are frequently used at the same time, and to assess the likelihood of these coincidental usage patterns occurring across the monitored households.

To assess the correlation between the usage of different appliances (or the purchase of different products) a series of "association rules" are determined. In the context of this study, these rules generally take the form: "if a household is using appliance A, then they are also likely to be using appliance B". This can be expressed as:

$$\{\text{Appliance A}\} \rightarrow \{\text{Appliance B}\}$$

Using association rules of this form, it is possible to assess the likelihood that Appliance B (referred to as the 'consequent appliance' or right-hand-side) will be in use if Appliance A (referred to as the 'antecedent appliance' or left-hand-side) is being used. Put simply, this tells us the likelihood that Appliance B is on at the same time as Appliance A.

The association rules are typically determined by examining a large database of transactions. In the case of a supermarket, the transactions usually correspond to the shopping basket contents of individual shoppers as presented at checkout. In the HES, the 'transactions' (or 'events', as they will be referred to in this report) consist of discrete 10 minute time periods within each monitored household. The household appliances that are active during each 10 minute time period make up the itemset (or 'shopping basket') contents for that particular event. Time periods when no appliances were in use (i.e. null events) are excluded from the event list to optimise data processing.

Association Rule Metrics

From the complete list of events (i.e. household-specific 10 minute appliance monitoring intervals), it is possible to determine several key metrics for assessing correlation between the use of different appliances. For the purposes of this analysis, the following measures for assessing the association rules were used:

Support: Determines how often a rule applies within a dataset. For example, the support for rule {Appliance A} ⟶ {Appliance B} tells us the fraction of events in the dataset in which both Appliance A and Appliance B were both in active use (corresponding to the shaded intersection area shown in the Venn diagram below). This can be expressed as:

$$supp(A \cup B) = \frac{\text{number of events containing both Appliance A and Appliance B}}{\text{total number of events}}$$

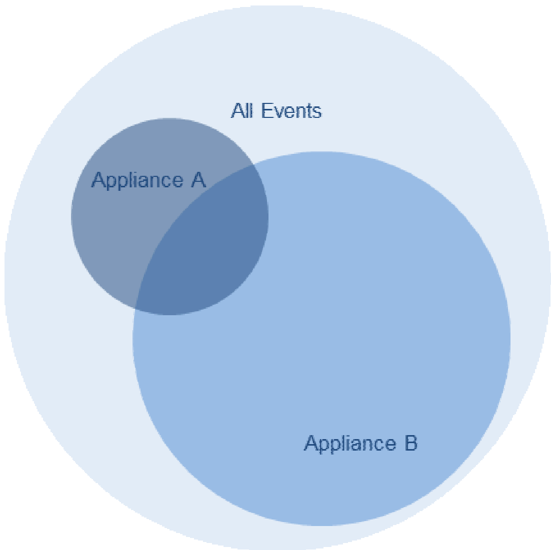
Confidence: Indicates how frequently the consequent appliance (i.e. Appliance B in the example above) appears in the events that contain the antecedent appliance (i.e. Appliance A). The confidence value effectively reveals the likelihood that Appliance B will be in use if Appliance A is active. This is can be written as:

$$conf(A \rightarrow B) = \frac{supp(A \cup B)}{supp(A)}$$

Lift: Measures the strength of an association between appliances over the random co-occurrence of these appliances. That is, lift indicates the confidence of an appliance association rule relative to the likelihood of that appliance being on due to random chance. Greater lift values imply stronger associations. Lift is found by dividing the confidence of an association rule by the support for the consequent appliance of that rule and is expressed as:

$$lift(A \rightarrow B) = \frac{conf(A \rightarrow B)}{supp(B)} = \frac{supp(A \cup B)}{supp(A) \times supp(B)}$$

In practical terms, a lift value of greater than 1 means that the use of the antecedent appliance (Appliance A) increases the probability that the consequent appliance (Appliance B) will be in use at the same time, and as such represents an important filter for appliance association rules. That is, if the lift is less than 1, the appliance association is no better than random chance.



This Venn diagram illustrates the relationship between events containing Appliance A, Appliance B and both appliances together.

The Apriori Principle

When building up the list of relevant association rules and their accompanying metrics, the Apriori principle is used to make it easier to process the large dataset involved. This states that "if an itemset is frequent, then all of its subsets must also be frequent"[26]. Conversely, if an itemset is *in*frequent, then all of its supersets must be infrequent and can be pruned from the analysis[27]. This process is known as "support-based pruning"[28] and is an accurate and efficient strategy for trimming the exponential search space that is covered when generating the association rules, which allows accurate investigation of large databases like the Household Electricity Usage Study.

Approach

Removing Appliance Standby Periods

Since many appliances were left on during much of the monitoring period, to obtain meaningful appliance associations, it was necessary to first determine the time periods when each appliance was on and in active use. This involved applying a high-pass filter (i.e. filtering to exclude values below a threshold) to remove periods when appliances were in standby mode. For this analysis, "standby" refers to any state in which an appliance is left on but is not active at full power levels (including lower-power standby or sleep modes for appliances equipped with such functions).

Several high-pass filter structures were tested, with the best resolution being obtained for a filtering approach using the mean and standard deviation of electricity use for each appliance in each household. This high-pass filter was of the form:

$$x > \mu + k\sigma + a$$

Where:

$\mu =$ appliance reading mean over the monitoring period
$\sigma =$ appliance reading standard deviation over the monitoring period
$k =$ standard deviation coefficient
$a =$ constant

Various set-points were examined for the user-defined elements of this algorithm (i.e. *k* and *a*) to refine the filtering outcomes for the full time series of all appliances. This was confirmed via testing the full set of appliances in several randomly selected households (including, as a minimum, households 101006, 101010, 103029, 201103, 201132, 201331, 202171, 202314, 203419 and 203493). It was found that a standard deviation coefficient, *k*, of 0.4 and a constant, *a*, of 0.3 Wh gave the most accurate high-pass filtering results. This filtering algorithm was then applied to all the appliances in each household within the database.

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26 Jiawei Han and Micheline Kamber "Data Mining: Concepts and Techniques", 2nd Ed, Chapter 5, Elsevier, 2006

27 This is based on the downward-closure property of support – i.e. the support for an itemset never exceeds the support for its subsets (also known as the anti-monotone property).

28 Pang-Ning Tan, Michael Steinbach, Vipin Kumar, "Introduction to Data Mining", Chapter 6, Addison-Wesley, 2005.

Aggregating appliance codes

Within the HES, several appliance codes exist for similar appliances (e.g. where a household possesses more than one television, each unit is recorded as a separate appliance in the dataset– e.g. TV 1, TV 2, TV 3, etc.). In order to establish meaningful appliance usage trends across the different households, we aggregated these similar appliance codes into a single condensed code (e.g. a single code for all televisions). Otherwise, the association trends for different households would not align where different appliances codes were used. General appliance usage associations would also be lost in the specifics of individual device use patterns (compounded by inconsistent appliance naming conventions between households) if this approach was not employed.

Building the event list

Once each appliance was assigned to an appropriate condensed appliance code, it was then necessary to convert each household's appliance usage data into a series of 10 minute long 'events' containing a list of the appliances (using the condensed appliance codes) that were on during that period. Each event was assigned an event ID, which consisted of a concatenated code capturing the household number, day and 10 minute time-period.

The events list was built from the high-pass filtered appliance use data (that was prepared in the first of the preceding steps) to ensure that only appliances that were in active use were included in each event. To optimise the processing times for the large event dataset produced, events when no appliances were active (i.e. all relevant appliances were off or in a standby state) were removed from the event list.

Appliances that were not relevant to the appliance association analysis were also removed from the analysis at this stage. These included appliances that were generally cycling throughout the entire monitoring period (i.e. cold appliances, circulation pumps and pond pumps) or were not appropriate to this study (sockets, lighting, mains readings, temperature readings as well as unknown and undefined appliances).

Determining the association rules

The complete events list was then exported from the database and loaded into R (a command line statistical package frequently used for this kind of analysis). Within R, each event was investigated for duplicate appliance occurrences (i.e. when more than one of the same appliance is on at the same time). Once identified, the appliance duplicates were removed, in keeping with common protocols for studies of this kind.[29,30] The resulting events list (containing 1,492,848 unique events) was then processed using the Apriori algorithm to develop the complete set of association rules with a minimum support level of 1×10^{-8}% and a minimum confidence of 50%.

While 50% represents a common confidence threshold for this kind of analysis, the minimum support level of 1×10^{-8}% was set particularly low to ensure that association rules for infrequently

[29] Michael Hahsler, Christian Buchta, Bettina Gruen and Kurt Hornik, "Mining Association Rules and Frequent Itemsets", 1996.

[30] Pang-Ning Tan, Michael Steinbach, Vipin Kumar, "Introduction to Data Mining", Chapter 6, Addison-Wesley, 2005.

used appliances were still captured within the study.[31] The impact of reducing the minimum confidence requirement to as low as 30% was examined and found to reveal little additional appliance associations beyond those already captured at the 50% level.

Refining the association rules list

A total of 270,757 association rules were produced by the Apriori analysis in R. To refine these down to the most meaningful set of appliance relationships, we applied these filters:

Minimum appliance patronage: Appliances for which fewer than 4 devices were available and in active use across all the monitored households (i.e. an appliance 'patronage' of less than 4) were excluded from the analysis since, in these cases, the sample size is statistically insufficient to distinguish individual household trends from broader national characteristics.

Minimum lift: Only association rules with lift values over 1 were included in the analysis outputs since, in these cases, the likelihood of the consequent appliance being on at the same time as the antecedent appliance is less than the background likelihood of the consequent appliance being on randomly. Caution still needs to be applied when examining association rules with lift values close to 1 since this implies that the association rule is approaching the same likelihood as random occurrence. For example, the high incidence of TV use in the monitored households meant that many appliance associations involving the TV were able to pass the minimum confidence (50%) requirements used to build the association rules. However, in these cases, the minimum lift requirement ensured that only association rules exceeding random occurrence were retained to include in this report.

Appliance exclusions: Appliances in which the power requirements for active usage were very similar to standby (as well as the "left on" but not in use state) offered limited potential for differentiating active use from the background level. Set-top boxes and DVD/VCR/Blue-ray players that did not engage a power saving standby mode were the most noteworthy examples of this behaviour. Since many households left these devices on for much of the survey period, it was difficult to resolve when they were in active use. Fortunately, since set-top boxes and DVD/VCR/Blue-ray players are generally used in conjunction with a TV (which generally has a much clearer power signature when in use) these kinds of activities were still captured under the association rules relating to general TV use. As such, specific association rules for set-top boxes and DVD/VCR/Blue-ray players are not shown here. Rather, the household activities requiring the use of these devices are reflected in the broader TV association rules.

Appliance subset exclusions: Appliance association subsets linking the use patterns of more than two appliances were excluded from the analysis since these did not offer significant appliance association insights beyond those already captured by the two appliance subset studies. Preliminary analysis of association rules involving sets of up to 10 appliances revealed that there was little additional insight to be obtained for the considerable increase in processing complexity involved.

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[31] Jiawei Han and Micheline Kamber "Data Mining: Concepts and Techniques", 2nd Ed, Chapter 5, Elsevier, 2006.

Sensitivities

To better understand the links between household characteristics and patterns of appliance use, sensitivities around household type, occupancy and social grade were explored. For each of these three sensitivities, the complete set of appliance events (i.e. the set of monitored 10 minute time periods in which at least one appliance was on and in active use) were subdivided by household characteristics (i.e. household type, household occupancy or social grade, depending which sensitivity was being run). Each of these event sets were then analysed individually in R with the Apriori algorithm, and their association rules were examined using the approach described above.

Analysis

The association rules produced using this approach are presented below, collected according to antecedent appliance type – i.e. cooking appliances, audiovisual appliances, ICT appliances, washing and water heating appliances and other appliances. In the context of the tables, the confidence level for each appliance association rule indicates the likelihood of the consequent appliance (on the right-hand side) being in active use (i.e. not off or in standby) if the antecedent appliance (on the left-hand side) in that household is active. The orientation of the appliances in the association rule is significant, and appliance associations that are valid in both orientations are shown as two separate rules (as is the case for the relationship between desktop computers and monitors).

The support values shown in the tables below reflect the fraction of events where both appliances are on at the same time (i.e. the association rule is satisfied) and give a relative measure of occurrence between the different association rules. The lift values provide a measure of the strength of the association between appliances – the higher the lift, the greater the appliance association relative to the random chance that these appliances are used simultaneously.

The appliance patronage values indicate the total number of each appliance that was actively used in the monitored period across all the households. This differs from the total number of appliances available because appliances that were not used during the monitoring period are excluded from the figures. Association rules containing appliances with a household patronage of less than 4 have been removed, and those with less than 10 are shown in red in the tables. The limited patronage association rules shown in red should be viewed with caution, since there is still potential for individual household trends to bias the association statistics.

Cooking Appliances

For the cooking appliance associations shown in the table below, the overriding pattern emerging is a trend towards TV use while cooking; a trend that is observable for as many as six different cooking appliances, with a confidence level of up to 74%. This means that, when cooking appliances are used, there is as much as a 74% chance that the TV will be active. (Note that this analysis only applies to electric cooking appliances – time of use data for gas appliances was not collected.)

It is worth noting that since the general support for TV use was very high (about 49% of all appliance events contain a TV), the maximum lift that is possible for appliance associations with the TV is limited to approximately 2 (i.e. 100% divided by 49%). This helps put the moderate lift values for associations with the TV into context.

As a secondary point, there was also an association between the fryer and the desktop computer.

While the confidence of this association (about 51%) was lower than those of the TV associations, the lift value was relatively high (about 2.7), owing to lower levels of support for the desktop computer within the appliance events.

As a final point, the associations between cooking appliances and other audiovisual devices, such as the radio and Hi-Fi, all had confidence levels below 30%, so were insufficient to include in the analysis.

Cooking appliances as antecedent appliance

Antecedent Appliance		Consequent Appliance	Confidence	Support	Lift	No. of Antecedent Appliances	No. of Consequent Appliances
Fryer	=>	TV	73.8%	0.022%	1.50	5	460
Food mixer	=>	TV	62.1%	0.004%	1.26	5	460
Oven	=>	TV	62.0%	0.786%	1.26	53	460
Microwave	=>	TV	58.5%	2.138%	1.19	219	460
Extractor hood	=>	TV	57.9%	0.192%	1.18	48	460
Toaster	=>	TV	56.0%	0.246%	1.14	68	460
Fryer	=>	Desktop computer	50.8%	0.015%	2.74	5	104

Audiovisual Appliances

The majority of the audiovisual appliance associations shown in the table below are for audio systems that are frequently used in conjunction with a TV or home computer – as an audio extension to these systems for improved sound quality (e.g. in a home entertainment system). In this context, the associations are not surprising. Similarly, the association between TV use and game console activity also makes sense, since many game consoles rely on a TV for visual display.

Audiovisual appliances as antecedent appliance

Antecedent Appliance		Consequent Appliance	Confidence	Support	Lift	No. of Antecedent Appliances	No. of Consequent Appliances
Home cinema sound	=>	TV	78.7%	2.306%	1.60	10	460
Game console	=>	TV	66.6%	3.656%	1.35	94	460
Audiovisual site	=>	TV	65.0%	7.913%	1.32	61	460
Hi-Fi	=>	TV	54.2%	3.731%	1.10	23	460
Home cinema sound	=>	Printer	52.0%	1.525%	7.61	10	173
Home cinema sound	=>	Monitor	55.3%	1.622%	4.19	10	105
Home cinema sound	=>	Desktop computer	57.7%	1.690%	3.11	10	104

ICT Appliances

The ICT appliance associations shown in the table below reflect strong links between different ICT devices, and between ICT appliances and the TV. The five strong associations among different ICT appliances (with confidence levels up to 85%) are as expected, since these devices are typically used concurrently and in many cases are reliant on each other. The cause of the associations between ICT appliances and the TV are less obvious, and could reflect a number of possible scenarios, including simultaneous computer and TV use by a single occupant, or well-aligned concurrent usage of these appliances by different household occupants. We will come back to this in the next section.

A final observation from this table is that speakers (defined as an ICT appliance in the HES classifications) show similar associations to the audio equipment discussed in the sections above – they carry strong associations with the appliances they are generally connected to (TVs and home computing equipment).

ICT appliances as antecedent appliance

Antecedent Appliance		Consequent Appliance	Confidence	Support	Lift	No. of Antecedent Appliances	No. of Consequent Appliances
Speakers	=>	TV	87.5%	1.490%	1.78	14	460
Monitor	=>	TV	63.6%	8.407%	1.29	105	460
Desktop computer	=>	TV	58.2%	10.793%	1.18	104	460
Computer equipment	=>	TV	51.7%	5.735%	1.05	55	460
Modem	=>	TV	50.4%	0.200%	1.02	12	460
Printer	=>	TV	50.4%	3.441%	1.02	173	460
Monitor	=>	Desktop computer	85.0%	11.234%	4.58	105	104
Speakers	=>	Desktop computer	80.7%	1.375%	4.35	14	104
Printer	=>	Desktop computer	51.6%	3.526%	2.78	173	104
Speakers	=>	Monitor	72.8%	1.240%	5.51	14	105
Desktop computer	=>	Monitor	60.6%	11.234%	4.58	104	105

Washing appliances and showers

The washing appliances associations shown in the table below demonstrate a recurrent link with TV use. The relatively low lift values for the washing appliance associations indicate that this relationship is not particularly strong, and may simply reflect the high probability of the TV being on while someone is home, using a washing appliance.

It is clear that the long time periods over which washing appliances operate, combined with the minimal user engagement required, allows for both single and multiple-user scenarios. It is less obvious if the association between shower operation and TV use precludes a single user scenario, and we come back to this in the next section, on sensitivities.

Washing appliances and showers as antecedent appliance

Antecedent Appliance		Consequent Appliance	Confidence	Support	Lift	No. of Antecedent Appliances	No. of Consequent Appliances
Washing/drying machine	=>	TV	53.0%	0.443%	1.08	46	460
Clothes dryer	=>	TV	52.4%	0.985%	1.07	114	460
Dishwasher	=>	TV	51.6%	1.463%	1.05	112	460
Shower	=>	TV	60.9%	0.491%	1.24	103	460

Other Appliances

Many of the appliances that fall into the "other appliances" classification used in the HES were owned by only a few households, as shown in the table below. This means the association rules should be viewed with caution. That said, there were still some interesting trends amongst these appliances that are worth noting.

The associations between fan appliances and TV, desktop computers, monitors and game consoles reflect common household activities that might be expected while a fan is on. Similarly, TV use while a steriliser is on can also be understood in terms of compatible background entertainment. The strong rules associating paper shredding with printing and desktop computer activities are unsurprising, and relate to the common ICT appliance dependencies discussed above. It is worth noting that the association between ironing (49 units owned) and TV watching had a low confidence of 48.6%, and a lift of 0.99 and was, therefore, excluded from the association rules table.

'Other appliances' as antecedent appliance

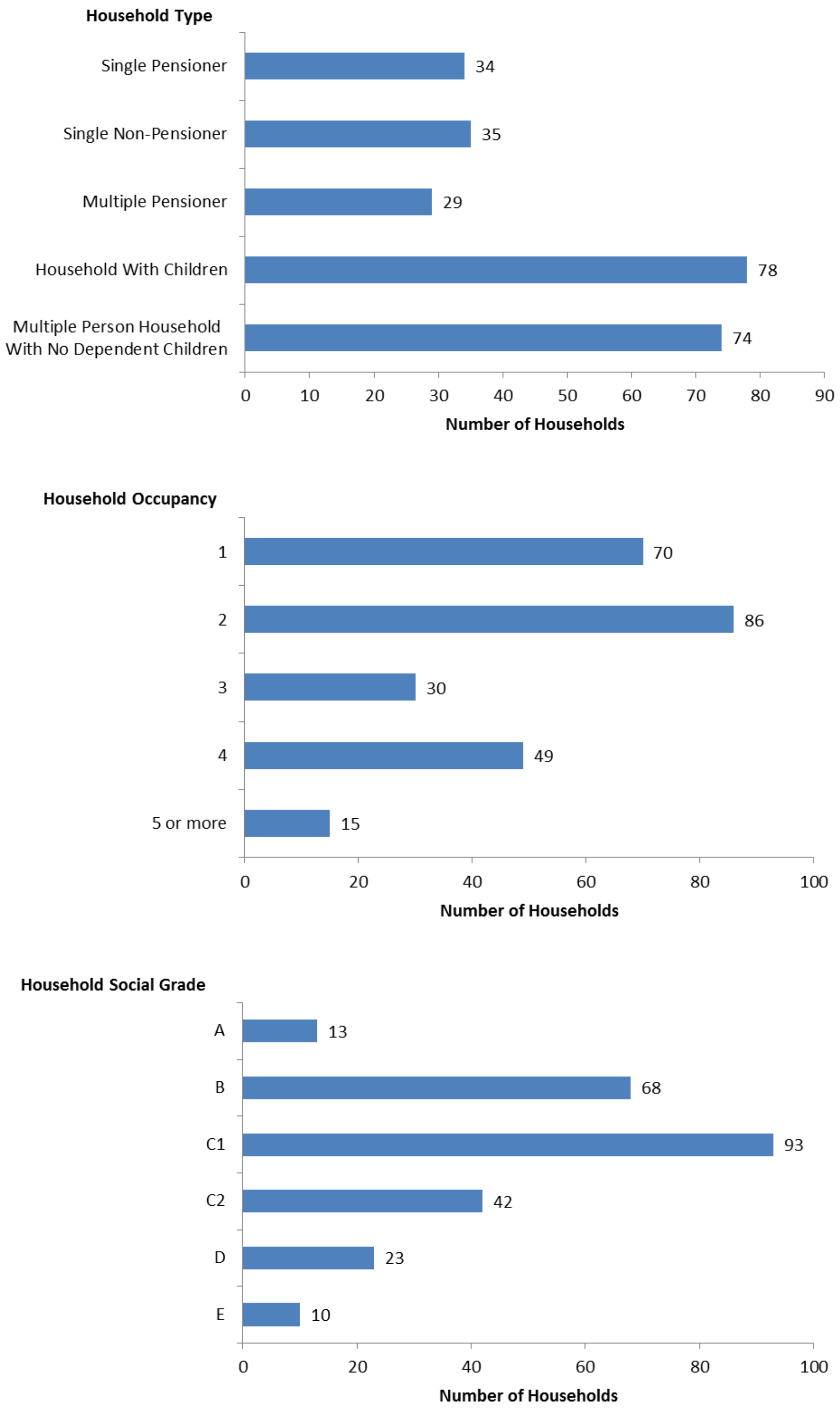
Antecedent Appliance		Consequent Appliance	Confidence	Support	Lift	No. of Antecedent Appliances	No. of Consequent Appliances
Fan	=>	TV	61.9%	1.140%	1.26	17	460
Steriliser	=>	TV	51.1%	0.021%	1.04	5	460
Paper shredder	=>	Printer	90.8%	0.013%	13.29	4	173
Paper shredder	=>	Desktop computer	88.4%	0.012%	4.76	4	104
Fan	=>	Desktop computer	79.9%	1.470%	4.30	17	104
Fan	=>	Game console	79.3%	1.460%	14.43	17	94
Fan	=>	Monitor	57.3%	1.056%	4.34	17	105

Sensitivities

Three sensitivity analyses were performed to investigate the links between the appliance association rules above and household type, occupancy and social grade. For each household characteristic examined, the confidence levels corresponding to each association rule were determined for all component categories (i.e. for each household type, occupancy or social grade) and plotted to illustrate the sensitivity of each association rule to these various household characteristics. For several of the association rules discussed above, sub-dividing into component household characteristics meant that the ownership level fell below 10. In those cases, the subcategory is shown as a semi-transparent bar in the sensitivity charts below.

This flags that caution is needed interpreting these cases without support from higher ownership instances. Where a given subcategory had no ownership for a given appliance, no bar is shown. Only association rules where at least two subcategories had appliance ownership of 10 or more were included in the sensitivity charts. Given the small sample of 250 households, it is important to bear in mind that all the trends discussed in this section are indicative rather than statistically significant.

The distribution of the 250 households investigated across the household type, occupancy and social grade subcategories is shown in the charts below. For each of the three sensitivities, households were distributed relatively unevenly through different subcategories in each case. Consequently, the subcategories containing a smaller fraction of the monitored households were more susceptible to low appliance patronage levels. Note that the social grade of one household (household number 203420) was not supplied and therefore there are only 249 households included in the social grade sensitivity analysis.



Summary of household type, occupancy and social grade in the HES

Sensitivity to household type

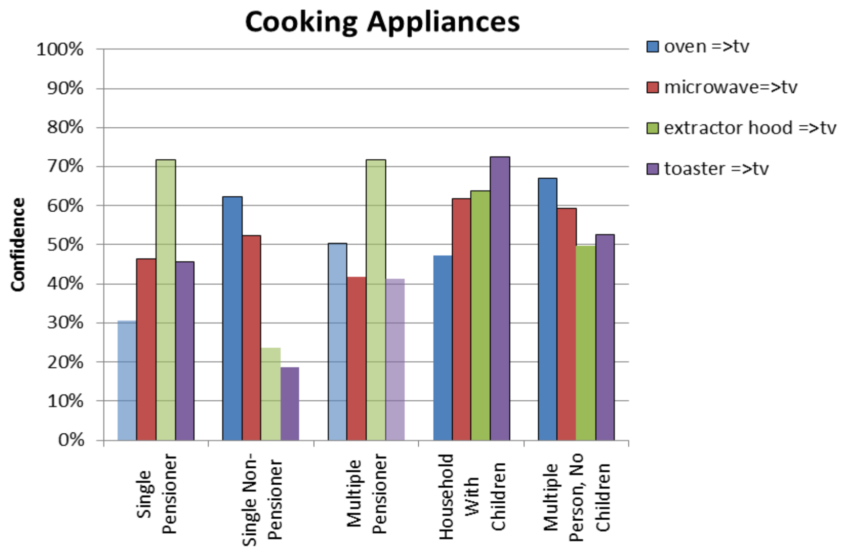
The sensitivity charts showing how the confidence for each association rule is influenced by household type are shown in the bar charts below. These charts provide considerable insight into the potential usage scenarios identified in the analysis above. So while the HES data does not explicitly reveal which occupant was using each appliance, it is still possible to obtain some insight into whether the identified appliance associations were due to a single occupant using the devices together (i.e. a single user association), or from correlated usage patterns from different household occupants with each appliance (i.e. a multiple-user association). The ability to distinguish between these two scenarios has potential ramifications for policy development, grid management and behavioural studies.

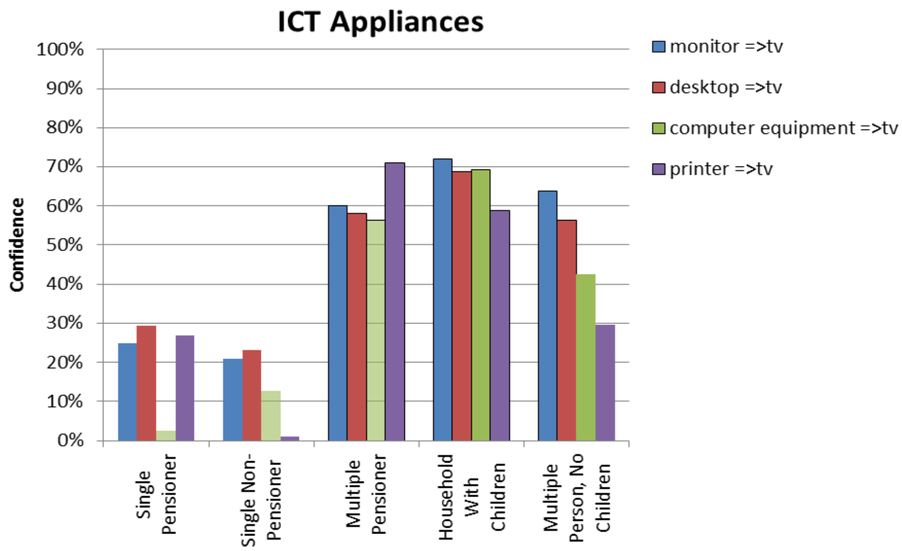
The bar charts below show that the association between cooking appliances and TV use were valid for single person households (i.e. single pensioners and single non-pensioners) as well as multiple person households (multiple pensioners, households with children and multiple person households with no children). This hypothesis is supported by the relatively high confidence levels, along with lift values of greater than 1, for each cooking appliance in single and multiple person household types. From this we infer that single user associations, in which the cook is watching TV, were common in the HES households, though it is not possible to determine their overall prevalence relative to multiple-user associations with the available data.

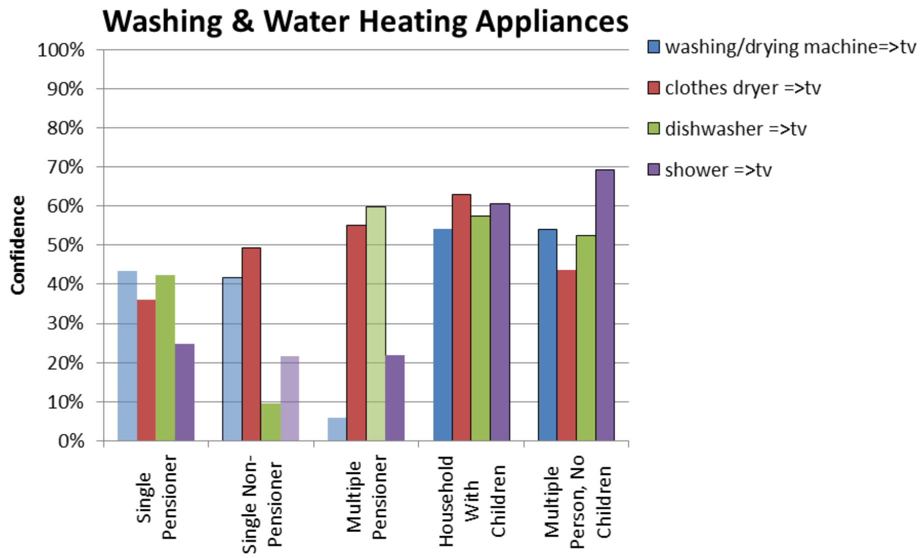
The charts below also indicate that the likelihood of the TV being in use while ICT appliances are on is significantly lower for single pensioners and single non-pensioners relative to multiple-person households. For single occupant households, the lift values for these association rules were all less than 1, signifying that the link between these appliances is no better than random chance. This finding supports the hypothesis that the association between ICT appliances and TVs arises primarily from concurrent use of these appliances by different household occupants.

There was limited association, if any, between watching TV when using washing and water-heating appliances (such as the washing/drying machine, clothes dryer, dishwasher and shower) in single person households. The confidence levels were relatively low in these cases and lift values were typically less than 1. The shower in particular showed little association with TV use in single occupant households, with single pensioner and single non-pensioner households having low confidence values (0.25 and 0.22, respectively) and lift values well below 1 (0.5 and 0.7, respectively) – i.e. no more likely than random chance.

In each of the charts, subcategories in which the lift was above 1 are shown with a black border around the confidence bar to indicate a valid appliance association. For cases in which the lift value fell below 1, no black outline is included, indicating that the association rule is no better than chance.

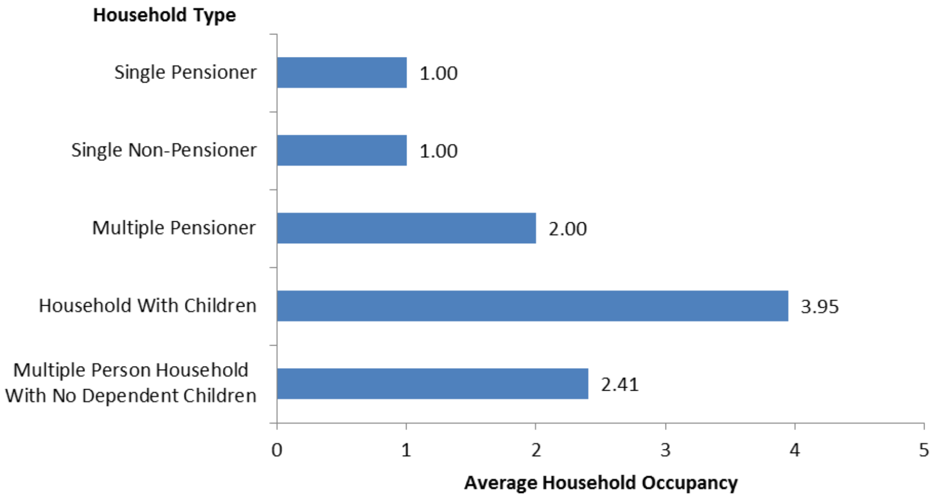






Sensitivity analysis showing the variation in confidence values for association rules across the HES household classifications. Bars are shown as semi-transparent where fewer than 10 appliances are involved and with a black border where the lift value is more than 1.

The impact of household type on confidence level appears to be linked to household occupancy in some cases. This is supported by the correlation of the occupancy profile for each household type (in the chart below) with the confidence profiles for ICT appliances and some washing appliances (in the charts above). To determine the impact of household occupancy on confidence levels, and to assess whether this was the cause of the confidence variations observed for different household types, we performed a sensitivity analysis focusing on this single parameter – see next section.

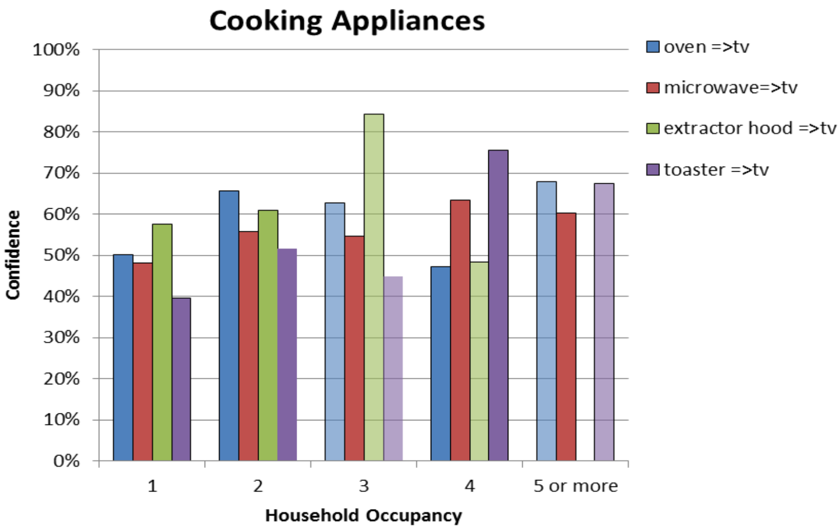


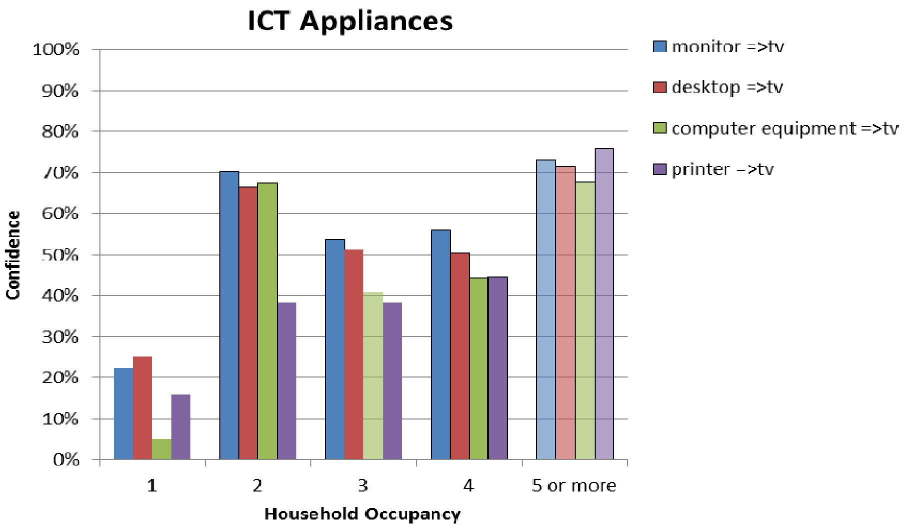
Average occupancy for each HES classification

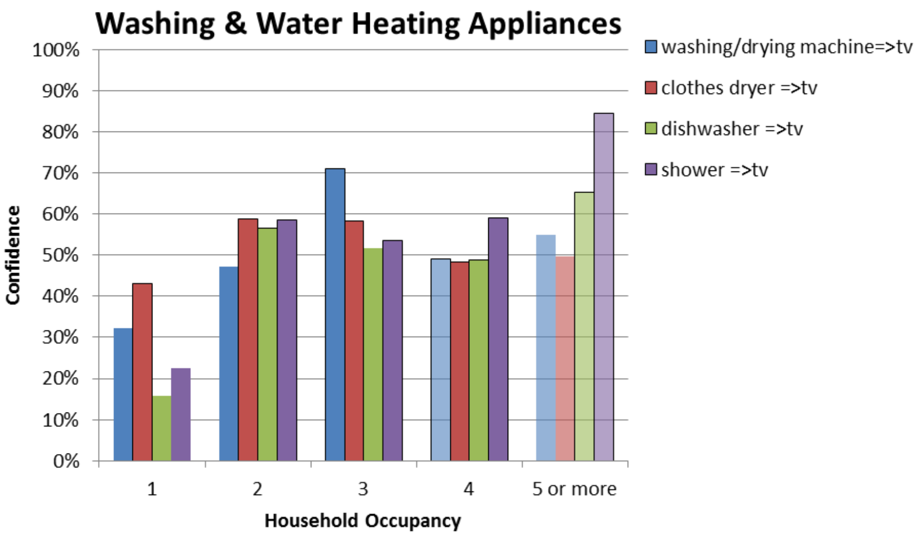
Sensitivity to occupancy

The impact of household occupancy on confidence in the charts below generally supports the observations above on single user associations. In addition, as occupancy increases, there is a trend towards increasing confidence that the TV will be in use if ICT appliances, and to a lesser extent, washing and water heating appliances, are on. While a larger sample size is required to confirm this, the data suggests that many of the trends in the household type sensitivity analysis could be related to occupancy. While further data on the appliance user in each household would be required to accurately determine the cause of this trend, it may reflect more multiple user associations with increasing household occupancy.

The confidence levels for associations between cooking appliances and the TV seem to be less related to household occupancy levels, seemingly largely independent from the number of inhabitants. Again, it is not possible to isolate the cause of this observation without additional user data, though it may indicate the strong link between TV use during cooking and single user scenarios, as discussed above.







Sensitivity analysis showing the variation in confidence for each association rule at different occupancy levels. Bars are shown as semi-transparent where fewer than 10 appliances are involved and with a black border where the lift value is more than 1.

Sensitivity to social grade

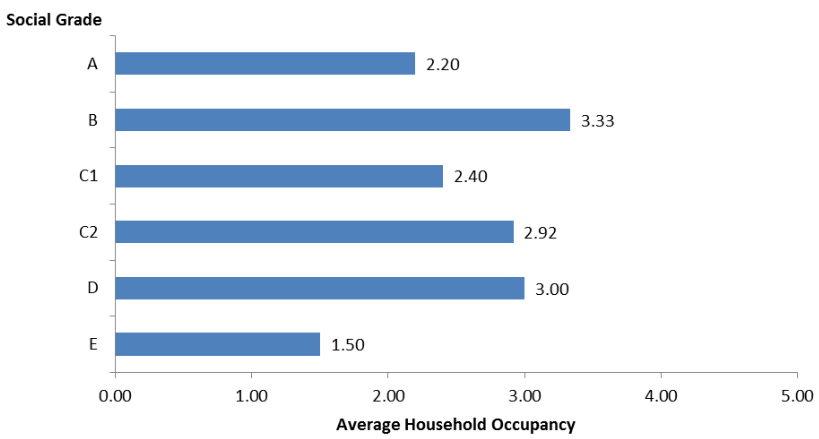
The final sensitivity analysis explores the impact of social grade on the appliance associations. The social grading system used in the HES is the National Readership Survey (NRS) social grading system, as outlined in the table below.

The NRS Grading System[32]

Social Grade	Description	% of Study Households	% of UK Population
A	Higher managerial, administrative or professional	5	4
B	Intermediate managerial, administrative or professional	27	22
C1	Supervisory, clerical and junior managerial, administrative or professional	37	29
C2	Skilled manual workers	17	21
D	Semi and unskilled manual workers	9	15
E	State pensioners, casual or lowest grade workers, unemployed with state benefits only	4	8

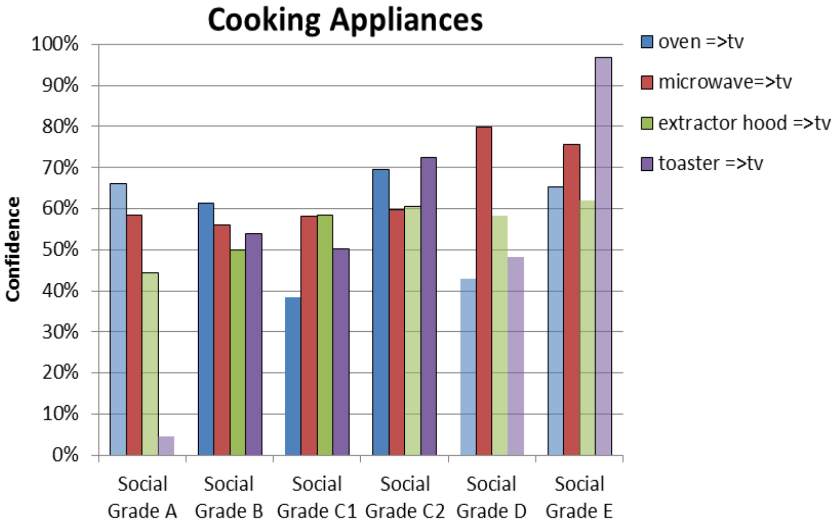
For most appliance associations in the charts below, there is a broad trend towards increasing confidence with decreasing social grade. Interestingly, this finding mirrors a more general trend towards increased support for TV use (on its own) with decreasing social grade (increasing from about 32% in social grade A to 65% in social grade E). Besides the obvious social and behavioural implications, this may have ramifications for targeted policies or demand-side response strategies relating to TV use. This is also consistent with our findings that lower social grades are more likely to leave appliances on when occupants are in different rooms (see 'Appliances left on' section below).

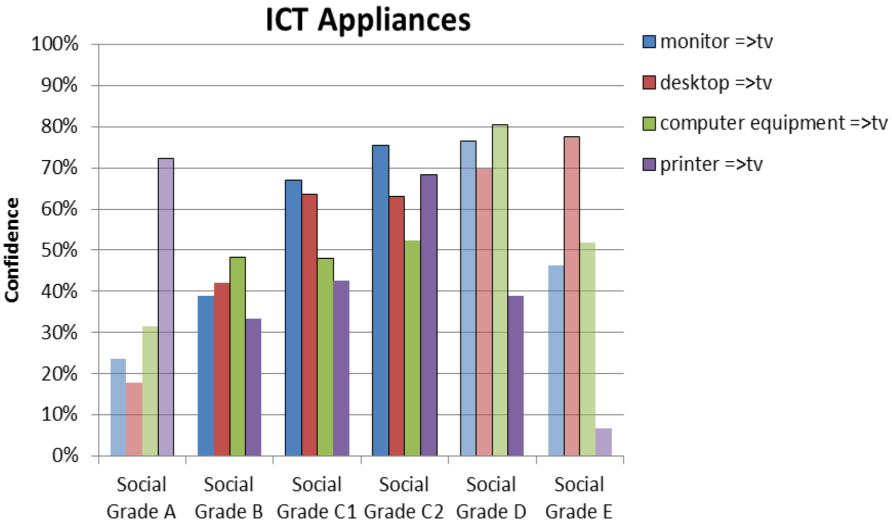
The trend towards increasing confidence with decreasing social grade does not appear to be linked to household occupancy, with little correlation between the occupancy profile (shown below) and confidence values for each social grade.

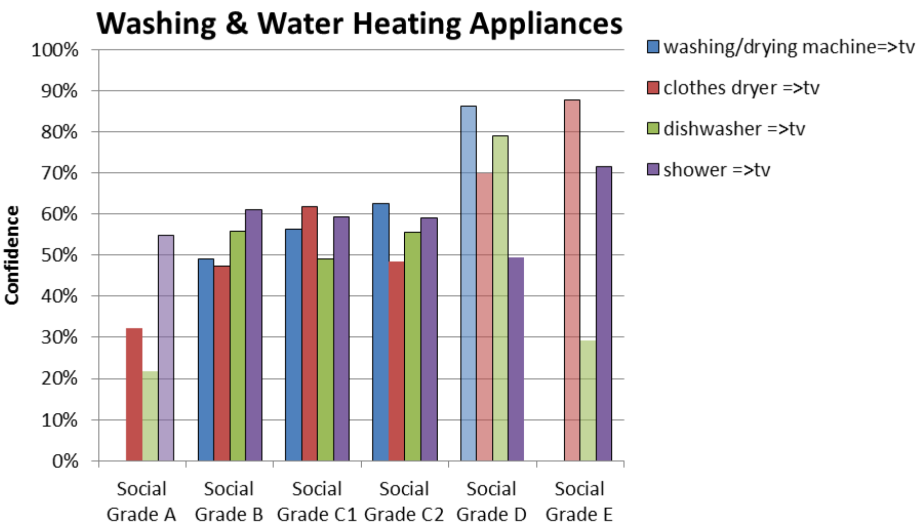


Average occupancy observed for each of the social grades in the HES

[32] National Readership Survey, 2010. Available from http://www.nrs.co.uk/lifestyle-data/







Sensitivity analysis showing the variation in confidence values for each association rule across social grades. Bars are shown as semi-transparent where fewer than 10 appliances are involved and with a black border where the lift value is more than 1.

Recommendations

- The common associations within ICT appliances (e.g. between desktop computers, monitors, printers, speakers, etc.) and audiovisual appliances (e.g. between TVs, home cinema systems, gaming consoles, Hi-Fi's, etc.) confirm the need to consider these appliances in aggregate when developing policy. Projections for electricity consumption from TVs should account for changes in ownership and power consumption of these associated appliances rather than focusing only on consumption by televisions.

- The strong and recurrent associations linking TV use to cooking, audiovisual, ICT, washing, water heating and other appliances indicate how common it is to have a TV on in the background while performing other tasks. While we cannot assess how engaged people are with the TV on these occasions, there may be scope for energy savings in scenarios where the TV is receiving limited or no attention. Many modern TVs are equipped with presence detectors and auto-off functions linked to remote control inactivity over a designated period of time. Such features offer scope for ensuring that TVs only stay on when receiving at least some attention, and could help save electricity (including at peak periods).

- The likelihood of the TV being on when other appliances are in use increases with decreasing social grade. While the small sample size limits the statistical significance of this finding, it does point to a potential correlation, which affects how to target policies, such as those related to the fuel poor. We recommend more research aimed at investigating the links between social grade and appliance usage, with a larger sample size.

- The associations for TV use during washing and cooking activities imply that these household tasks are often performed during leisure periods. This points to a potential barrier for shifting electricity demand from the evening peak period, which corresponds to a principal leisure time for many households. While timers in modern cooking and washing appliances are a mechanism for shifting some use from peak periods (particularly for washing appliances), additional incentives may be required to overcome these established behavioural tendencies. We also recommend more work looking at the elasticity of these appliance associations and demand profile characteristics, which would help understand if it is possible to separate or shift the time of use of these devices.

- Some appliance associations were found only in multiple person households (e.g. TV use at the same time as ICT use). This observation suggests that these appliance associations are not due to the actions of a single person – rather, they are due to correlations between the appliance activities of different household occupants. There may be merit in obtaining more user information to understand the complexities of these user dynamics in future studies. However, the additional monitoring and reporting burden required to obtain this information is significant and may preclude this.

Assess electricity demand for products with high agency

The Departments wished to find out how much electricity demand could be reduced by consumers changing the way they use appliances – especially appliances where householders have opportunities to choose different ways of using the appliances. This is termed 'high agency', or 'discretionary' use, and applies to most forms of entertainment, washing appliances and some aspects of lighting.

Approach

There is a very large variation between households as to how much energy they use for different purposes. Some of this variation is due to personal circumstances but much of it is due to preferences and habits. In some areas there is much wider variation than others. For example, there is a factor of 16 difference between energy use for lighting in the highest and lowest households, but only 2.3 for cold appliances.

The initial analysis of the HES[33] showed histograms of energy use for each appliance type by household type, but did not establish if the differences between household types were significant. For example, is there a statistically significant difference between television watching in households with and without children? Is there a significant difference between TV use in one pensioner versus multi-pensioner households? We performed these tests and, depending on the results, we reduced the number of household type/appliance type combinations. Then for each of these we estimated how much demand would be reduced if above-average households changed their behaviour to the level of the mean – representing the saving that would be achieved by persuading high using members of each group to reduce their use to the average for all households.

We selected the appliance types to investigate based on the extent of variation in use. Then we determined how to group household types for that appliance. We then used the student's t-test to determine where there is a significant difference between household types. For each appliance/household type combination, we set up tables and charts of their use, with means calculated as shown.

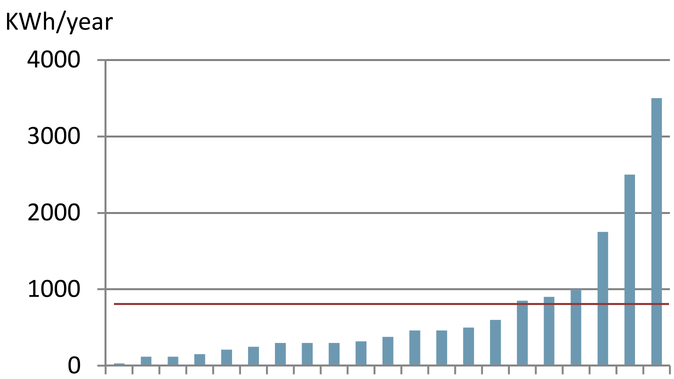


Chart showing the range of energy consumption for an appliance, with mean level marked (the horizontal line). Each vertical bar represents a household.

Then we estimated the savings that would be made if households moderated their use to match the cut-off level (removing the area of the graph above the horizontal line).

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[33] Zimmerman et al (2012) Household Electricity Survey: A study of domestic electrical product usage. Milton Keynes: Intertek/EST/DECC/DEFRA.

Data analysis

The method of analysis is best illustrated with an example. Starting with cooking energy, where we had energy data for 249 households, we considered each of the demographic and housing factors where data was available that could have a bearing on energy use: whether the household receives a pension, whether there are children, how many people there are in the household, what house type it is (terrace, semi-detached, flat, etc.), and what the floor area is.

The first line of the table below records that there were 34 'single pensioner' households recording energy use for cooking. These households had mean energy consumption of 272 kWh/year for cooking. The remaining 215 households, which we call 'Rest of group', had a higher average energy consumption per year for cooking: 478 kWh. However, how do we know whether this difference is statistically significant, or just a random variation that comes as a result of the sampling? The answer comes from mathematical calculations called significance tests, see box.

The next column of the table, labelled t-test, gives the test statistic, t. This is a measure of the difference between the means in units of standard deviations. This means that the t value is large for large differences and low variability. Conversely, it is low for low differences or large variability. In the case of the single pensioner, this tells us that the mean for single pensioners is lower than the mean for the rest of the households (it is a negative number).

Significance tests

In statistics, a result is deemed 'significant' if the result is unlikely to be due to chance alone. This study has only 250 households: not a large sample, and not enough to be sure about small differences between groups, especially if there is large variability (i.e. dispersion) within groups. The significance of each result is described by the p-value, which is 0.05 for a 5% chance. Since this part of the analysis involves approximately 160 tests, we can expect around 5% - i.e. 8 or so - results to appear significant at this level by chance alone. When the p-value is 0.01 or smaller, indicating no more than a 1 in 100 chance, then the significance is more certain.

The next column, 'p-value' shows the probability of getting this value by chance – < 0.001, or less than a 1 in a 1000 chance. This is very low probability, and much less likely than the 1 in 20 or 5% threshold, so the significance test is accepted. The row is highlighted and marked with asterisks (**) to indicate the data shows a statistically significant difference between the means of the test sample and the rest of the group. This applies not just for this sample of homes, but for the whole population (all homes in England).

There are similarly low probabilities for non-pensioners, households with children, and multiple households getting these differences in means by chance. For multiple pensioner households the group mean is close to the overall mean so there is no significant difference.

The findings are less clear for house type, where the p-value is less than 5% in only two of the groups, for mid-terrace and detached houses. Even in those cases, the p-value is not as low as for the household

A note on cooking data

Regrettably, the survey did not include meters on gas appliances, so although we have data on the total gas use in each household, it is not possible to say what proportion was used for cooking. Nor do we know anything about the time of use of gas cooking. This means that this part of the report, and other parts addressing cooking, deal only with *electric* cooking appliances.

type groups, showing that the difference is less certain, in particular for the Mid-Terrace case, where there is a two in a hundred chance that the distinction is due to random chance.

Detached households as a group use more cooking energy than other households, which suggests that it would be good to explore this further to understand the reasons for this, and to assess the potential for detached households to achieve savings. However, the link with house type is not necessarily direct. In this case there is also a significant effect from house size, and detached houses tend to be larger: in this study the average floor area for a detached house was 134 m^2, whereas it was only 93 m^2 for other homes. If the government wished to target specific households for efforts aimed at reducing energy use for cooking, detached homes would be a reasonable place to start – given that there is a statistically significant tendency to use more energy for cooking among these households.

The strongest factor affecting cooking energy use is the number of people in the household. Single person households use much less energy than other groups (238 kWh, or nearly 50% less, on average). Whereas two- and three-person households used more than other household types, on average.

Size also emerged as significant for small homes from 50 to 100 m^2, and medium-sized homes of 100 to 150m^2, showed a statistically significant link to energy consumption here (t-test probabilities of 0.004 and 0.007). Households living in small homes used a fifth less energy than others for cooking, while medium homes used just over a fifth more, on average.

Other Evidence on High Agency Savings

A study[34] carried out following gathering electricity use data over two years for 72 households in the UK in the early 2000s also categorised the households as high, medium and low-electricity consumers. Due to differences in the analysis approach and the data collected, the results cannot be compared directly with the findings of the HES study. However, using a similar approach (i.e. assuming that the high energy consumers can reduce to the overall mean energy use) suggests that this would reduce annual energy consumption of cold, active and continuous/standby appliances by 7%, 20% and 28% respectively. This amounts to a total drop of almost 20% in household electricity consumption.

[34] Firth, Steven, et al. (2008) Identifying trends in the use of domestic appliances from household electricity consumption measurements. Energy and Buildings 40.5: 926-936.

Appliances		Test Sample		Rest of Group		t-Test	
		Sample size	Mean (kWh/y)	Sample size	Mean (kWh/y)	t-value	p-value
Cooking	**Single pensioner****	**34**	**272**	**215**	**478**	**-4.0**	**< 0.001**
	Single non-pensioner**	**35**	**279**	**214**	**478**	**-3.9**	**< 0.001**
	Multiple pensioner	29	502	220	443	1.0	0.15
	Household with children**	**78**	**514**	**171**	**421**	**2.4**	**0.009**
	Multiple household**	**73**	**525**	**176**	**419**	**2.7**	**0.004**
	Mid-Terrace**	**50**	**378**	**199**	**468**	**-1.97**	**0.025**
	End-Terrace	27	481	222	446	0.6	0.276
	Semi-Detached	77	458	172	446	0.29	0.385
	Detached**	**57**	**536**	**192**	**424**	**2.59**	**0.005**
	Bungalow	27	394	222	457	-1.06	0.144
	Flat	11	334	238	455	-1.36	0.088
	1 Person**	**70**	**279**	**179**	**517**	**-6.3**	**<0.001**
	2 Persons**	**86**	**509**	**163**	**419**	**2.3**	**0.01**
	3 Persons**	**30**	**581**	**219**	**432**	**2.7**	**0.004**
	4 or more Persons	63	498	186	434	1.5	0.06
	50 to 100 m^2**	**128**	**402**	**121**	**501**	**-2.71**	**0.004**
	100 to 150 m^2**	**91**	**509**	**158**	**416**	**2.46**	**0.007**
	150 to 200 m^2	15	529	234	445	1.08	0.14

****Statistically significant at the 95% level.**

The same analysis for lighting energy found statistically significant differences between detached and non-detached homes, with mean lighting energy much higher for detached homes and a tiny probability of this happening by chance. The difference in means is considerable – 274 kWh/year – which makes the finding all the more important. As with cooking energy, this could be at least partly related to house size.

Living in a detached home is one of the most important demographic or housing determinants of lighting energy use, as significant as whether the household has children or receives a pension, see table below. This analysis suggests there may be a case for specifically targeting detached houses for efforts to reduce energy use for lighting. (Note that there is only lighting data for 246 homes – four homes did not have monitoring data for their lighting circuit.) However, we show later that the potential savings are higher for other types of house as a proportion of lighting energy, see below.

The number of people in the household is also significant, and the analysis also brought to light strong links between households with one person, three people and four people, and energy use for lighting. Households with just one person used less than half as much as other households, on average. Those with three people used two-thirds more, on average. And those with four or more people used 44% more energy for lighting than other households.

The lighting work also found significant differences for the size of homes, and all three size bands showed significant differences from other sizes of dwellings. The smallest homes (50-100m^2) used about two-thirds of the energy, on average, of other homes. Medium-sized homes (100-150m^2) used about a third more, on average; and larger (150-200m^2) homes used 80% more than other homes, on average. The p-value is highest for the smallest size band, indicating more certainty.

Appliances		Test Sample Sample size	Test Sample Mean (kWh/y)	Rest of Group Sample size	Rest of Group Mean (kWh/y)	t-Test t-value	t-Test p-value
Lighting	**Single pensioner****	**34**	**225**	**212**	**534**	**-3.3**	**< 0.001**
	Single non-pensioner**	**35**	**256**	**211**	**530**	**-3.0**	**0.002**
	Multiple pensioner	29	384	218	505	-1.2	0.12
	Household with children**	**76**	**687**	**169**	**402**	**4.2**	**<0.001**
	Multiple household	72	563	174	461	1.4	0.079
	Mid-Terrace	49	430	197	507	-0.93	0.176
	End-Terrace	27	412	219	501	-0.84	0.200
	Semi-Detached	78	468	168	502	-0.47	0.318
	Detached**	**55**	**704**	**191**	**430**	**3.56**	**<0.001**
	Bungalow	26	413	220	500	-0.82	0.207
	Flat	11	243	235	503	-1.64	0.051
	1 Person**	**70**	**252**	**176**	**586**	**-4.81**	**<0.001**
	2 Persons	83	485	163	495	-0.14	0.44
	3 Persons**	**30**	**763**	**216**	**454**	**3.14**	**<0.001**
	4 or more Persons**	**63**	**637**	**183**	**441**	**2.63**	**0.005**
	50 to 100 m^2**	**127**	**385**	**119**	**604**	**-3.4**	**<0.001**
	100 to 150 m^2**	**90**	**576**	**156**	**442**	**2.0**	**0.025**
	150 to 200 m^2**	**14**	**846**	**232**	**470**	**2.7**	**0.004**

****Statistically significant at the 95% level.**

For audio-visual appliances single-person households and households with children both had statistically significant differences in mean energy use (see table below). Single person households of working age use dramatically less energy, on average, for AV appliances: less than half as much as other groups. Conversely, households with children use much more energy for AV – more than 50% more – than other groups.

The number of people in the household is another significant demographic characteristic affecting energy use for AV appliances. Large households with four or more people use twice as much energy for AV as other households, on average. It may be hard to change this, because it probably suggests that larger households have more diverse tastes and do not use AV appliances together.

Information and communication appliances (principally computers and screens) are quite different from AV. Here there are five significant determinants of use: single non-pensioners, multiple households with no children, one-person households, semi-detached homes, and larger homes (see second table below). Multiple households without children use 50% more power for ICT (309 kWh/year, compared to 204 kWh/year) than other groups, on average.

One-person households use significantly less power for ICT – a mean of 144 kWh/year, against a mean of 269 for other groups. Large households of four or more people do not show a statistically significant difference from other household types.

There is a significant relationship between larger homes and increased ICT use. Average use by people living in homes more than 150 m^2 is nearly double ICT energy use in other groups. This could be linked to higher incomes for many households living in larger homes, which allow them to buy and use more IT equipment, and possibly also to having more space to accommodate ICT equipment.

Appliances		Test Sample		Rest of Group		t-Test	
		Sample size	Mean (kWh/y)	Sample size	Mean (kWh/y)	t-value	p-value
Audiovisual	**Single pensioner****	**33**	**396**	**215**	**564**	**-1.8**	**0.034**
	Single non-pensioner**	**34**	**247**	**214**	**588**	**-3.9**	**<0.001**
	Multiple pensioner	29	443	219	555	-1.2	0.13
	Household with children**	**78**	**713**	**170**	**463**	**3.8**	**<0.001**
	Multiple household	74	600	174	517	1.2	0.11
	Mid-Terrace	50	556	198	538	0.23	0.409
	End-Terrace	27	640	221	529	1.11	0.135
	Semi-Detached	78	537	170	543	-0.09	0.464
	Detached	57	522	191	547	-0.34	0.368
	Bungalow	26	521	222	544	-0.22	0.413
	Flat	10	398	238	547	-0.94	0.174
	1 Person**	**68**	**317**	**180**	**626**	**-4.59**	**<0.001**
	2 Persons**	**86**	**468**	**162**	**80**	**-1.71**	**0.044**
	3 Persons	30	576	218	537	0.41	0.34
	4 or more Persons**	**64**	**862**	**184**	**430**	**6.55**	**<0.001**
	50 to 100 m^2	128	532	120	551	-0.31	0.378
	100 to 150 m^2	91	571	157	524	0.72	0.236
	150 to 200 m^2	15	441	233	548	-0.81	0.209
ICT	Single pensioner	21	149	196	248	-1.5	0.068
	Single non-pensioner**	**31**	**137**	**186**	**255**	**-2.14**	**0.017**
	Multiple pensioner	21	201	196	242	-0.61	0.273
	Household with children	73	249	144	233	0.39	0.350
	Multiple household**	**71**	**309**	**146**	**204**	**2.55**	**0.006**
	Mid-Terrace	40	191	177	249	-1.14	0.127
	End-Terrace	24	229	193	240	-0.16	0.436
	Semi-Detached**	**69**	**287**	**148**	**216**	**1.69**	**0.046**
	Detached	54	253	163	234	0.43	0.333
	Bungalow	21	171	196	246	-1.13	0.129
	1 Person**	**53**	**144**	**164**	**269**	**-2.78**	**0.003**
	2 Persons	76	267	141	223	1.07	0.143
	3 Persons	27	235	190	196	-0.07	0.470
	4 or more Persons	61	287	156	208	1.54	0.062
	50 to 100 m^2	107	218	110	258	-1.03	0.153
	100 to 150 m^2	84	237	133	239	-0.04	0.484
	150 to 200 m^2**	**14**	**429**	**203**	**225**	**2.59**	**0.005**

****Statistically significant at the 95% level.**

Data is available for fewer households regarding washing appliances – particularly tumble driers (which were only recorded in 112 homes). However, here the significant determinants were household size, having children, and pensioner status. People living alone emerged with a significantly lower energy use for washing machines – mean consumption 113 kWh/year lower than other groups.

Larger households and households with children had significantly higher energy use for washing: about 100 kWh/year more for households with three or more people, and more than double other groups for households with children.

Single pensioners used a little less energy for washing clothes than other single households, but multiple pensioners used quite a bit less energy than multiple households of working age: about 40% less, on average.

However, these differences were less certain than others with a lower p-value: as noted in the box on p82, we expect some misleading results to occur randomly from such a large number of tests.

Single-person households use dramatically less energy to run tumble dryers than other household types: less than a third as much, on average. Conversely, households with children use more than double other households for drying clothes.

So too, the largest households – with four or more people (inevitably including some households with children) – also use significantly more energy for tumble driers. Again, they use more than double other households, on average.

There is no statistically significant link between dwelling size and tumble drier use. It may be that despite having higher incomes, on average (which would allow them to run tumble driers), the owners of large homes also have more space to dry clothes indoors (which would mean they have an easy alternative to using the tumble drier).

Appliances		Test Sample		Rest of Group		t-Test	
		Sample size	Mean (kWh/y)	Sample size	Mean (kWh/y)	t-value	p-value
Washing machines	**Single pensioner****	**27**	**67**	**179**	**172**	**-4.20**	**<0.001**
	Single non-pensioner**	**29**	**84**	**177**	**171**	**-3.49**	**<0.001**
	Multiple pensioner**	**23**	**95**	**183**	**166**	**-2.60**	**0.005**
	Household with children**	**68**	**246**	**138**	**115**	**7.93**	**<0.001**
	Multiple household	59	161	147	157	0.19	0.430
	Mid-Terrace	41	169	165	156	0.6	0.274
	End-Terrace	20	173	186	157	0.56	0.289
	Semi-Detached	70	166	136	155	0.6	0.274
	Detached	46	168	160	156	0.56	0.287
	Bungalow	23	105	183	165	-2.16	0.016
	1 Person**	**56**	**76**	**150**	**189**	**-6.2**	**<0.001**
	2 Persons**	**69**	**131**	**137**	**172**	**-2.2**	**0.013**
	3 Persons**	**25**	**246**	**181**	**146**	**3.8**	**<0.001**
	4 or more Persons**	**59**	**236**	**150**	**130**	**5.8**	**<0.001**
	50 to 100 m^2	108	143	98	175	-1.82	0.035
	100 to 150 m^2	76	183	130	144	2.15	0.016
	150 to 200 m^2	12	147	194	159	-0.32	0.375

****Statistically significant at the 95% level.**

Tumble Dryer	**Single pensioner****	**7**	**100**	**105**	**360**	**-1.76**	**0.040**
	Single non-pensioner**	**9**	**140**	**103**	**361**	**-1.68**	**0.047**
	Multiple pensioner	12	305	100	348	-0.37	0.356
	Household with children**	**41**	**457**	**71**	**278**	**2.45**	**0.008**
	Multiple household	43	328	69	353	-0.33	0.370
	Mid-Terrace	16	299	96	351	-0.51	0.307
	Semi-Detached	39	373	73	327	0.6	0.274
	Detached	33	373	79	331	0.53	0.297
	Bungalow	12	183	100	363	-1.55	0.062
	1 Person**	**16**	**122**	**96**	**389**	**-2.57**	**0.006**
	2 Persons	44	284	68	382	-1.33	0.094
	3 Persons	17	310	95	349	-0.39	0.348
	4 or more Persons**	**35**	**535**	**77**	**256**	**3.80**	**<0.001**
	50 to 100 m^2	44	340	68	346	-0.08	0.467
	100 to 150 m^2	47	370	65	324	0.62	0.268
	150 to 200 m^2	12	200	100	360	-1.38	0.085

****Statistically significant at the 95% level.**

Turning to the use of kettles (another high-agency appliance), small households of one or two people, and pensioners, show significant relationships to energy use. (See table, next page.) One-person households and single pensioners use about 30% *less* energy than other groups, while two-person households and multiple pensioners use 20-30% *more* energy than other groups, on average.

It is counter-intuitive that there is no statistically significant link between household size above two people and the use of electric kettles. We might expect larger households to make more hot drinks, and so to use kettles more. However, there is no evidence from the HES that the differences are significant, apart from one and two-person households. Similarly there is no significant link between kettle use and dwelling type or floor area, although larger dwellings do have more residents on average.

Appliances		Test Sample		Rest of Group		t-Test	
		Sample size	Mean (kWh/y)	Sample size	Mean (kWh/y)	t-value	p-value
Electric Kettle	**Single pensioner****	**33**	**124**	**201**	**175**	**-2.9**	**0.002**
	Single non-pensioner**	**33**	**105**	**201**	**178**	**-4.3**	**<0.001**
	Multiple pensioner**	**27**	**216**	**207**	**162**	**2.8**	**0.003**
	Household with children	71	179	163	163	1.1	0.13
	Multiple household**	**70**	**190**	**164**	**159**	**2.3**	**0.012**
	Mid-Terrace	46	148	188	173	-1.58	0.058
	End-Terrace	25	179	209	167	0.61	0.273
	Semi-Detached	75	174	159	166	0.6	0.274
	Detached	52	160	182	170	-0.69	0.246
	Bungalow	26	193	208	165	1.43	0.077
	Flat	10	167	224	168	-0.02	0.49
	1 Person**	**67**	**116**	**167**	**189**	**-5.6**	**<0.001**
	2 Persons**	**83**	**190**	**151**	**156**	**2.7**	**0.004**
	3 Persons	29	191	205	165	1.4	0.080
	4 or more Persons	55	185	179	163	1.5	0.063
	50 to 100 m^2	123	163	111	174	-0.93	0.177
	100 to 150 m^2	84	176	150	163	0.99	0.163
	150 to 200 m^2	14	192	220	167	0.97	0.166

Dishwasher use is most strongly affected by household size and having children. Smaller households of one or two people use 20-35% less energy to run dishwashers, on average (see table). Conversely, larger households of three or more people use from a quarter to a third more energy for dishwashers. Households of four or more people use less energy for dishwashers, on average, than households of three people. It is not clear why this should be.

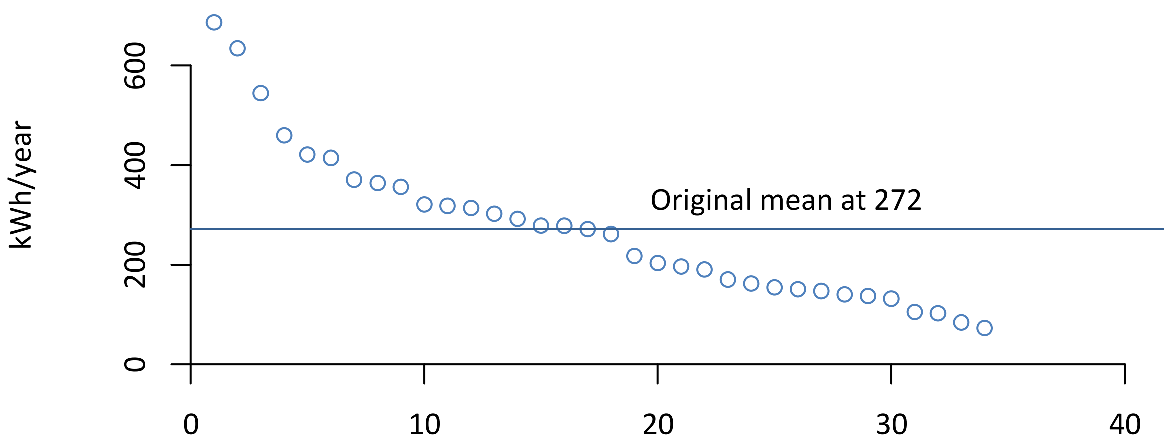
Larger households are more likely to have children, and the HES households with children used a third more energy to run dishwashers, on average. Single pensioners, on the other hand, emerged as less likely to have heavy dishwasher use: they typically used more than 40% less energy for dishwashers.

Appliances		Test Sample		Rest of Group		t-Test	
		Sample size	Mean (kWh/y)	Sample size	Mean (kWh/y)	t-value	p-value
Dishwasher	**Single pensioner****	**6**	**170**	**106**	**297**	**-1.9**	**0.032**
	Single non-pensioner	9	220	103	296	-1.4	0.088
	Household with children**	**43**	**342**	**69**	**257**	**2.8**	**0.0034**
	Multiple household	45	284	67	294	-0.3	0.383
	Mid-Terrace	16	286	96	290	-0.1	0.459
	End-Terrace	10	315	102	287	0.51	0.306
	Semi-Detached	41	275	71	298	-0.72	0.235
	Detached	29	337	83	273	1.83	0.035
	Bungalow	12	266	100	293	-0.54	0.294
	1 Person**	**16**	**197**	**96**	**305**	**-2.5**	**0.006**
	2 Persons**	**42**	**249**	**70**	**315**	**-2.1**	**0.019**
	3 Persons**	**15**	**392**	**97**	**274**	**2.7**	**0.004**
	4 or more Persons**	**39**	**333**	**73**	**267**	**2.1**	**0.020**
	50 to 100 m^2**	**48**	**246**	**64**	**322**	**-2.51**	**0.007**
	100 to 150 m^2	52	303	60	278	0.81	0.211
	150 to 200 m2	**8**	**427**	**104**	**279**	**2.54**	**0.006**

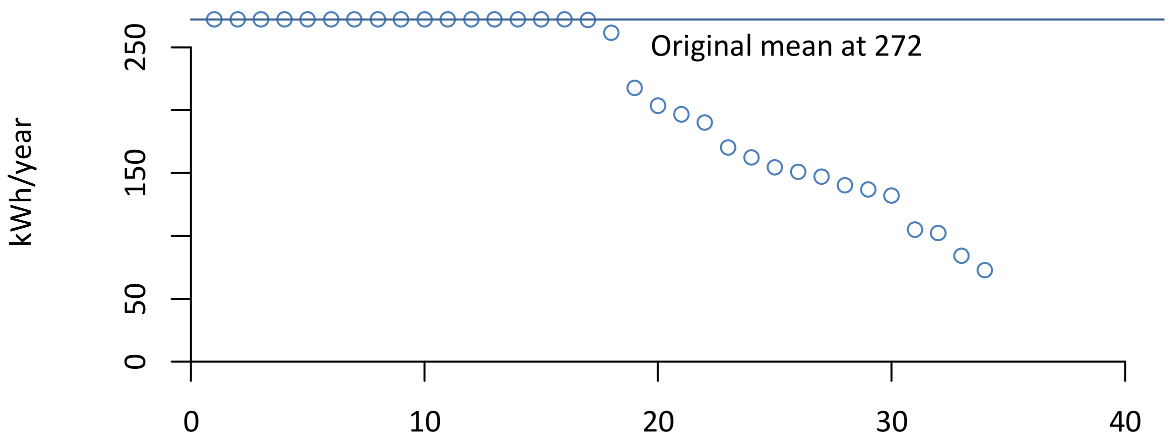
Assessing savings

We have assessed the possible savings from each of the combinations of demographic and dwelling size factors that has a statistically significant influence on energy consumption for different types of appliances. We have calculated the saving assuming that it is possible to cut the energy use of high using members of each group so that their use matches the mean of homes in their group (see plots below). This is a best-case estimate of potential savings, because there may be specific reasons why at least some of the high use households are unable to change – for example, no outdoor space, which prevents them from drying clothes outdoors.

Cooking: single pensioner households - before adjustment



Cooking: single pensioner households - after adjustment



The table below shows the mean energy consumption for each appliance type before and after the high use members of each group have reduced their energy use of that appliance. There is more than one row (and therefore estimate of savings) for appliance types that show multiple groups with a significant difference.

Appliances		Before		After		Saving	
		Sample size	Mean (kWh/y)	Adjusted homes	New mean (kWh/y)	kWh/y	%
Cooking	Single pensioner	34	272	16	213	2000	22%
	Single non-pensioner	35	279	14	183	3382	35%
	Household with children	78	514	32	383	10,212	25%
	Rest of Group	102	519	47	412	10,844	21%
	Total	**249**	**450**	**109**	**344**	**26,479**	**24%**
Cooking	Mid-Terrace	50	378	20	276	5107	27%
	Detached	57	536	26	403	7579	25%
	Rest of group	142	441	61	329	15,836	25%
	Total	**249**	**450**	**107**	**335**	**28,522**	**25%**
Cooking	1 person	70	279	29	200	5481	28%
	2 persons	86	509	40	398	9520	22%
	3 persons	30	581	14	466	3467	20%
	Total	**249**	**450**	**107**	**344**	**26,371**	**24%**
Cooking	50 to 100 m^2	128	402	53	293	13,984	27%
	100 to 150 m2	91	509	39	391	10,700	23%
	Rest of group	30	475	14	350	3759	26%
	Total	**249**	**450**	**106**	**336**	**28,443**	**25%**
Lighting	Single pensioner	34	225	9	146	2678	35%
	Single non-pensioner	35	256	11	146	3868	43%
	Household with children	77	687	26	470	16,756	32%
	Rest of group	100	513	40	368	14,536	28%
	Total	**246**	**491**	**86**	**337**	**37,839**	**31%**
Lighting	1 person	70	252	23	150	7116	40%
	2 persons	83	485	34	342	11,807	29%
	3 persons	30	763	8	474	8665	38%
	4 or more	63	637	25	475	10,213	25%
	Total	**246**	**491**	**90**	**337**	**37,800**	**31%**
Lighting	50 to 100 m2	127	385	39	237	18,862	39%
	150 to 200 m2	14	846	7	650	2734	23%
	Rest of group	105	572	47	413	16,769	28%
	Total	**246**	**491**	**93**	**335**	**38,364**	**32%**

Lighting	Detached	55	704	23	503	11,033	29%
	Rest of group	191	430	67	278	29,038	35%
	Total	**246**	**491**	**90**	**328**	**40,071**	**33%**
Audiovisual	1 Person	68	317	30	221	6536	30%
	4 or more	64	862	25	624	15,230	28%
	Rest of group	116	496	48	387	12,600	22%
	Total	**248**	**541**	**103**	**403**	**34,366**	**26%**
Audiovisual	Single non-pensioner	34	247	15	166	2756	33%
	Households with children	78	712	32	526	14,530	26%
	Rest of group	136	517	53	379	18,725	26%
	Total	**248**	**542**	**100**	**396**	**36,011**	**27%**
ICT	Multiple Household	71	309	17	174	9591	44%
	Rest of Group	146	204	45	129	10,889	37%
	Total	**217**	**238**	**62**	**144**	**20,480**	**40%**
ICT	1 person	53	144	13	81	2790	37%
	Rest of group	164	269	51	165	17,016	39%
	Total	**217**	**238**	**64**	**147**	**19,806**	**38%**
ICT	150 to 200 m2	14	429	6	290	1942	32%
	Rest of Group	203	225	63	136	18,173	40%
	Total	**217**	**238**	**69**	**146**	**20,115**	**39%**
Washing machine	Single pensioner	27	67	10	48	503	28%
	Single non-pensioner	29	84	10	58	766	31%
	Multiple pensioner	23	95	8	67	632	29%
	Households with children	68	246	23	194	3498	21%
	Multiple households	59	161	20	125	2132	22%
	Total	**206**	**158**	**71**	**122**	**7530**	**23%**
Washing machine	1 person	56	76	21	53	1271	30%
	2 persons	69	131	29	97	2342	26%
	3 persons	25	246	7	202	1112	18%
	4 or more	56	236	22	185	2815	21%
	Total	**206**	**158**	**79**	**122**	**7540**	**23%**

For example, the top row tells us that the 34 single pensioner households in the study had mean energy use for cooking of 272 kWh a year. Of these, 16 had energy consumption above the mean for this group. Assuming it is possible to reduce energy use in these homes to the average for the group, how much would they save? The next column shows the effect of cutting energy use in the 16 high use households to the mean for single pensioner homes – it reduces energy use for cooking in detached homes to 213 kWh/year, a saving of 22%.

The 'rest of group' row brings together all other households in the sample, which in the top section of the table means 'non-pensioner and 'non-single' homes (i.e. households of working age, or with more than one occupant). The total row at the bottom of each section simply adds together the possible savings if all groups could reduce their energy use to the mean. This is between a fifth and two-fifths in nearly all cases.

The potential savings are highest for lighting, ICT and tumble dryers (below), where there is most difference between households. Interestingly, it is not always the higher using groups where there are most savings to be made – for example for lighting there is more potential for savings in small dwellings from 50 to 100m^2, where there is more variation, rather than large houses, even though large houses use more energy.

Appliances		Before		After		Saving	
		Sample size	Mean (kWh/y)	Adjusted homes	New mean (kWh/y)	kWh/y	%
Tumble Dryer	Households with children	41	457	18	313	5882	31%
	Rest of Group	71	278	23	148	9213	47%
	Total	**112**	**343**	**41**	**208**	**15,096**	**39%**
Tumble Dryer	1 person	16	122	6	71	820	42%
	4 or more	35	535	15	384	5276	28%
	Rest of Group	61	291	21	163	7815	44%
	Total	**112**	**343**	**42**	**219**	**13,911**	**36%**
Electric kettle	Single pensioner	33	124	13	98	846	21%
	Single non-pensioner	33	105	11	78	876	25%
	Rest of group	168	189	77	153	6144	19%
	Total	**234**	**168**	**101**	**134**	**7866**	**20%**
	1 person	67	116	26	89	1827	23%
	2 persons	83	190	37	149	3407	21%
	Rest of group	84	187	39	155	2719	17%
	Total	**234**	**168**	**102**	**134**	**7953**	**20%**
Dishwasher	Households with children	43	342	17	277	2803	19%
	Rest of Group	69	257	31	200	3953	22%
	Total	**112**	**290**	**48**	**230**	**6756**	**21%**
Dishwasher	1 Person	16	197	7	155	669	21%
	3 Person	15	392	6	310	1223	21%
	Rest of Group	81	289	38	232	4625	20%
	Total	**112**	**290**	**51**	**232**	**6518**	**20%**
Dishwasher	50 to 100 m^2	48	246	24	194	2525	21%
	150-200 m^2	8	427	2	358	554	16%
	Rest of Group	56	307	28	245	3522	20%
	Total	**112**	**290**	**54**	**231**	**6602**	**20%**

The high potential savings from ICT do not reveal big differences between groups – rather, there are high savings for all groups. This suggests that there is no particular merit in targeting specific groups of households for energy savings from these appliance types, but that there could be worthwhile potential savings in all household groups.

The highest listed potential saving is for households without children for tumble-dryer use (possible savings of up to 47%). This points to the great variability in the way different households use tumble-dryers – with some households using dramatically more energy to run dryers than other households.

Ostensibly similar appliances – like dishwashers, washing machines and tumble dryers – show quite different possible savings. This too is a function of the variability of energy use between these appliances, with a narrower range of consumption for dishwashers when broken into groups than for tumble dryers or washing machines.

Recommendations

■ The analysis shows that there are considerable variations in household energy use for lighting and cooking, clothes washing and tumble dryer, and audio visual appliance use. The demographic characteristics (and particularly the number of occupants in homes) have a significant effect on energy use for these sorts of appliances. The number of people in the household proved a significant driver of energy use for many appliances with 'high agency' – where householders have discretion about how much they use an appliance.

■ Dwelling type is much less significant, with only certain categories of dwelling showing a significant link to increased energy use for lighting, cooking or ICT.

■ There seems to be considerable potential for reducing energy use for ICT and tumble dryers, and households without children may offer greater potential for saving energy by reducing tumble-dryer use.

■ Dividing up the total savings by the number of 'adjusted homes' (those using above-average energy for their group) gives an indication of the potential saving per household from changing their pattern of use. This estimate suggests possible savings of 445 kWh/year for lighting, on average, 368 kWh/year for tumble dryers, 360 kWh/year for audiovisual appliances, and 330 kWh/year for ICT.

Assess savings from smaller, simpler appliances

The Departments wished to find out how many households are buying larger items than they used to and how much electricity could be saved if they used smaller appliances. Some people may argue that if households had smaller appliances in the past, but now have larger ones, this suggests they now have larger appliances than they need, which represents an opportunity for downsizing and saving energy.

Approach

Appliance size is a consideration for TVs, cold appliances, ovens, dishwashers, washing machines and tumble dryers. We examined each of these to see what evidence there is that the 250 households in the HES are acquiring larger appliances, and how actual energy use is affected by any changes in size. We looked at the year of purchase against appliance size, measured in units appropriate for each appliance (screen size in inches for TVs, loads measured in kg for washing machines, volume in litres for fridges, and so on).

We then searched for correlations suggesting that newer appliances are larger than older ones, and actual energy consumption trends related to increasing size – *all the energy data in this section is metered electricity use from the survey*.

Where we found a positive correlation between size and energy, we estimated the savings that would come from returning new appliances to the same size as equivalent appliances purchased longer ago. To do this we calculated mean size for appliances bought before 2004, and calculated mean energy use for appliances of this size bought from 2004 onwards.

Data analysis

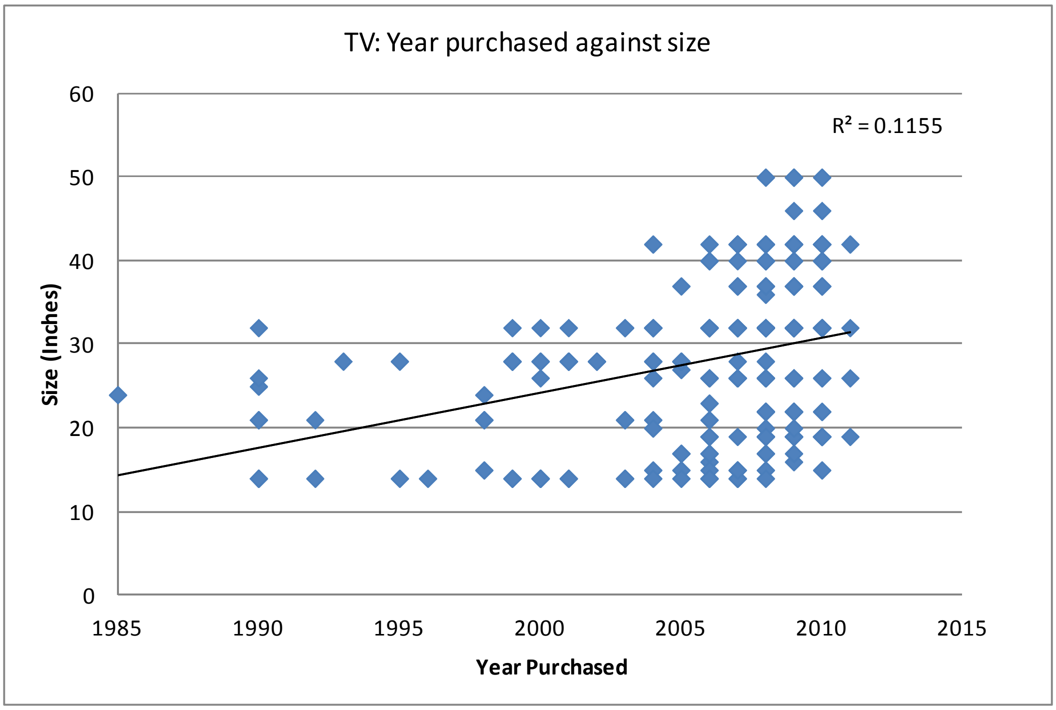
We used linear regression to see whether there was a trend of increasing size with newness for each appliance type. This involves plotting datapoints against each other and fitting a line of best fit to the correlation between two factors.

For all of these analyses, we could only use the data available, and around a third of appliances had at least some missing data – typically either the year of purchase or the size of the appliance. It is very likely that households had less certainty about the year of purchase of older appliances than for the new ones. This almost certainly skews the sample somewhat for this section, because older appliances are more likely to be omitted. Nevertheless, we have some data for appliances purchased in the mid-1990s for all appliance types.

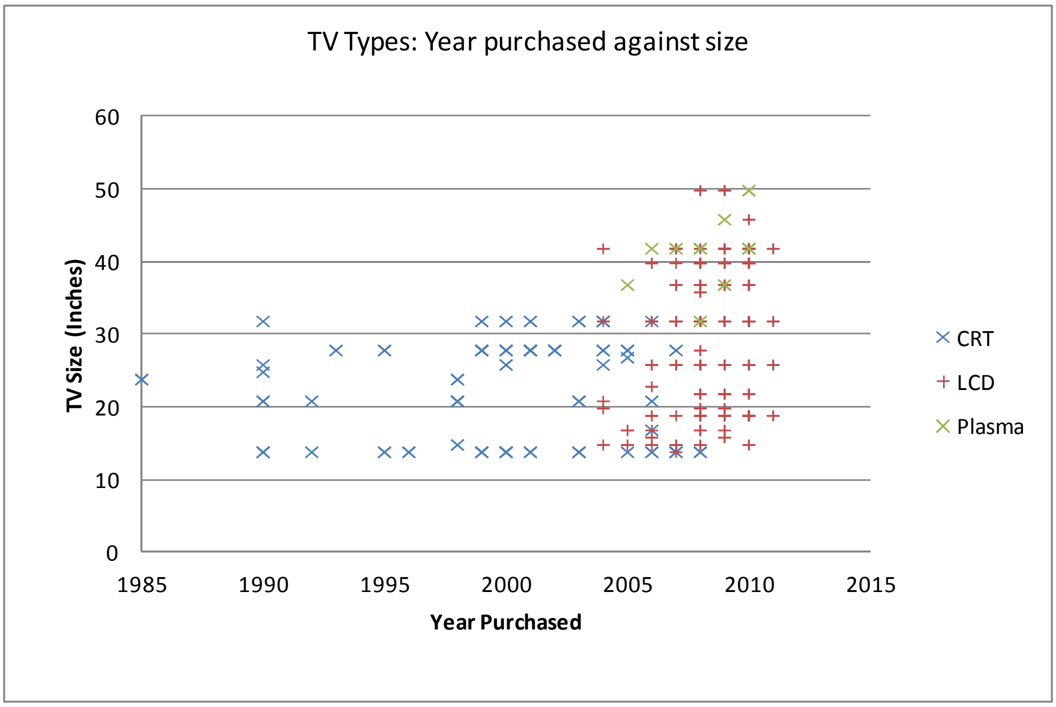
TVs

Starting with televisions, the plot of size against the year the appliance was bought (below) does indeed show a gradual increase in average screen size over time. The mean screen size for TVs bought before 2004 was 23”, against a mean size of 30” for TVs purchased after 2004. (Screen sizes are measured across the diagonal, from corner to corner.) TVs measuring more than 32” are a new phenomenon among these households – only beginning to appear in 2004 – and households fairly recently started to acquire very large TVs measuring 50”. However, not all TV purchases followed the trend, and some households continued buying small 14” TVs until 2008.

The trend to manufacturing and purchasing ever larger TVs could continue, although there is evidently an upper limit on TV size – how large a TV will fit in living rooms.

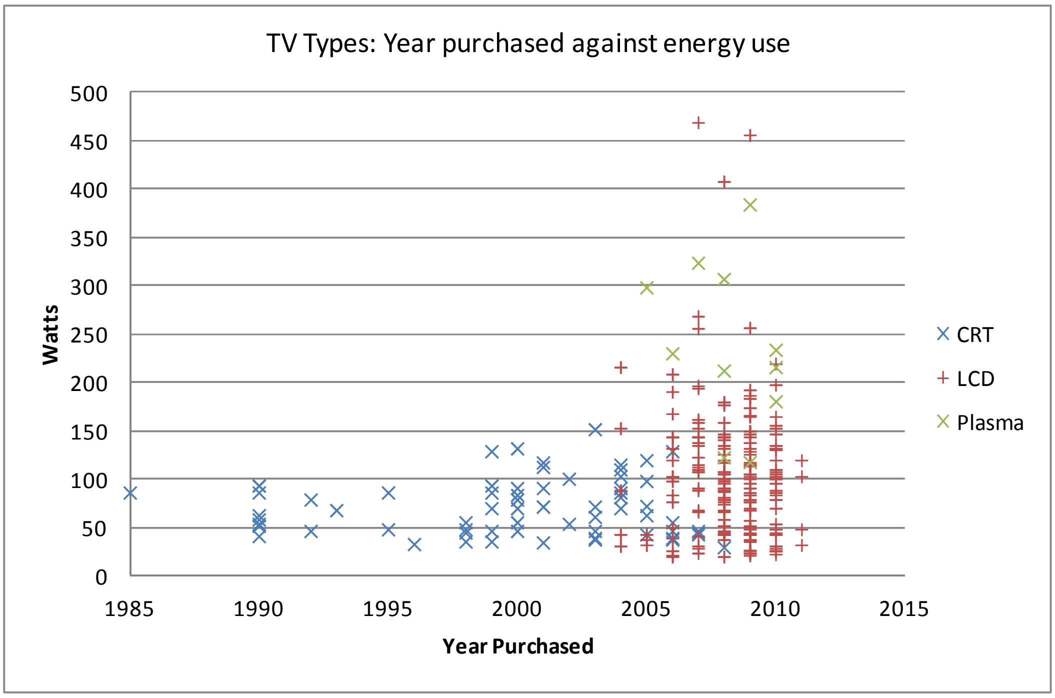


Alongside the average increase in screen size, there was a dramatic shift in the way TVs are designed and manufactured: from cathode-ray tubes to liquid crystal display and plasma screens. This change has energy implications, because LCDs are usually more energy efficient. These households started to switch over to LCD and plasma screens in 2004, and by 2009 they had stopped buying CRT TVs completely, see plot below.

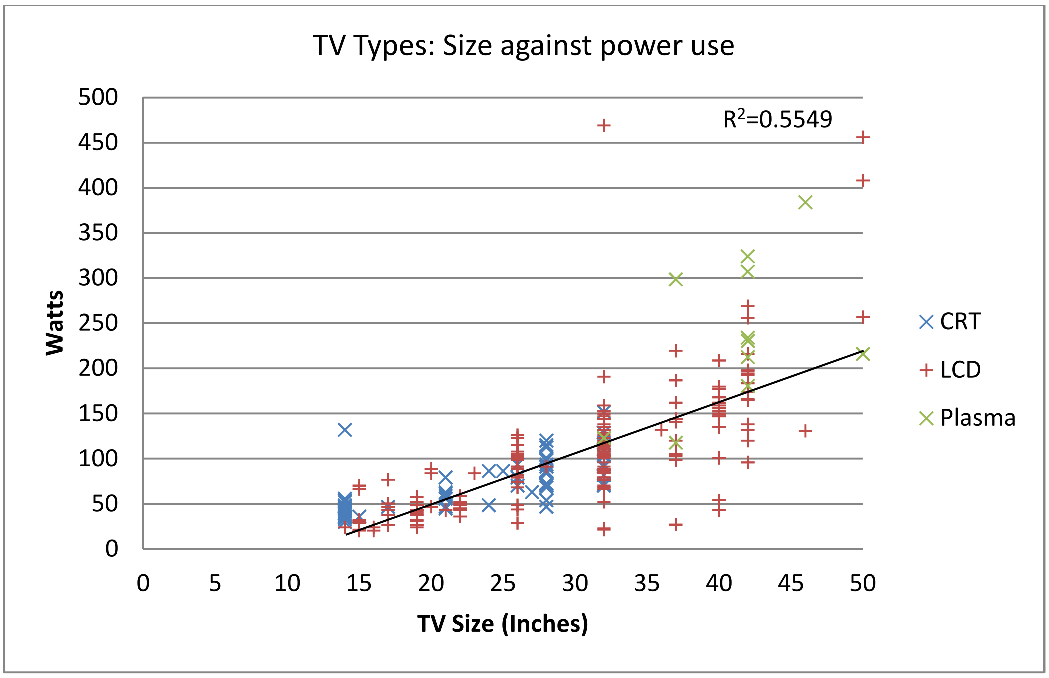


How does this switch to LCD and plasma TVs relate to energy use when the TVs are switched on? Broadly, CRTs have a lower, narrower distribution of energy consumption in Watts than either LCDs or plasma TVs: from 30 to 150 W according to the monitoring data. LCDs have consumption from just 25 to a remarkably high 460 W (largely determined by the screen size). And plasma TVs in these households have consumption from 120 to 380 W.

This means that, on average across all TV types, and ignoring their size, mean power use rose from 71 W for TVs purchased before 2004 to 109 W for TVs bought from 2004 onwards.



How much of this variation in energy use is due to screen size, and how much to changing technologies for TVs? Plotting energy use against screen size shows that there is quite a close correlation between size and energy consumption, see plot below. The size of screen is a more important determinant of energy use than the type of TV technology, although plasma screens do tend to have higher energy consumption.



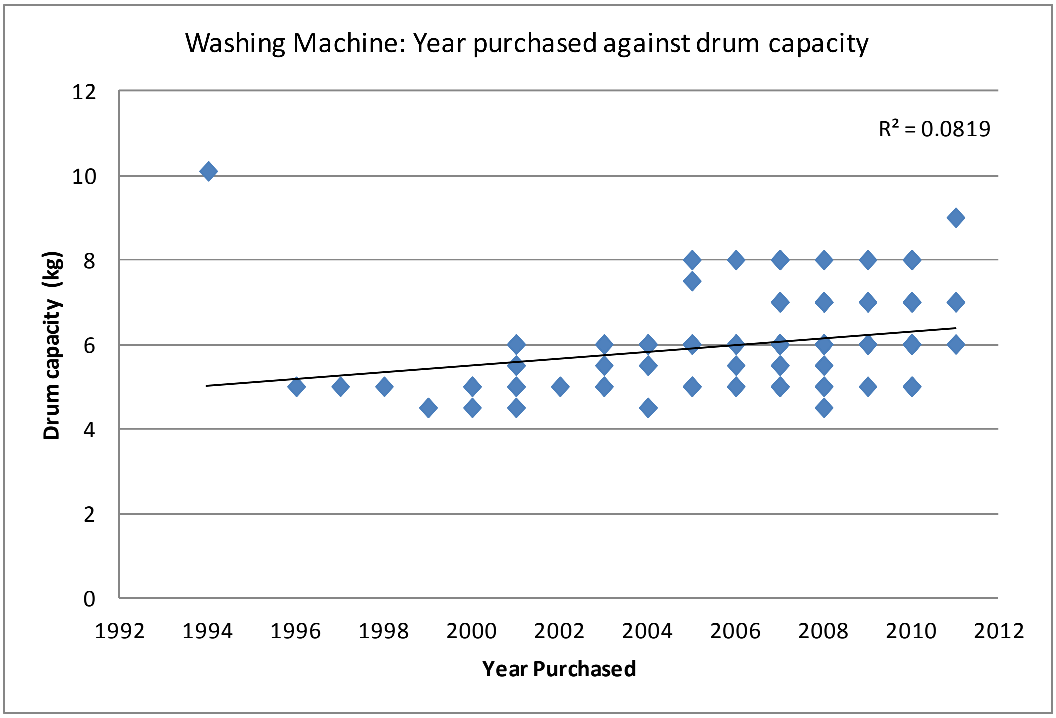
This brings us to the specific (but somewhat hypothetical) question posed by the Departments: how much energy could be saved if these households had bought new TVs no larger than the ones they bought previously? We calculated the average TV size before and after 2004, and average energy use for these TVs – see table below. On average, TVs bought from 2004 onwards were 33% larger, and used 50% more electricity when switched on. We then examined the energy use of modern (2004-onwards) TVs of the same average size as older TVs (20-24”). On average, we found that HES metering showed they used 55.7 Watts – 47% less than the average energy use of all modern TVs.

This means, on paper, that if the households that bought new TVs from 2004 onwards had purchased TVs of the same size as they were buying before 2004, we would now see savings of 50 W per household when the TV is being used. This would almost certainly bring savings to both annual energy use and peak power demand.

Television energy use (including integrated VCRs+DVDs)	pre-2004	2004 onwards
Mean size (")	22.2	29.5
Mean energy use all TVs (Watts)	70.1	105.7
Mean energy use (20-24", Watts)	60.5	55.7
Mean saving from pre-2004 size, post-2003 efficiency (Watts)		**50**
Percentage saving		**47.3%**

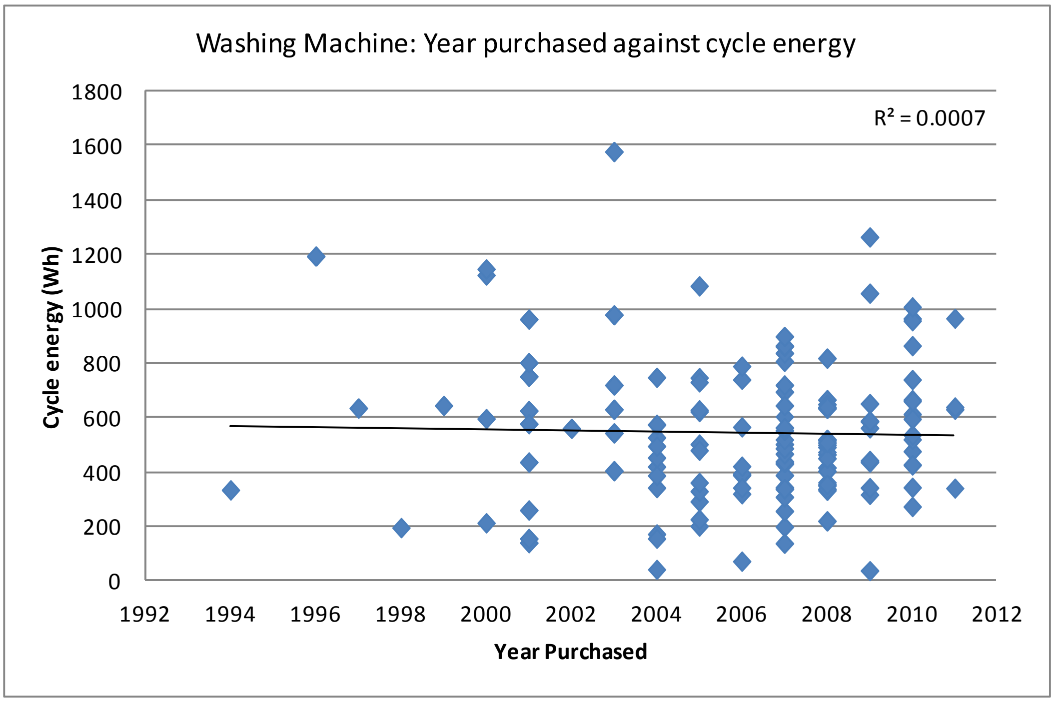
Washing machines

The same approach for washing machines suggested again that there is some trend towards larger capacity machines, see graph below. Mean capacity rose from 5.4 kg for machines bought before 2004, to 6.1 for machines bought from 2004 onwards.



However, unlike TVs, washing machines do not show an increasing trend in actual energy use (per wash) over time. In fact, there is a very gradual trend in the opposite direction, with average energy use falling marginally for machines bought more recently – see graph below. For machines bought before 2004, the average energy use for a wash cycle was 648 Wh, against 521 Wh for machines bought from 2004 onwards.

Part of this improvement may be linked to limescale formation on heating elements and other components in the washers, making older machines less efficient, but it impossible to know which households use water softeners and/or limescale removers in their washing appliances.



This improvement in energy efficiency seems to be very weakly linked to the capacity of machines, see plot below. As you would expect, on average larger machines do use a little more energy than smaller ones. However, there is only a very weak correlation between energy use and capacity – underscored by the very low R^2 [35] for this plot. The energy savings probably had much more to do with reduced water volumes used in more modern washing machines, but sadly the water volumes for washes were not recorded as part of the HES survey.

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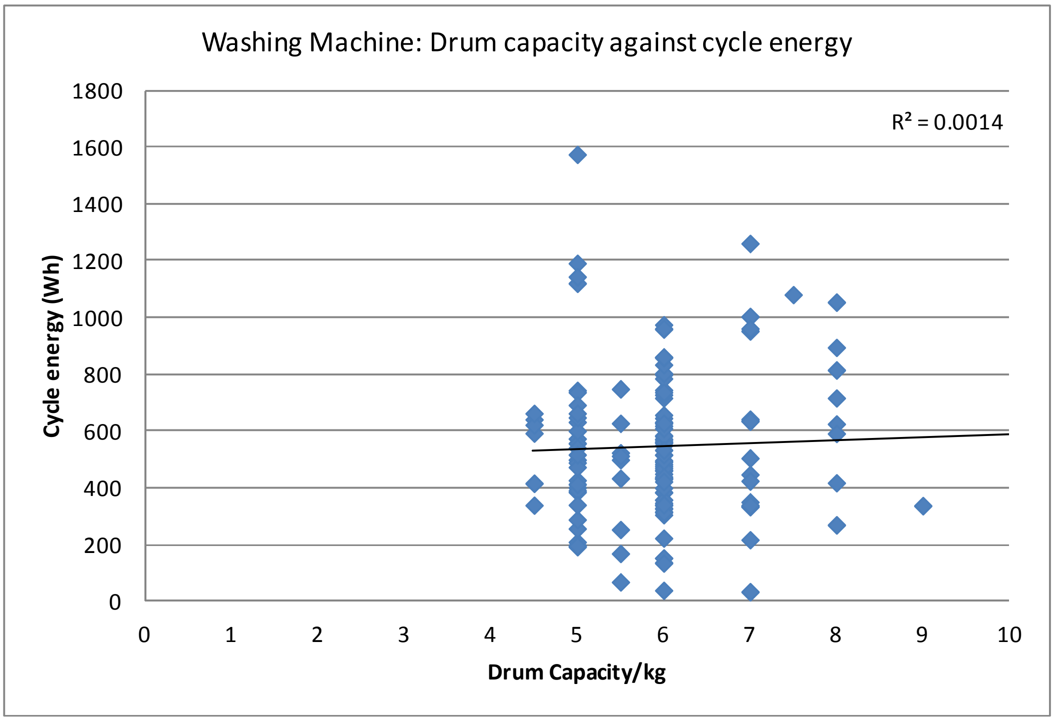
[35] R^2 is a measure of how much variation is explained by the factor under consideration rather than randomness or due to other factors. The maximum value is 1, in which case all the variation is due to the factor (each case lies on a straight line), and the minimum is 0. When there are many cases well off the regression line then R^2 is low because there is a lot of unexplained variation.



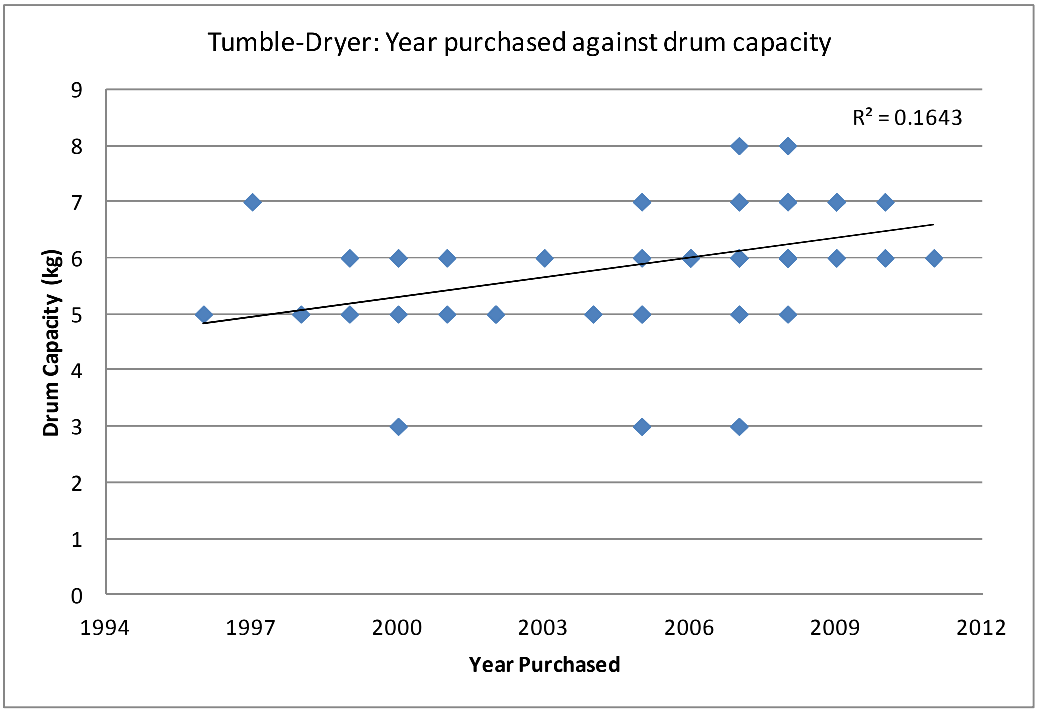
Accepting that drum size is not the major determinant of energy use – but that it is probably related in some way to water use – we repeated the estimate of energy saving under the scenario 'households continue purchasing washing machines the same size as they did before 2004'. The figures are shown below, but these should be used with caution because size is very weakly related to energy use, and other factors are more important.

This shows an indicative saving just under 5% per wash, on average, for households that replace their machines without increasing their capacities. (This excludes any benefit from having a larger machine that allows households to wash more clothes at once, which may result in fewer washes over the year.)

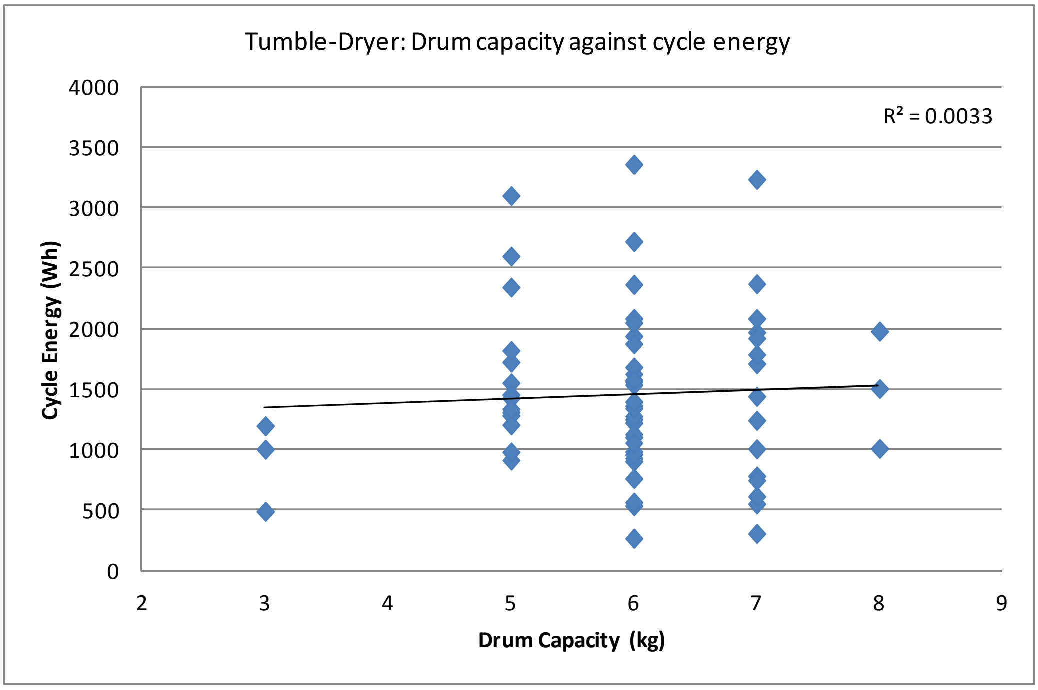
Washing Machines	pre-2004	2004 onwards
Mean capacity (kg)	5.4	6.1
Mean cycle energy (Wh)	647.6	521
Mean energy use (5-6kg, Wh)	666.3	495.6
Mean saving from pre-2004 capacity, post-2003 efficiency (Wh)		25.4
Percentage saving		4.9%

Tumble Dryers

Repeating the analysis for tumble dryers suggested once again that there is a trend for newer appliances to be larger. A mean capacity of 5.4 kg for dryers bought before 2004 rose to 6.1 kg for machines bought 2004 onwards, see plot below.



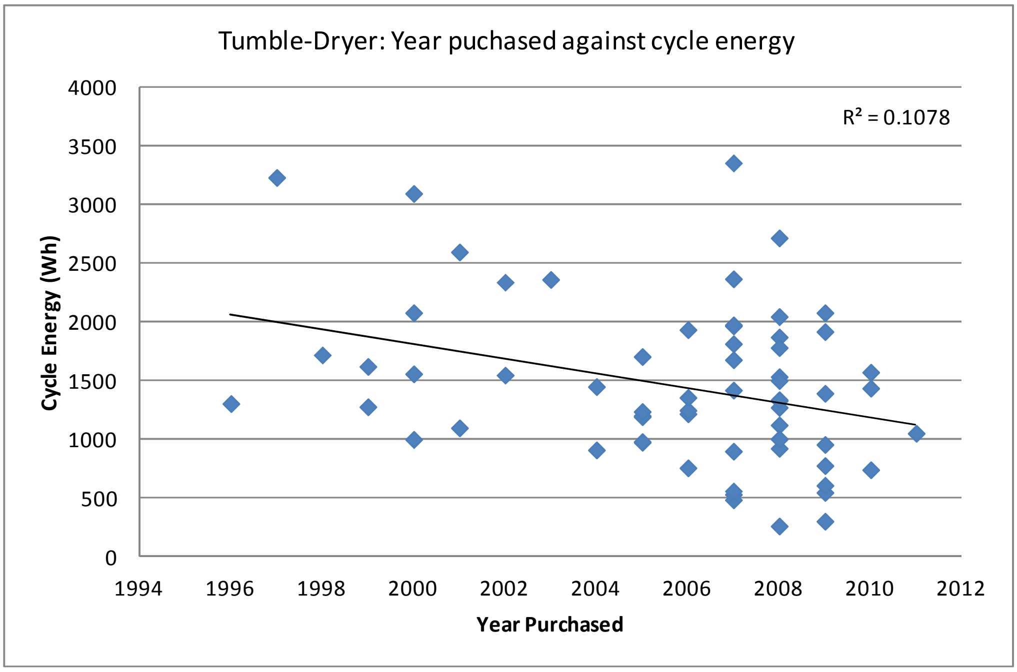
What impact does this increase in drum capacity have on the energy use per cycle of tumble dryers? Very little according to this data, see plot below. The gradient of the line of regression is very low, and the R^2 coefficient of determination is also low – indicating that things other than drum capacity are more important in shaping energy use. This is not particularly surprising – the energy use of tumble dryers is more closely linked to the quantity of water to be removed from the clothes. A larger machine does not necessarily mean a householder will put more clothes into a dryer.



Overall, in spite of increasing capacities, newer tumble dryers do tend to use less energy per cycle, see graph below. The mean cycle electricity use fell from 1917 Wh for machines bought before 2004 to 1327 Wh for dryers bought from 2004 onwards – a dramatic improvement. However, this saving may not be due to more efficient machines alone because apart from humidity controls there are limited opportunities for improvement. There is definitely scope for improved dryer controls – in particular in replacing a crude timer control with a humidity sensor that automatically turns of the dryer when clothes are dry.

However, the most important factor affecting energy use by tumble dryers is how damp the clothes are when they are loaded into the machine. This depends critically on how effective the spin cycle of the washing machine used with the tumble dryer. (Hand washes also affect dampness, but are likely to be less frequent than machine washes.)

Households with new tumble dryers may also have new washing machines, and indeed households may replace both together (necessarily so for households with combined washer-dryers). This means the downward trend in energy use per tumble dryer cycle may actually be largely a function of improved spin cycles in new washing machines.



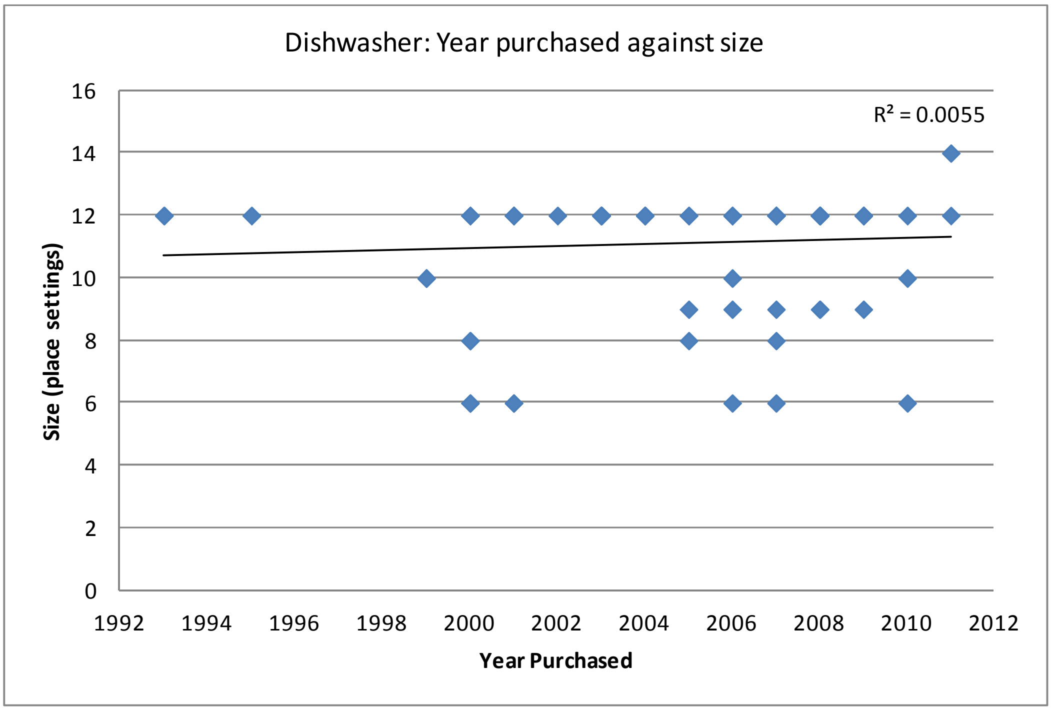
Repeating the calculation we did above for TVs and washing machines shows quite a different result. You might reasonably expect smaller, modern tumble driers to be more economical, but they actually use slightly *more* energy per load on average than larger ones – possibly because smaller drums do not allow air to circulate and evaporate water as effectively. This means there would be no saving from replacing recently-purchased dryers with units with the capacity of older machines, see table below.

The best prospect for saving energy from dryers is almost certainly to replace washing machines with ineffective spin cycles and to replace tumble dryers without humidity controls with units with humidity sensors that turn them off when clothes are dry.

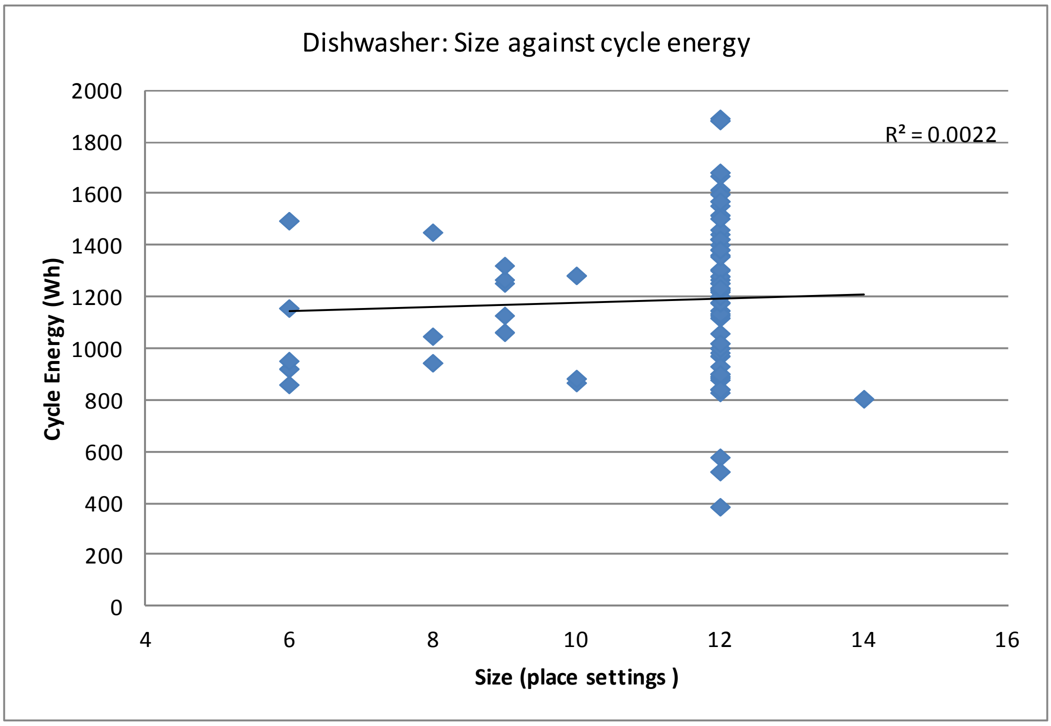
Tumble Dryers	pre-2004	2004 onwards
Mean capacity (kg)	5.4	6.1
Mean cycle energy (Wh)	1917	1327
Mean energy use (5-6kg, Wh)	1884	1346
Mean saving from pre-2004 capacity, post-2003 efficiency (Wh)		**-19**
Percentage saving		**none**

Dishwashers

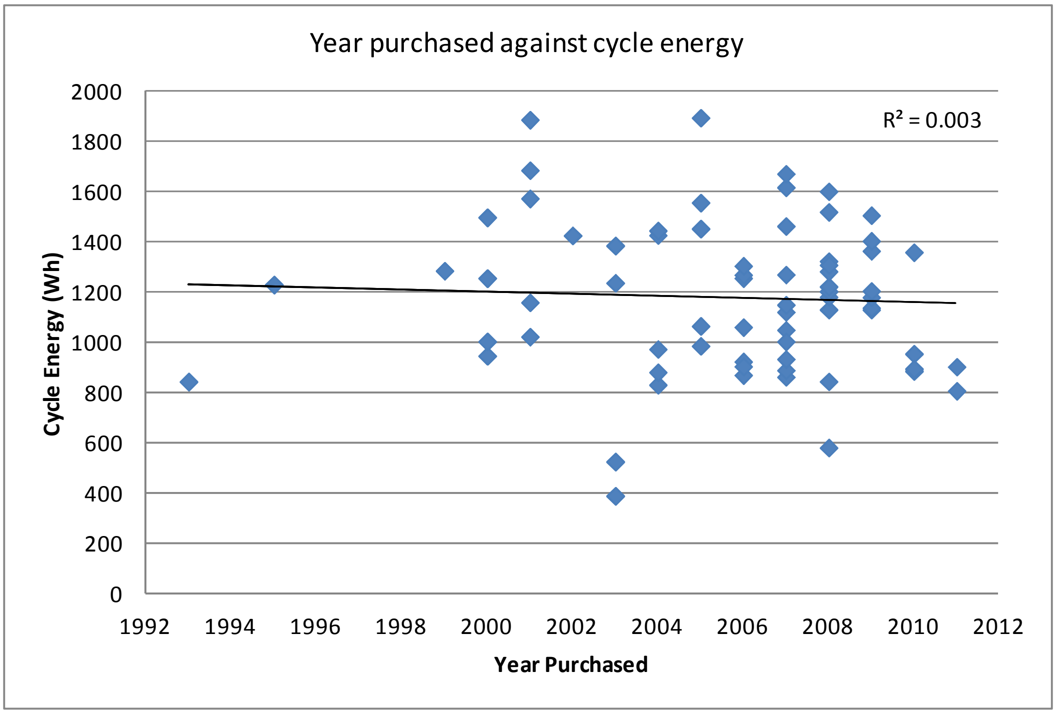
We have size data for 86 households with dishwashers (out of 147 recorded as owning them). The same analysis for dishwashers showed that the vast majority of dishwashers had a capacity of 12 place settings (65 of them, or 76%). This means the distribution of sizes is quite different for dishwashers than for the other appliances we examined, see plot below. There is no significant correlation between the year of purchase and dishwasher size. (The mean dishwasher size is 11.1 settings.)



Having so many appliances of the same size complicates the analysis of size compared to energy efficiency, but there is a very weak correlation between size and energy use per cycle, see plot below. As for washing machines, the most significant factors are probably the water temperature and how much water is used per cycle, and we do not have data on hot water use.

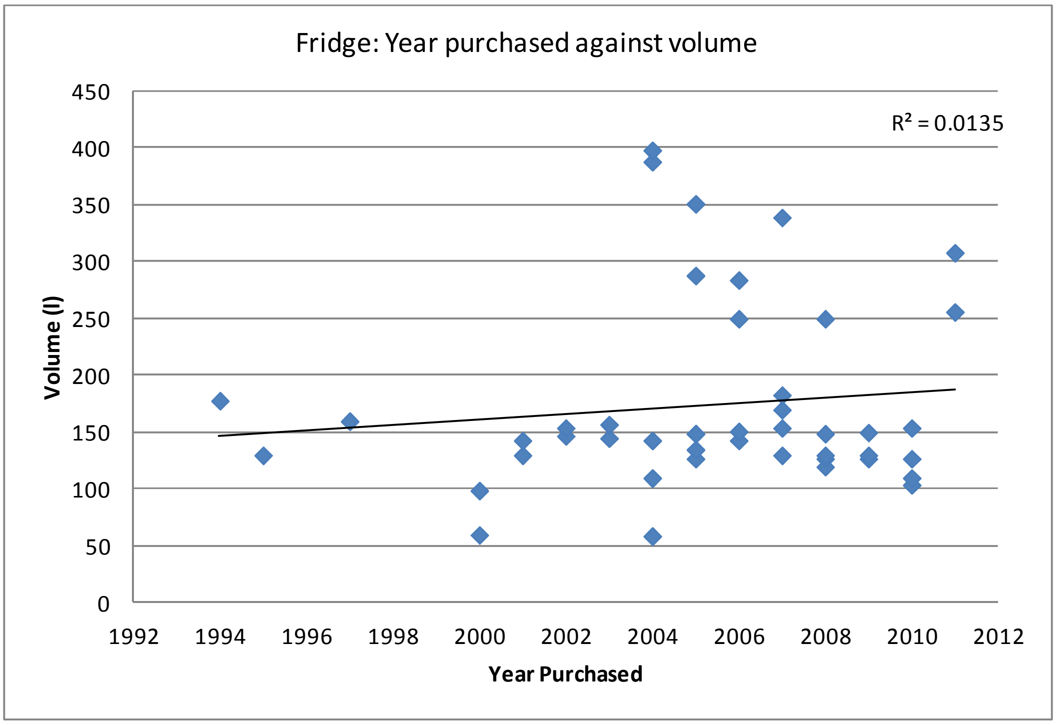


There is no significant correlation between appliance age and energy use per cycle for dishwashers, see plot below. Recently purchased appliances use only marginally less energy per load, on average, than older ones even though dishwashers have been included in the EU Eco-Label since they were established in 1992.

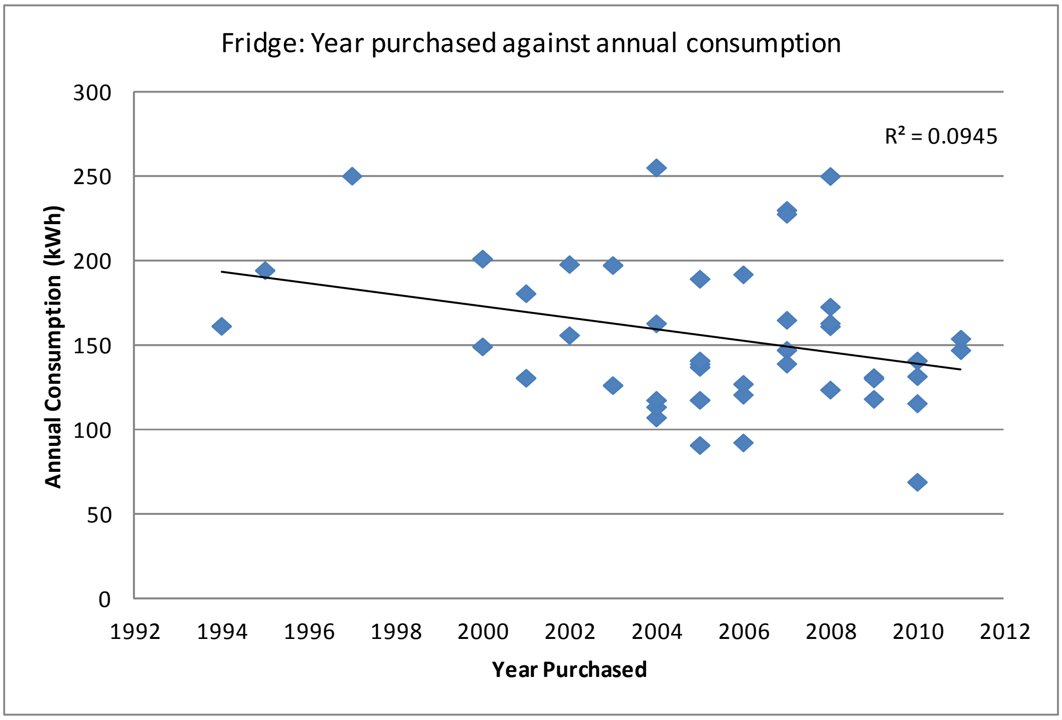


Fridges

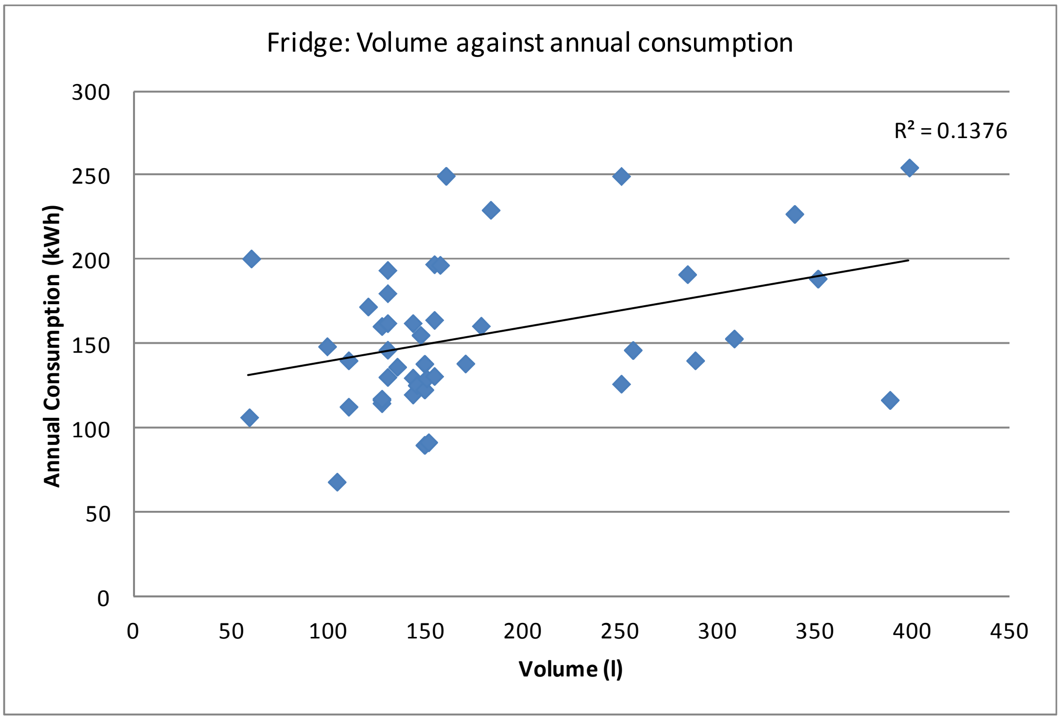
We examined fridges, freezers and fridge-freezers separately. Fridges are simplest, so we start with them here. There has been a gradual increase in mean fridge size from 1994 to 2011, see graph. For fridges bought before 2004 the average capacity was 137 litres, against 187 litres for fridges bought from 2004 onwards. (Remember that this excludes fridge-freezers, which may be larger still.) Large capacity fridges – say above 180 litres – are a new phenomenon for these households, and none of them had a large fridge until 2004.



What about energy use? For fridges and freezers, we focused on annual energy use in kWh (since cold appliances usually run continuously, and are not turned on manually to run discrete cycles). Over the course of a year, we found that fridges used from 69 to 255 kWh a year. There was some link between the year of purchase and energy use, with more recent appliances using just over a quarter less electricity a year than older ones, on average.



As to whether this energy saving was linked to the size of the fridge or other factors, the data does suggest a weak correlation between volume and annual energy use, see plot below. Taken together with the trend to purchase larger fridges, this suggests it is legitimate to ask 'how much energy would we save by buying the same size fridges we used to buy?'.

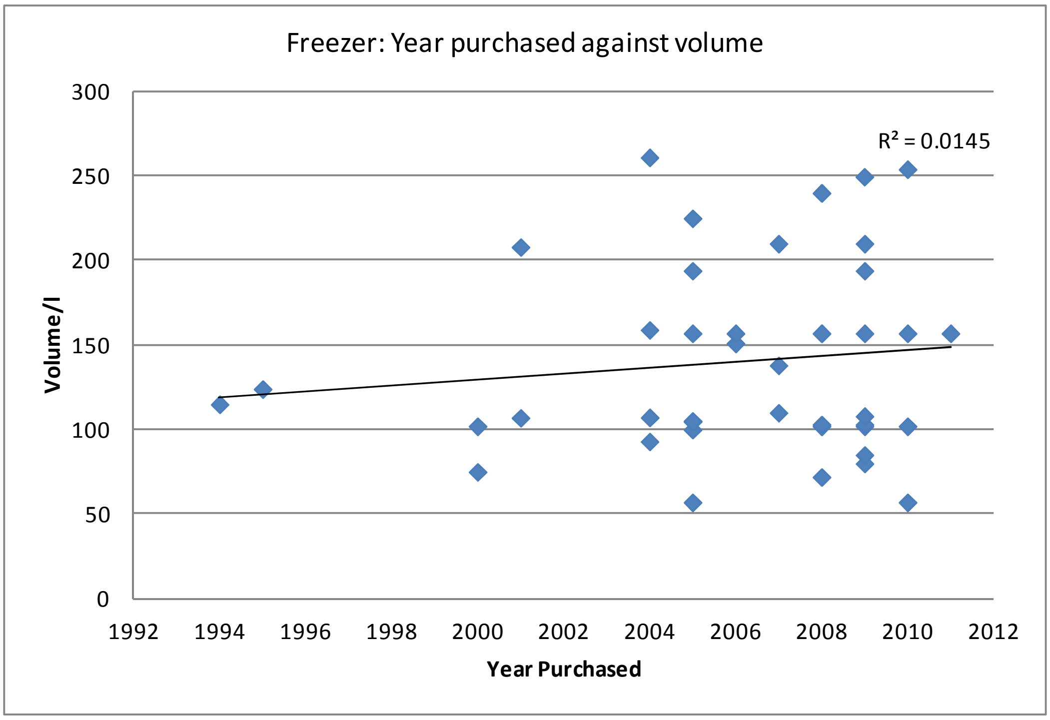


To answer this question we repeated the calculations we did for TVs and washing machines above, calculating average size and energy consumption pre- and post-2004, see table below. This suggests that if the households from the sample who replaced their fridges had kept the same average size as they did before 2004, they would now save an average of 14 kWh/year, or 9.5% of the energy used to run their fridges.

Fridges	pre-2004	2004 onwards
Mean capacity (litres)	136.6	186.6
Annual energy (kWh)	177	148
Mean annual energy use (116.6-156.6l, kWh)	161	134
Mean saving from pre-2004 capacity, post-2003 efficiency (kWh)		**14**
Percentage saving		**9.5%**

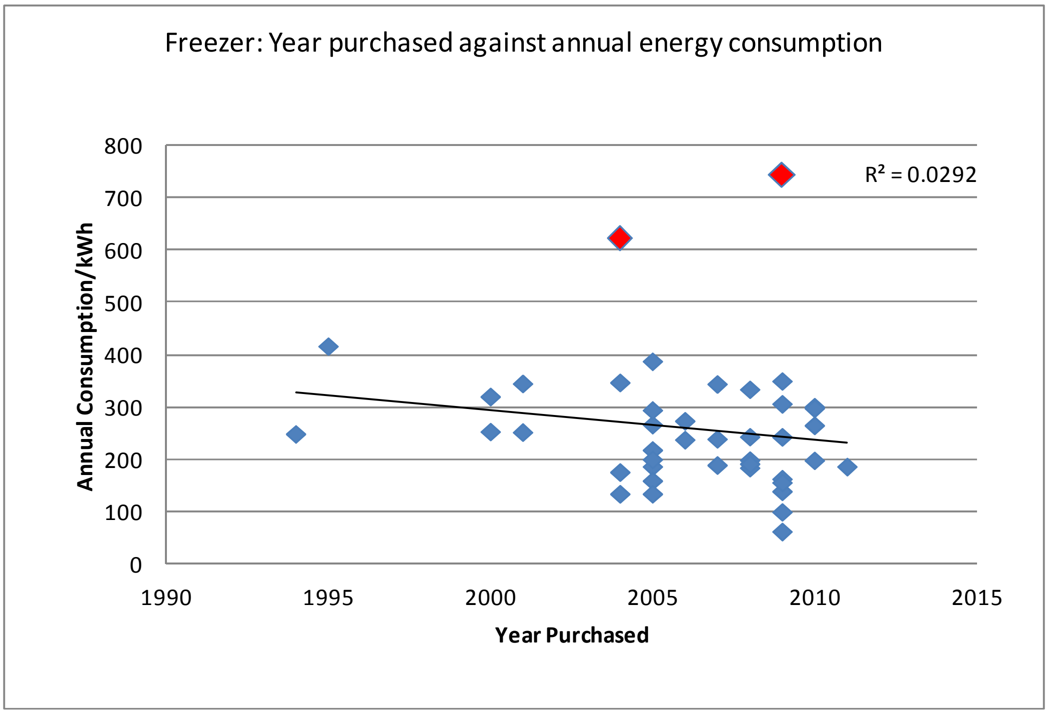
Freezers

For freezers, as for fridges, there is a gradual increase in volume over time, although there is only a very weak link between volume and the year of purchase, see graph below. Freezers in the monitored homes are all between 50 and 260 litres in volume – a large range, which is likely to have implications for energy use.

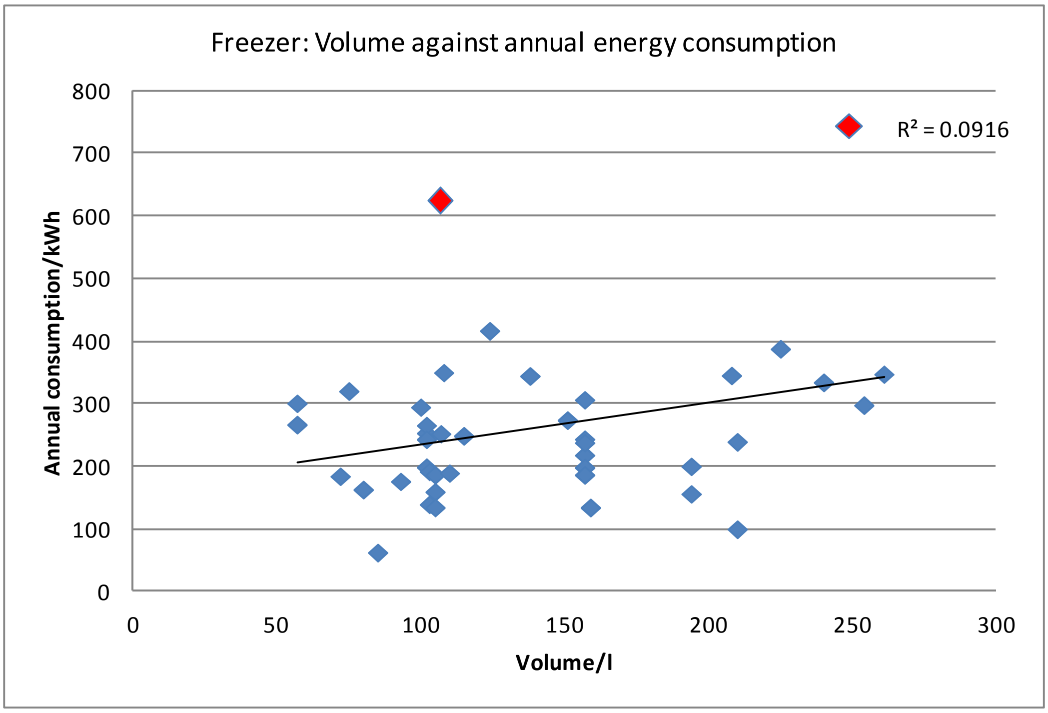


In spite of the slight upward trend in average freezer size, the data suggests that freezers are becoming more efficient, on average (see graph below). The average energy use for freezers purchased before 2004 was 307 kWh per year, against 253 kWh per year for freezers bought from 2004 onwards – an improvement of 18%. (Part of this saving is probably due to seals in older appliances wearing out, and possibly to compressors working less efficiently.)

However, there are two outliers in the data, marked red in the plot. We have scrutinised the energy profiles for these two appliances, and the compressors in both appear to run much more frequently than in other freezers – suggesting that their thermostats are set too low, or that seals are inadequate, or both. These two appliances use around double the electricity used by other freezers purchased the same year. They are not especially old: purchased in 2004 and 2009. We have included both outliers because they both seem to have been recorded accurately and there is no good reason to exclude them from the analysis.



How does the energy consumption of freezers relate to their size? This data suggests that there is a weak correlation between freezer volume and energy use, with larger freezers using about 100 kWh/year more electricity, on average (see plot below). However, this is due to the balance between conflicting trends for larger sizes and better energy efficiency.



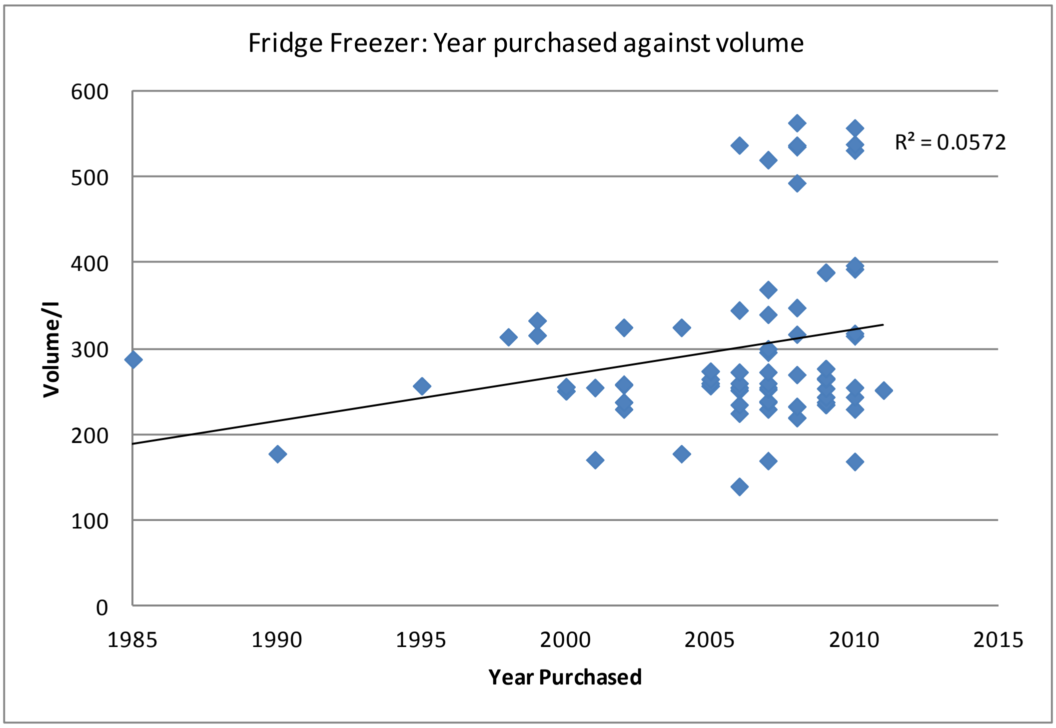
We repeated the analysis above, to ask what saving we would expect if households that replace their freezers in future refrain from buying a larger appliance from the average size they had before 2004. But this found no saving in average energy use for smaller new appliances, see table below. This suggests there would be no saving if households refrained from buying larger freezers.

However, this analysis was affected by the two outliers (with poor seals and/or controls). We repeated the analysis without them, and found a 9 kWh, or 4% annual saving from maintaining the pre-2004 size of appliance.

Freezers	pre-2004	2004 onwards
Mean capacity (litres)	121.8	142.3
Annual energy (kWh)	307	253
Mean annual energy use (101.8-141.8l, kWh)	294	253
Mean saving from pre-2004 capacity, post-2003 efficiency (kWh)		**0**
Percentage saving		**0.0%**

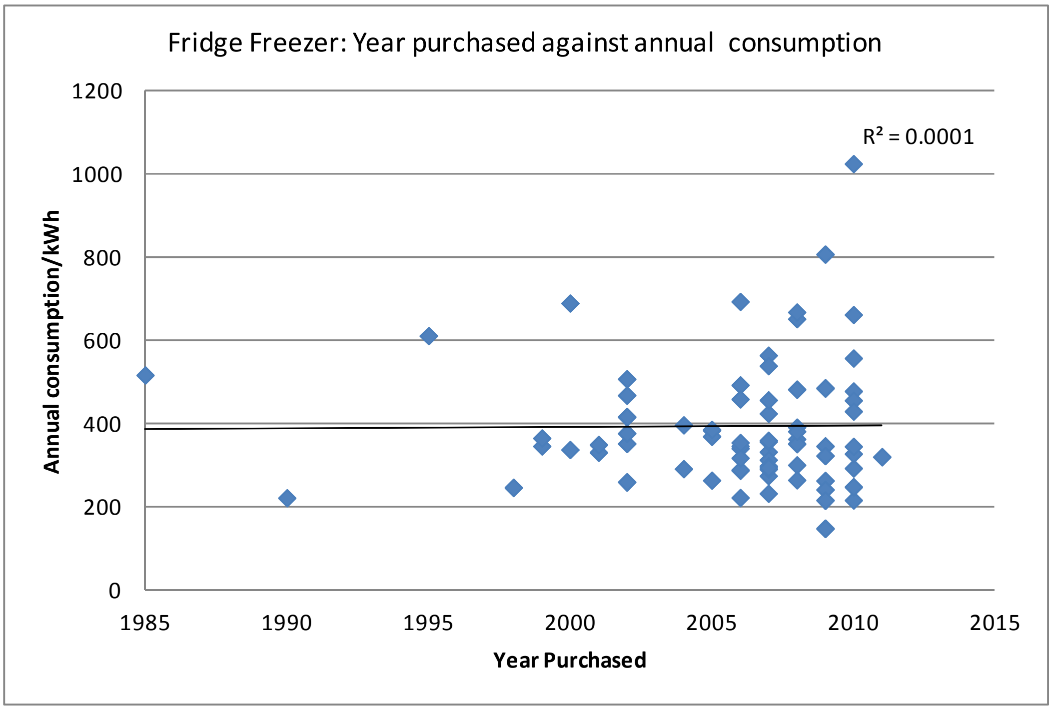
Fridge-Freezers

Fridge-freezers tend to be larger than fridges or freezers, with volumes from 140 to 560 litres, see plot below. Again, there is a weak link between age and volume, with a tendency for fridge-freezers bought more recently to be larger. The mean capacity for appliances bought before 2004 was 260 litres, compared to 310 for fridge-freezers bought from 2004 onwards.



There is almost no link between the year of purchase of fridge-freezers owned by the HES households and their energy use. Again, this is remarkable given that cold appliances are included in the EU Energy Label. (This may change over time, as anything below ‘A+’ was withdrawn from sale by law in the UK from July 2012[36].) Up until now, the trend for larger fridge-freezers has undermined efforts to improve appliance efficiency.

[36] See http://www.which.co.uk/energy/saving-money/guides/energy-labels-explained/fridge-and-freezer-energy-labels/



It appears to be no coincidence that the highest-consuming fridge-freezer is also one of the largest. The plot below indicates there is a positive relationship between energy use and volume. Although there are three exceptions, most of the appliances consuming more than 600 kWh per year have capacities of more than 500 litres. Conversely, all of the smaller fridge-freezers have energy use between 200 and 330 kWh/year.

Very few fridge-freezers were purchased before 1998 (just three), although purchasing combined fridge-freezers became more common later. This may have coincided with increased purchasing of frozen foods, with households that used a simple fridge with freezer compartment upgrading to fridge-freezers. (This upgrade comes at an energy cost of around 200 kWh/year, with fridge-freezers using considerably more energy.)

Other Evidence on Savings from Smaller, Simpler Appliances

Research carried out by the Environmental Change Institute in Oxford[37] found that between 1995 and 2001, there was an improvement of 25% in the energy efficiency of cold appliances sold in the UK. However, during this period the average size of appliances increased by 15%, offsetting some of the benefits in terms of total electricity consumption.

Projections suggest[38] that increasing appliance sizes, alongside a growth in household numbers, may reduce the impact of improvements in appliance energy use by 40-50% (i.e. a 20% improvement in energy efficiency could result in a 10-12% drop in energy use).

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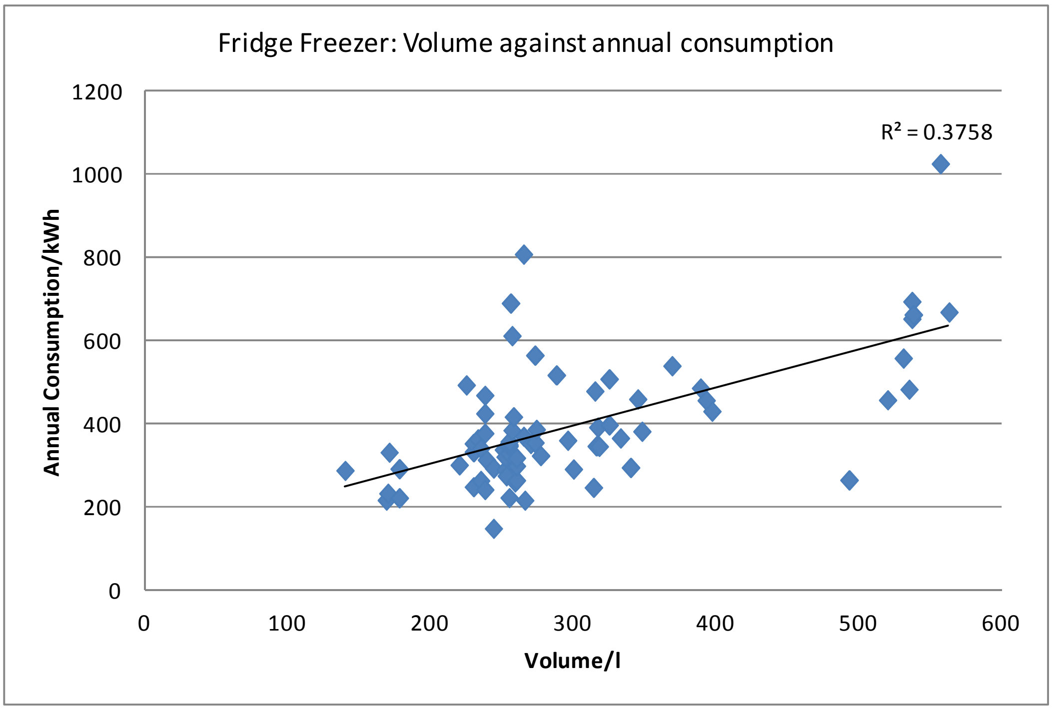
37 Boardman, Brenda (2004). Achieving energy efficiency through product policy: the UK experience. Environmental Science & Policy 7.3: 165-176

38 PIU (2002). The Energy Review: A Performance and Innovation Unit report. London: Cabinet Office.



Since there is no trend linking year of purchase and energy use for these homes, the data seems to suggest that the gradual increase in size of fridge-freezers has offset efficiency gains over the period. If the households that have not yet replaced their fridge-freezers did so with smaller units, like those bought before 2004, they might save 47 kWh a year of energy, or about 12% of the energy use of a fridge-freezer.

Fridge-Freezers	pre-2004	2004 onwards
Mean capacity (litres)	260	310
Annual energy (kWh)	400	391
Mean annual energy use (240-280l, kWh)	444	344
Mean saving from pre-2004 capacity, post-2003 efficiency (kWh)		47
Percentage saving		12.0%

Summary

Based on the evidence from the 250 HES households, the biggest percentage saving from reverting to smaller appliances for these appliance types comes from televisions, see table below.

Appliance type	Rising trend in size?	Strength of trend	Saving from smaller appliance	Percentage saving
TV	Yes	Medium	50 W	47%
Washing machine	Yes	Low	25 Wh	5%
Tumble dryer	Yes	Medium	None	-
Dishwasher	No	-	None	-
Fridge	Yes	Medium	14 kWh	10%
Freezer	Yes	Low	None	-
Fridge-freezer	Yes	Low	47 kWh	12%

Recommendations

■ The increase in TV screen size from 1985 to 2011 increased power consumption of TVs in these households by an average of 50W per household when the TVs are being used.

■ Washing machines purchased since 2004 use a little less energy per wash, on average, than older machines – in spite of increased drum sizes.

■ There is no evidence that replacing tumble dryers with smaller units would save energy. The best prospect for cutting energy from tumble dryers is probably to improve the spin cycle of washing machines so clothes are drier, then to ensure dryers have humidity controls.

■ The average size of all cold appliances (fridges, freezers and fridge-freezers) purchased by these households rose from 1985 to 2011. On average, this increase in size undermined the efficiency gains made by appliance manufacturers. If households that have yet to replace their cold appliances could be persuaded to buy the smaller cold appliances commonly purchased before 2004, this might save as much as 47 kWh/year, or up to 12% of refrigeration energy.

Unpack the data on use of washing machines

The Departments wish to extract as much information as possible from the diary data for washing machines and use this, among other things, to determine if households segregate wash types.

Approach

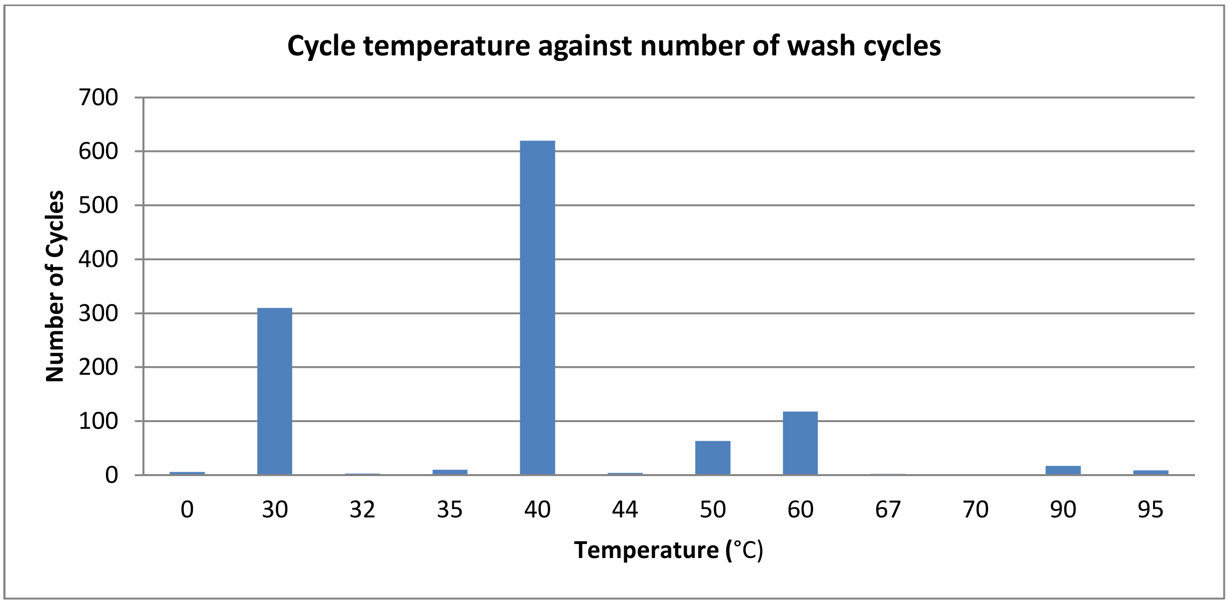
The diary data completed by households records the program, temperature, spin speed, other options and drum fullness for each occasion they used the washing machine. For each household, we determined how many different wash settings they use and how full the washing machine was, on average. We took using more than one wash setting as evidence of segregation, especially if the washing loads were not usually full.

We then grouped the data by household type and looked for significant differences between household types. Finally we correlated these settings against recorded energy use by the machine, focussing particularly on temperature and energy use.

Data analysis

In total we have diary data covering 2 weeks for each household, including 1109 washing cycles. We found that the majority of washing cycles (56%) were at 40°C, see bar chart below. 40°C appears to be the standard temperature setting for most households, although a significant proportion set their washing machine at 30°C on at least some occasions, resulting in about a quarter of washes being at 30°C.

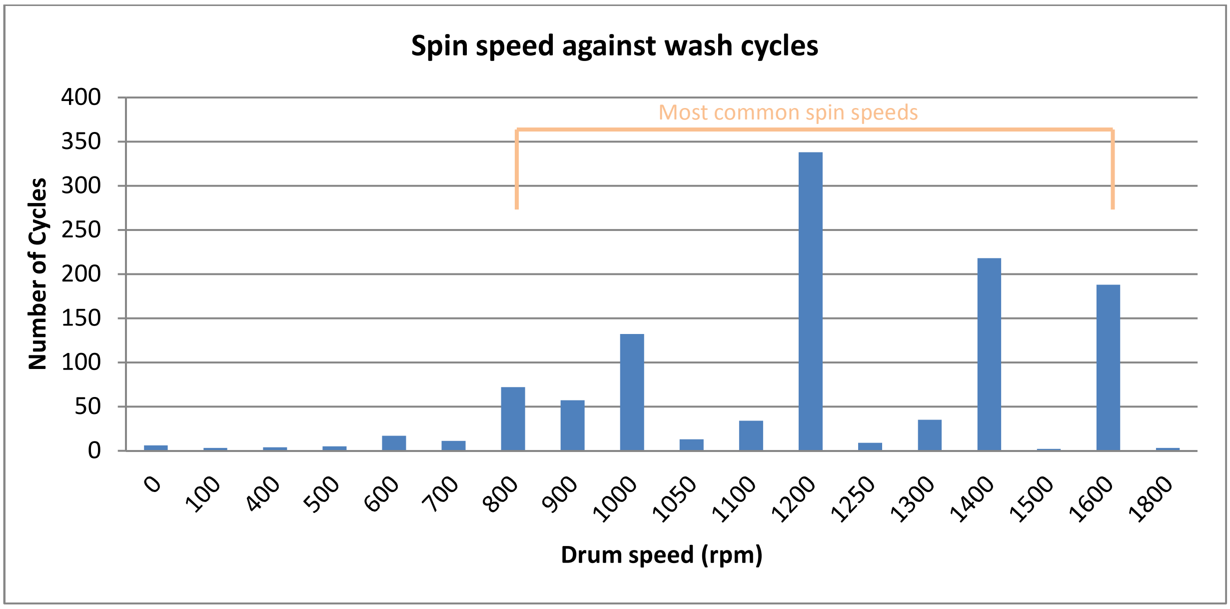
This suggests that new washing machines and washing powders designed for low temperature washes have been relatively successful in encouraging more energy efficient low temperature wash modes.



When we came to look at spin speeds we found that nearly all wash cycles were run with the spin speed in a range from 800 to 1600 revolutions per minute (see bar chart below). More than 90% (96%) were in this range, with the most common setting 1200 rpm. The next most common settings were 1400 rpm, 1200 rpm and 1000 rpm.

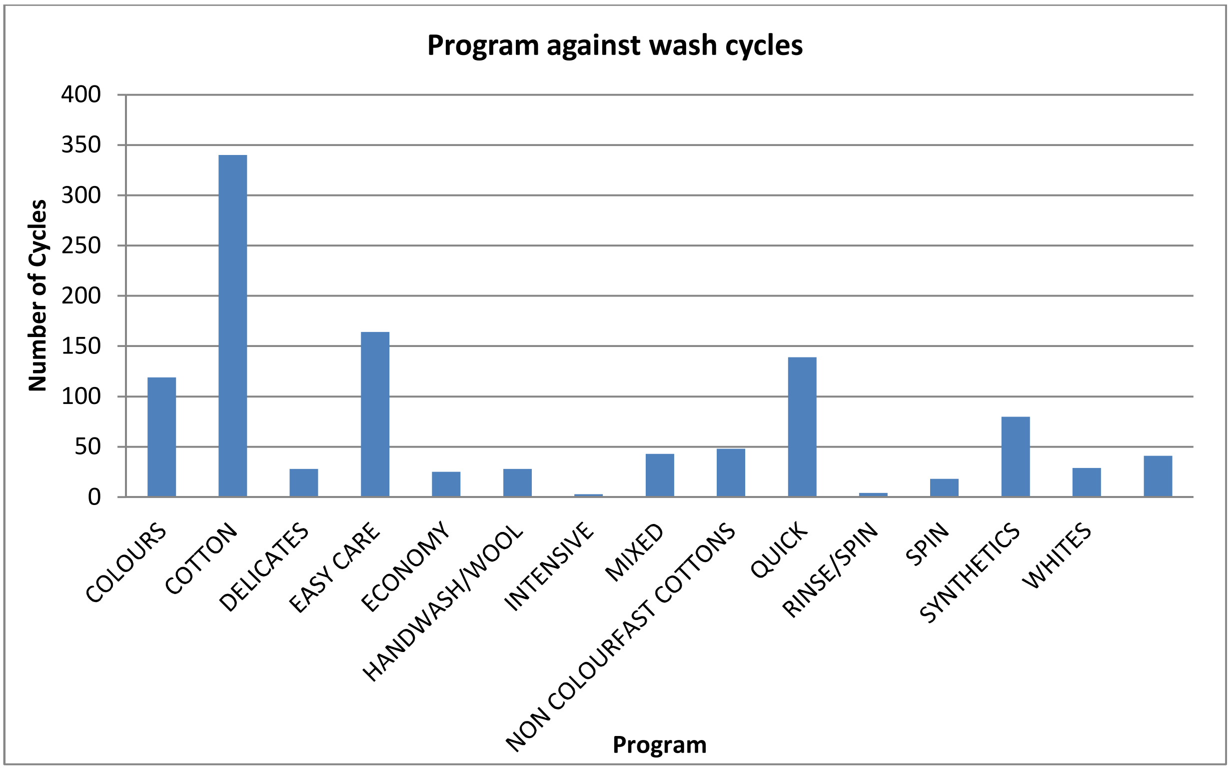
These are all quite high spin speeds, which inevitably increases energy use by the washing machine.

However, if the household uses a tumble dryer (or even radiators) to dry clothes, there is an energy saving overall.



Which washing programs were used most often? The bar chart below shows that 'cotton' was the most common setting, accounting for 30% of washes (we simplified the settings to account for different machines using different naming conventions). 'Colours', 'easy care', and 'quick' were the next most common, but still used for modest proportions of all washes.

The significant finding here is that only a tiny fraction of washes use an 'economy' setting (just 2.3%). The other wash cycles are likely to use higher water temperature, and higher spin speeds – both resulting in increased energy use. It would be worthwhile persuading these householders to make greater use of 'economy' settings.



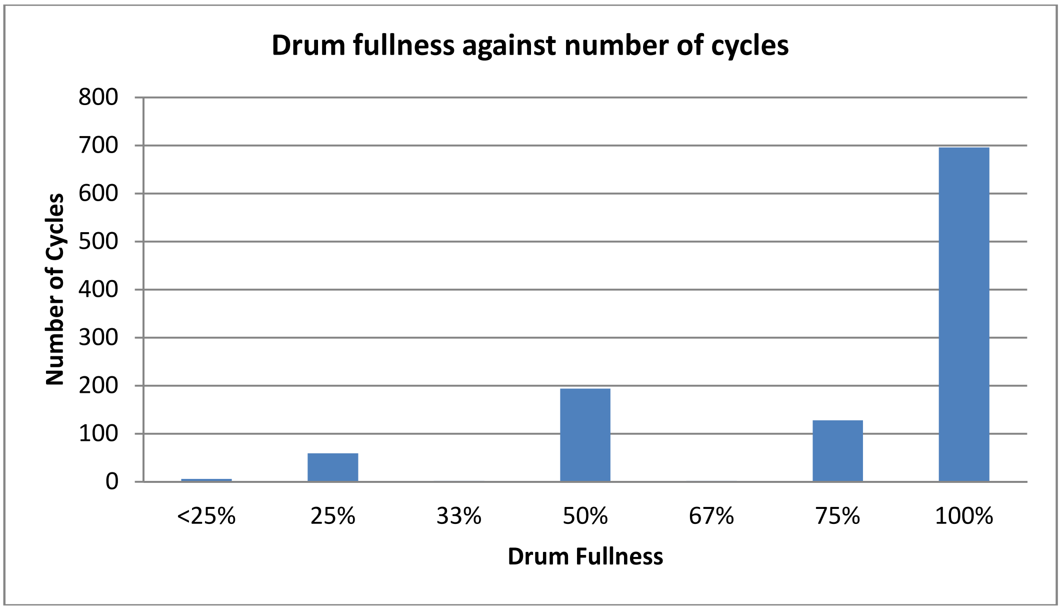
We looked in more detail at six households that recorded using ‘economy’ settings, see table below. Households A and B used both ‘economy’ and other settings, while Households C to F used exclusively ‘economy’ settings. Householders might reasonably expect that ‘Economy’ settings save energy. However, the data shows they did not lead to energy savings except when comparing washes at the same temperature: the mean energy use for an ‘economy’ wash is more than 40% higher than the mean across all monitored washing machines (590 Wh/cycle). Household B used significantly more energy for a 60°C ‘economy’ wash than a 35°C normal wash – the temperature is clearly more important than the setting. Either the ‘economy’ mode was incorrectly recorded in diaries, or the machines are not operating truly economical cycles when they are in this mode.

		Temp (°C)	Spin Speed (rpm)	Fullness %	Energy (Wh)	Duration (min)	Max Power (W)
Household A	**Non-Eco**	40	1100	100%	791	98.7	2224
	Eco	40	1200	100%	864	95.3	2073
Household B	**Non-Eco**	35	1400	88%	659	77	2400
	Eco	60	1400	100%	1056	100	2520
Household C	**Non-Eco**	N/A	N/A	N/A	N/A	N/A	N/A
	Eco	67	1200	50%	1219	114	2340
Household D	**Non-Eco**	30	550	100%	370	120	2054
	Eco	60	900	25%	859	138	2223
Household E	**Non-Eco**	N/A	N/A	N/A	N/A	N/A	N/A
	Eco	40	950	67%	562	93	2138
Household F	**Non-Eco**	N/A	N/A	N/A	N/A	N/A	N/A
	Eco	40	1000	100%	528	72	1908

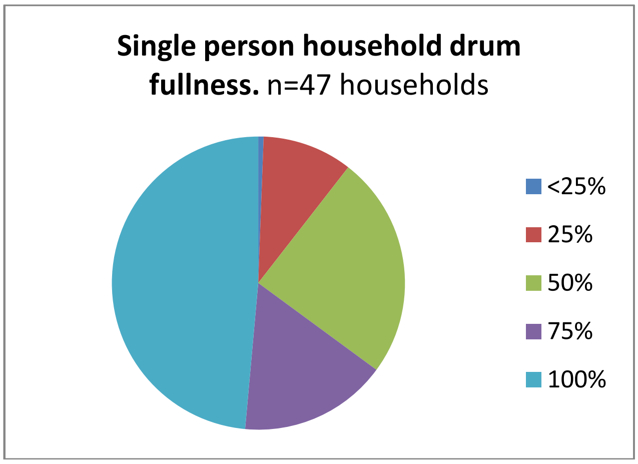
Mean non-eco	455
Mean eco	848
Mean saving per wash	-
Percentage saving	-

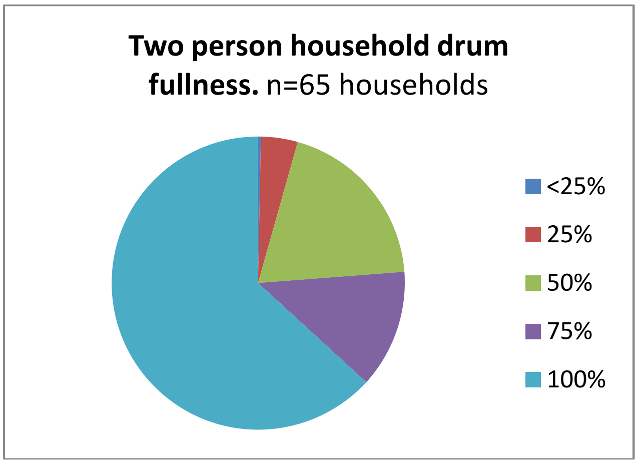
Naturally, one of the factors affecting total energy use for washing is how full households choose to use their washing machines. If there is a tendency to run machines only partly filled, this suggests there is potential to reduce energy consumption by waiting for full loads and washing more clothes together.

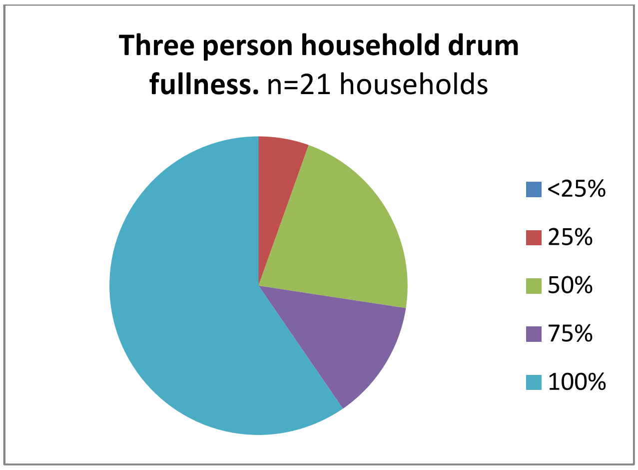
Diary data from the HES shows that these 250 households mainly run their washing machines with a full load (see bar chart below). Just under two-thirds of washing cycles during the monitored period were fully loaded. However, a reasonable minority are half- or a quarter-full. Households doing this could save electricity by using their washing machines less frequently, fuller.

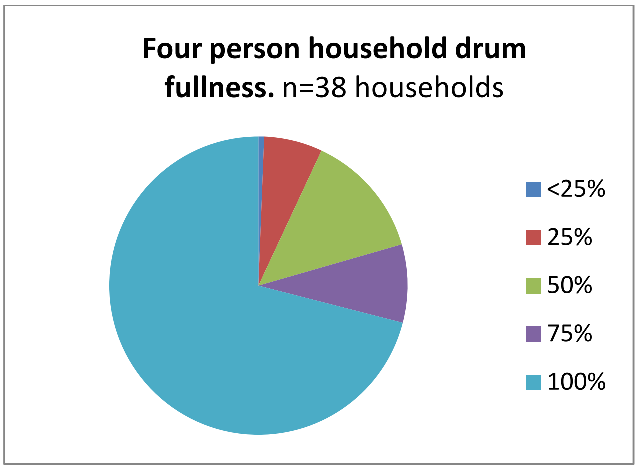


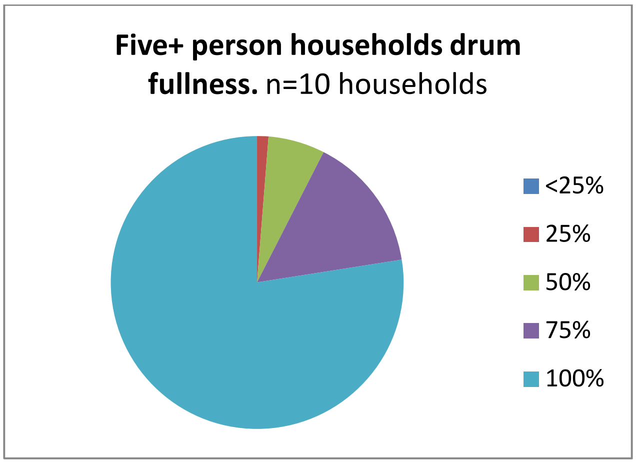
There may be some link between how full households load their washing machines and the number of people in the household. We examined how different sizes of household tended to fill their washing machines (see pie charts below, which omit 33% and 67%). Most household sizes appeared to 100% fill their washing machines for half to three quarters of their washes.



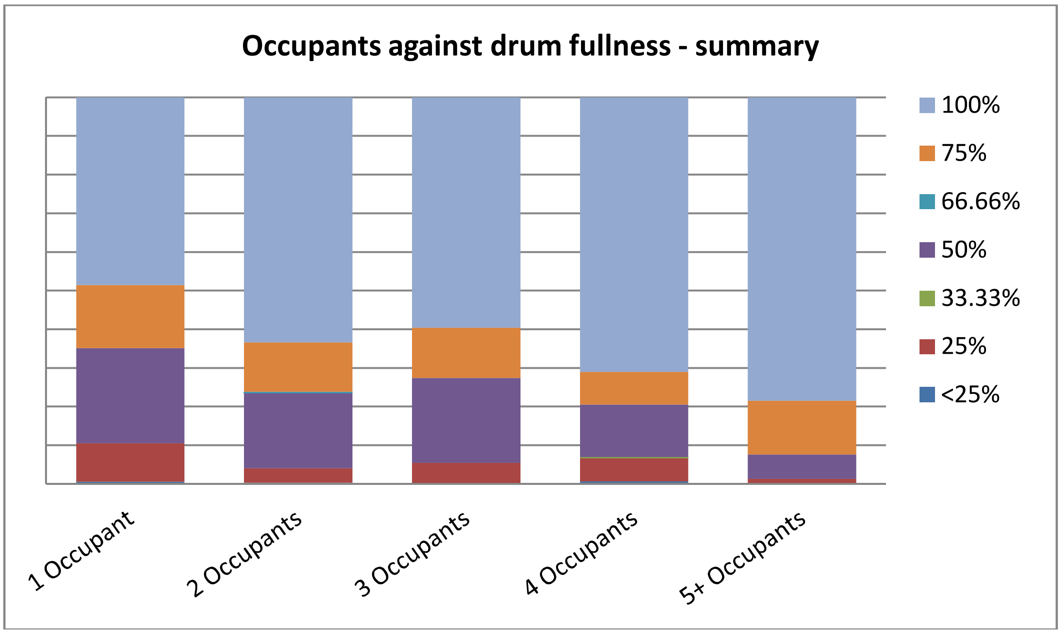




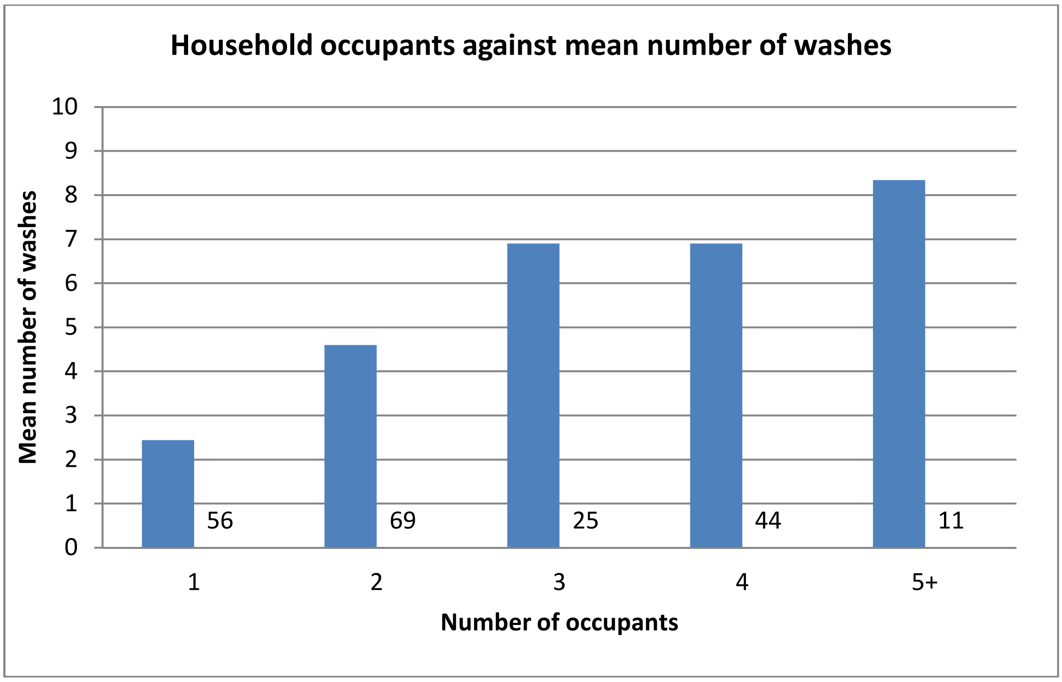




There is a significant correlation ($p < 0.036$) between household size and how full the washing machines were, with larger households more likely to fill to 100% (see summary chart below). However, all household sizes recorded at least some partial filling, so even large households do not completely fill their machines all the time.



We hypothesised that the number of people in households would be correlated to the number of washing machine cycles (derived not from the diary data but from the washing machine electricity use over the whole period of monitoring). It is: two-person households run their machines nearly twice as often as single person households. However, the effect tapers off: four-person households run only 50% more cycles than two-person households.



Energy data

We looked at the energy use of each of the washing events recorded in the diary data, focusing in particular on parameters likely to affect energy use: temperature and spin speed. In fact there is less of a link than you might expect between temperature and energy use per wash, see scatter plot below. There is a very wide variation in energy per cycle for all three of the common temperature settings (30°C, 40°C and 60°C). Energy use for these three is recorded as anything from 50 to 1800 Wh[39], and the mean energy use for all recorded machines was 590 Wh per cycle.

The straight line on the graph below shows a simple linear regression of energy use against washing temperature. This indicates that on average energy consumption increases with higher temperature

Other Evidence on Washing Machine Use

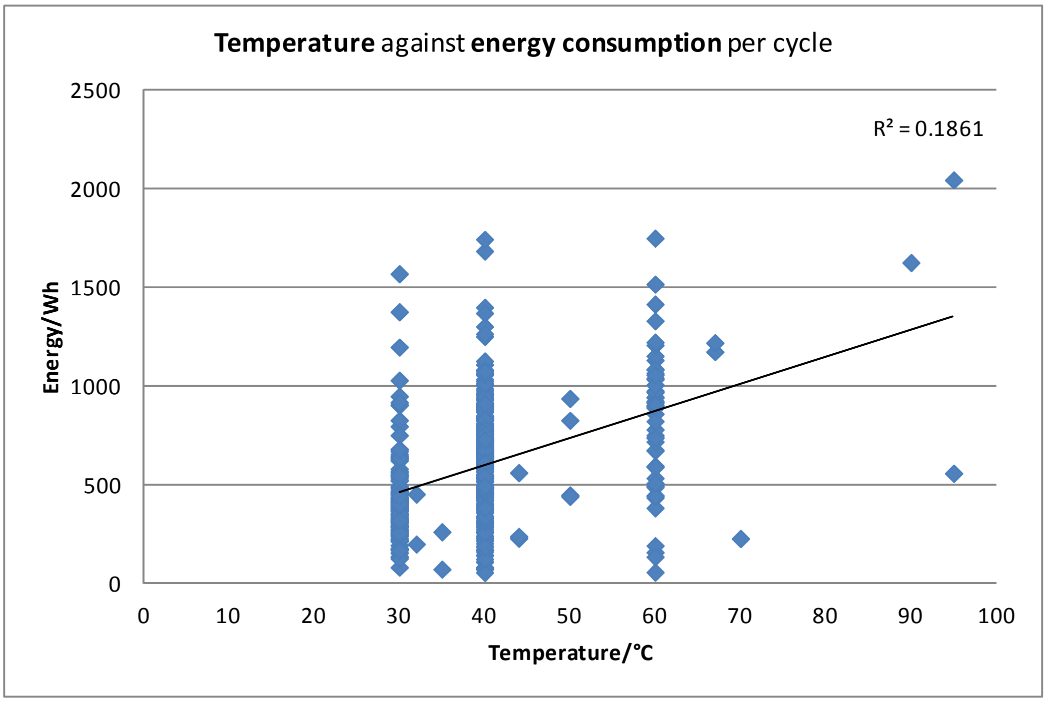
The energy and water temperatures found in the HES compare favourably with a large study carried out in 2001. Questionnaires and two week diaries covering the washing machine use of 325 households across the UK (reportedly representative of the national breakdown) found roughly 40% of washes at over 40°C, with an average water temperature of 48°C.

If the HES study is representative of the UK as a whole, this suggests a move towards colder washes in the last decade, particularly when taking into account the fact that the 2001 data showed very little change in water temperature when compared with a similar study from 1997.

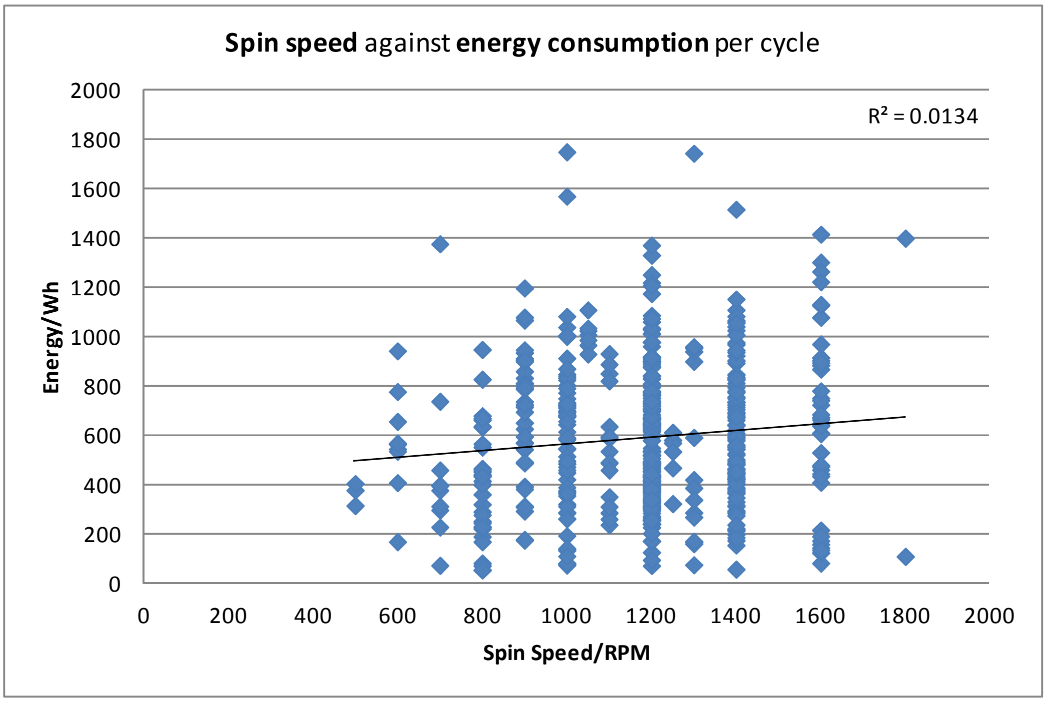
[39] Some of the low figures are suspiciously low, and these wash cycles may have been interrupted part-way through. About one third of the cycles recorded from 50 to 200 Wh were 'quick' or 'economy' settings. There is also evidence that one of the heating elements in these washing machines has failed – bringing energy savings, but presumably at the cost of dirtier clothes.

[40] IBM (2002). AISE code of good environmental practice: Final report to the European Commission 1996-2001. London: IBM.

settings. However, the link is very weak. The 'coefficient of determination', R^2, indicates how well a linear regression fits recorded data. It ranges from 0 (poor fit) to 1 (perfect fit). In this case an R^2 of 0.19 underlines how poor temperature is as an indicator of energy use.

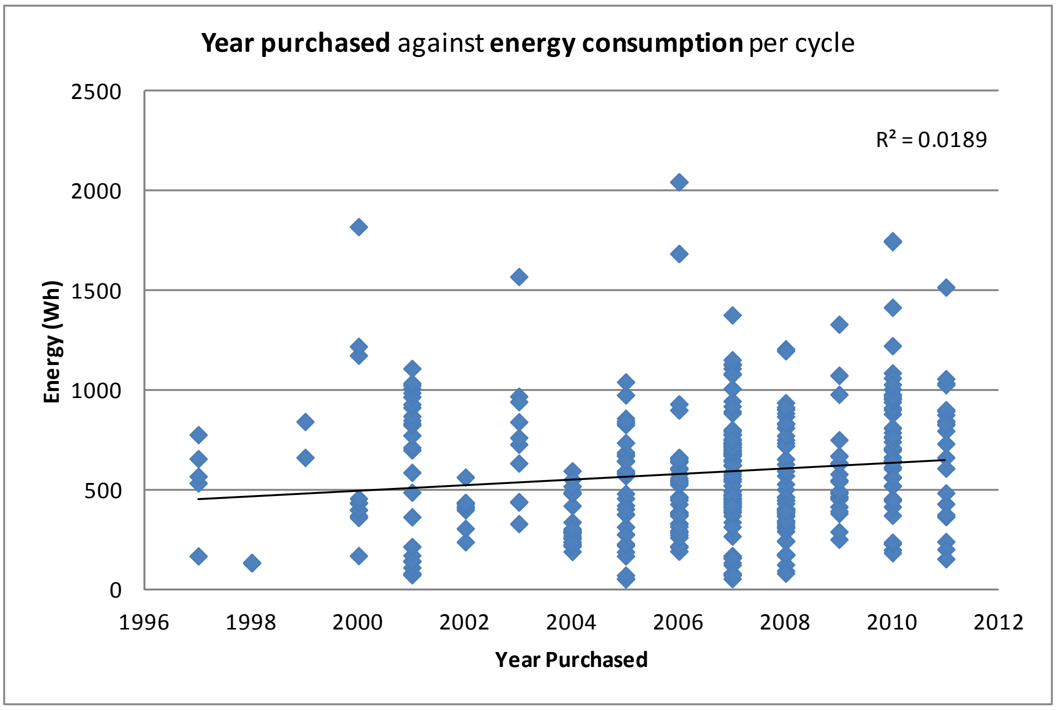


The link between spin speed and energy use per wash is even weaker, as shown in the plot below. The very low R^2 value of 0.013 indicates that spin speed alone is not sufficient as an indicator of energy use per cycle. As for temperature, there is a wide range of recorded energy consumptions for different spin settings, although the mean energy use does show some upward trend for higher spin speeds.

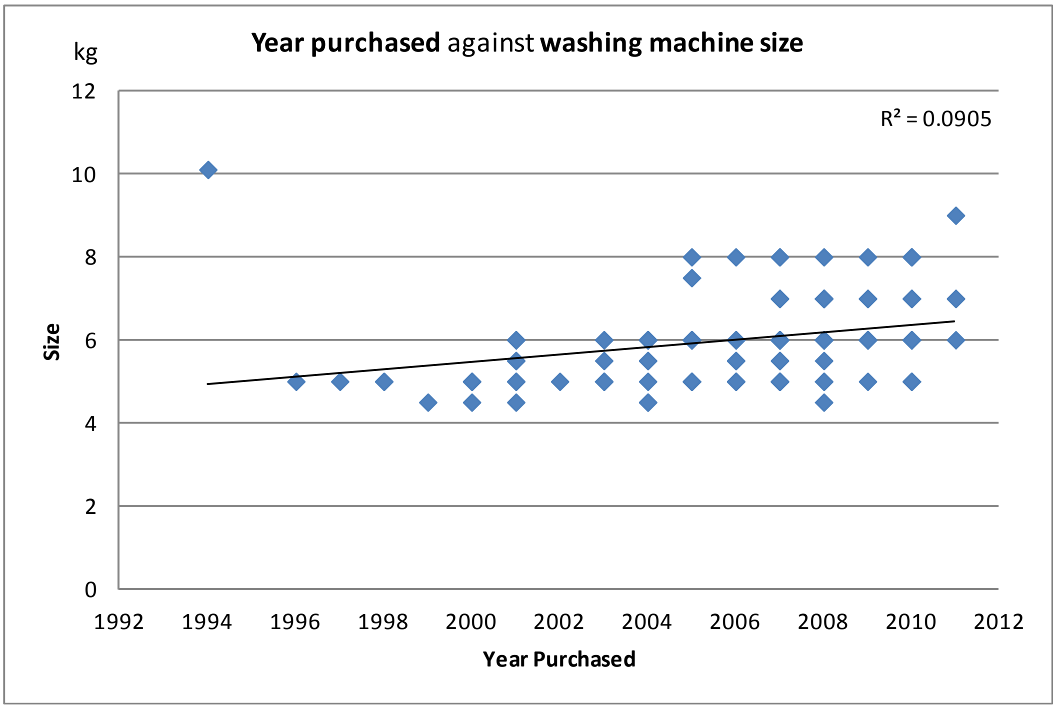


Given that washing machines are one of the appliance types included in Eco-Labelling, it is likely that newer washing machines use less electricity per cycle than older machines. Do they? No, among the households in the HES, the opposite appears to be true: washing machines purchased more recently were recorded using more power per wash on average than those purchased longer ago (see regression line on the plot below).

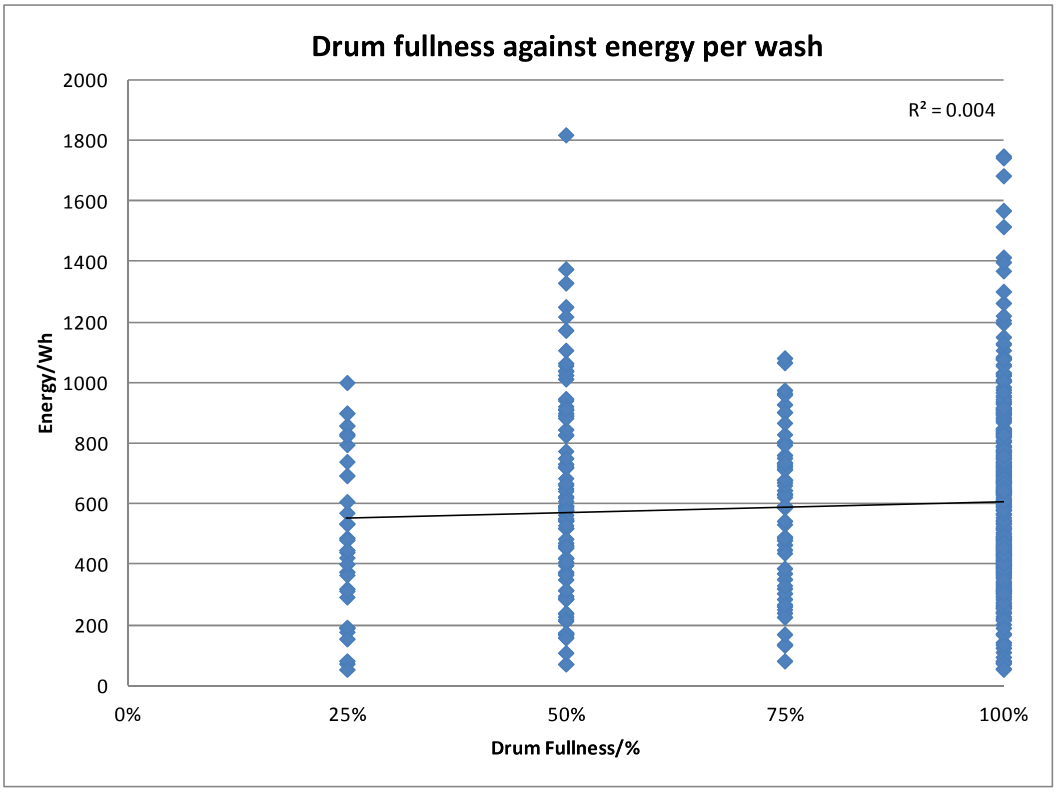
As for temperature and spin settings, the distribution is quite complex, and the correlation between appliance age and electricity use per cycle is weak (R^2 is only 0.019). Nevertheless, appliance age alone is not a predictor of energy use.



Is something else affecting the power use of more recent washing machines – size, perhaps? Based on this sample of homes, washing machines are becoming gradually larger over time, see plot below. Whereas the average size of machines purchased from 1996-1998 was 5 kg, the average size of machines bought from 2009-2011was 6.5 kg. It appears that energy efficiency gains over time were undermined by the households purchasing larger washing machines. (Naturally, larger machines allow people to wash more clothes at a time, so although energy per cycle increases, total energy use for washing may fall as households with larger machines run fewer washes through the year. The evidence for this hypothesis was inconclusive, with newer machines tending to have higher energy use per year – possibly because machines with high use are replaced more frequently.)



We also looked at how full the households load their washing machines, and how this affects energy use per wash, below. This found a very weak link between fullness and energy use, with part-filled machines using slightly less energy on average. However, the saving is marginal, and this is certainly no argument for part-filling washing machines for energy saving reasons. The section on single person households below found that where washing machines have a part load option this sometimes saves energy but not always.



Recommendations

■ Only a tiny proportion (2.3%) of washing cycles use an 'economy' setting. However, there is no evidence that 'economy' settings actually save energy, so encouraging more households to use 'economy' settings may not save any electricity.

■ New washing machines and washing powders designed for low temperature washes have been relatively successful in encouraging more energy efficient low temperature wash modes.

■ However, new washing machines are not demonstrably more energy efficient than older models. On average, machines purchased in 2010-11 used about 35% more electricity per cycle than machines bought in 1997-98. Balancing against this is the increased volume of newer machines, allowing more clothes per wash, and average volume increased about 20% between these years.

■ Energy label calculations should reflect normal use, which for washing machines is a wash temperature of 40°C. However, the existing rating calculation is based on 5 out of 7 washes at 60°C.

■ It is better to run a full washing machine less often than a part-filled machine to save energy.

Investigate electric heating in conservatories

The Departments know that if householders heat their conservatories this can be responsible for a considerable proportion of heating energy. If the heating is delivered using electricity, this can be both very expensive and generate high CO_2 emissions. The Departments asked us to examine patterns in electrical heating used in the conservatories in the HES households.

Approach

Five conservatories were monitored as part of the electricity study. This is a very small number and so the statistical significance of our conclusions is inevitably low, however, data from the Energy Follow-Up Survey (EFUS)[41] enables us to set the measurements in context and to begin a targeted response to the challenge of direct electric heating in conservatories. EFUS suggests that 42% of all conservatories have a connection to the main central heating system (and as a consequence fall under Building Control Part L). A further 32% use electricity for heating and are not necessarily controlled. Among these heated spaces 57% are heated every day through the winter period (December to February), demonstrating that most households wish to use their conservatories all year. The current population of conservatories in England is around 4 million[42].

Data from the HES includes two 'high users' who use electric heating for 10 hours per day in January and February. It is revealing that *both of these conservatories also have a central heating radiator,* and so electricity is being used as a supplement to gas heating. It appears to be the enabling factor that makes winter use viable in a hard to heat space.

All five cases in the survey use a mains gas boiler in the house, with three of the five (60%) having a radiator in the conservatory (data from the RdSAP data file). This is in line with the EFUS, which reports that within a sample of heated conservatories, 55% would be expected to have heating connected to the central heating system. While it is possible that electric heating is used instead of gas during the day, where the electrical profile extends into the evening peak it seems clear that both energy sources are used together. A more thorough survey would be required to resolve the detailed pattern of usage, as well as the motivations of users.

Three of the properties were monitored for 27 days, and one for 23 days. The fifth was monitored for a full year and yielded 112 days of non-zero data between January and May. Short duration datasets were subject to seasonal adjustment[43] to obtain an estimate of energy use for a full year. The adjustment factors come from five properties where electric heating use was monitored continuously for a full year. Only one of these had a conservatory. The seasonal adjustment is therefore related to secondary heating in general, of which conservatories form a small sub-set.

From the total of 250 monitored dwellings, 52 were monitored for electrical heating. In some cases the measured energy was zero, so this data cannot be seasonally adjusted reliably. In one case the monitored appliance was a night storage heater rather than secondary heating. The analysis is presented both with and without these exceptional cases – to show how sensitive the results might

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[41] BRE (2013) Energy Follow-up Survey 2011. Watford/London: BRE/DECC (Dec 2013).
[42] CAR's analysis of English Housing Survey data 2011.
[43] See CAR (2013) Household Electricity Survey: Cleaning the Data. Cambridge: CAR.

be to known quirks in the data. The most typical cases, as expected, use gas central heating within the dwelling, and this applied to all of the monitored conservatories.

Of the five examples in the dataset just one was monitored for a full 12-month cycle. It was heated continuously during the autumn using a thermostatic heater operating 24 hours a day. This is an unusual and expensive behaviour and may indicate that the heating was left on accidentally, for delicate plants, or that the householder did not understand the cost of continuous heating. On 21st December the heating was turned off for a period of four weeks, and when it resumed it showed a much more restrained profile. The gap in heating could be because the occupants were away, but the change in behaviour afterwards suggests either the previous use pattern was an accident, or another factor was involved, perhaps the arrival of a bill. We estimate the 24-hour heating would have added £134 to the quarterly cost.

As a consequence the data for the autumn period is not considered to be representative of normal user behaviour and is excluded from the behavioural analysis[44]. However, the spring data shows the householder to be in control of the heating system and therefore is included.

Analysis

As a reference figure for secondary heating across the full English housing stock, we drew on the Cambridge Housing Model for 2010[45,46], which shows average demand of 1800kWh for secondary heating (all fuel types, and not just conservatory heating). The table typically shows lower values than this for the monitored electric heating, as one would expect for the more expensive fuel.

Category	Total electricity use kWh, average	Secondary heating kWh, average	Proportion of heating
Five properties monitored for a year	8,483	709	9.3%
Five properties with conservatories	11,286	1,019	9.0%
High user conservatories	16,533	1,838	11.1%
Low user conservatories	7,788	472	6.1%
37 dwellings with gas CH and non-zero electric heating	8,082	712	8.8%
51 dwellings where heat was measured	7,756	846	10.9%
52 dwellings where heat was measured	8,019	1,160	14.5%

The data is quite consistent despite the small sample sizes, for example, just two high user

[44] It is of technical interest because the energy use can be correlated with the weather conditions to derive an approximate heat loss coefficient for the conservatory.

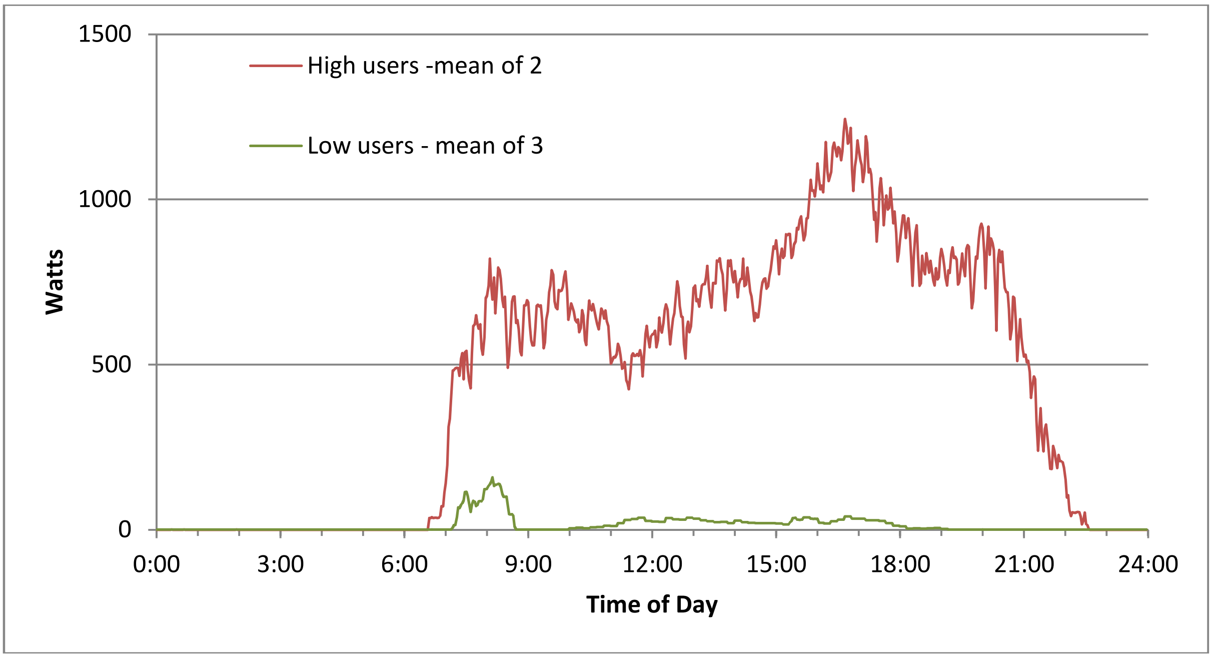
[45] Cambridge Housing Model, CAR Ltd.

[46] https://www.yousendit.com/sharedFolder?phi_action=app/orchestrateSharedFolder&id=yoztP438Ra-fjVwTVEhtK1nx6UGwpjDleJ63mmD0GU8

conservatories. The last entry with 52 dwellings includes the one storage heater that was monitored, showing that a single example of primary electric heating can skew the data significantly. At the low end of the scale the three low user conservatories include the example where usage appeared out of control in the autumn period. If this is excluded, the proportion of heating for the remaining two is just 1.3%. This is a clear indication that conservatories which are used with restraint in cold weather can be good examples of energy conservation.

The high user conservatories are not outstanding in terms of the proportion of electric heating they use, but because they are associated with high-consuming households. The heating of this single space uses more delivered energy than the national average for secondary heating of complete households. This figure is only supplementary heating - in addition to the central heating radiator. The EFUS suggests that there may be 1.8 million examples of this type, and the associated carbon emissions are 1.4 million tonnes CO_2 per annum.

The daily profile of use is shown in the following chart, plotting the average behaviour over the monitoring period. Heating appliances are typically rated at 1 to 2kW but in the case of low users where heating might only be used for a few days per month, the average profile can drop below 200W. Nevertheless, even low users contribute to the morning peak in demand.

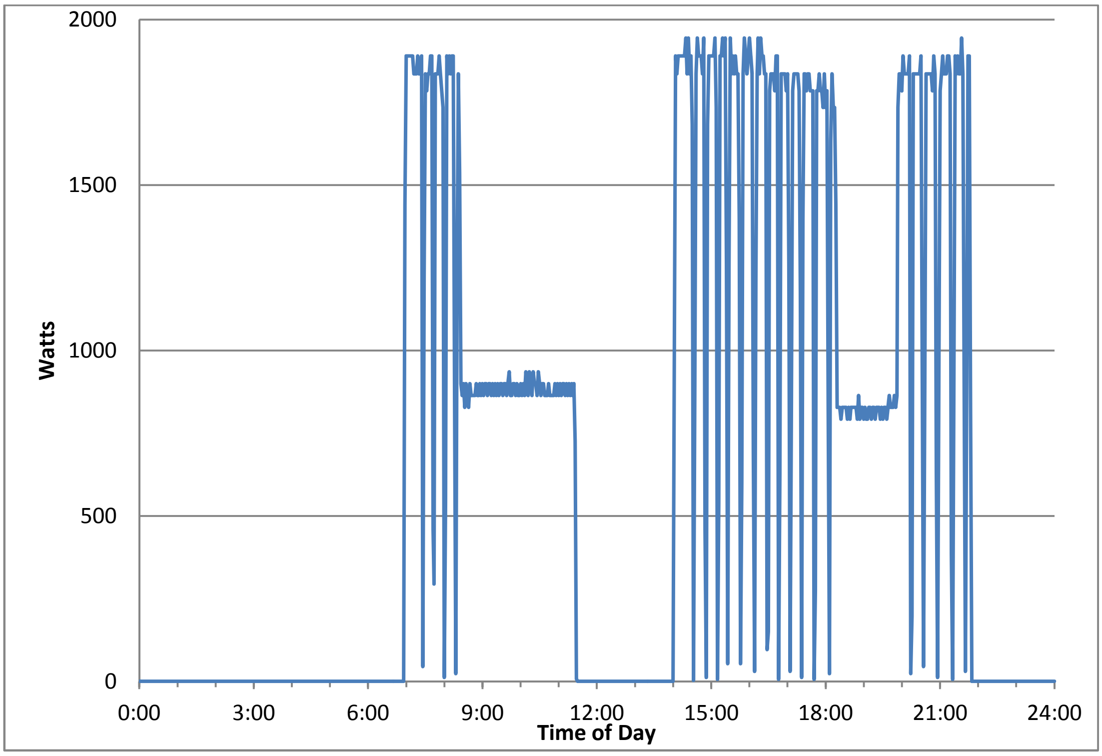


Average electric heating in the conservatories (winter/spring)

Combining this data with the EFUS population figures suggests that potentially 1.8 million English conservatories are demanding 750W during the morning peak, giving a load of 1.3GW. In the evening peak this may rise to 1.6GW. We should remember that the red curve shows data from only two dwellings, so we should be extremely cautious in extrapolating results to a population of 1.8 million. Since the impact on grid demand and on emissions is serious, this begs more data, not least to understand the form of the profile.

The plateau from 6 to 9pm (after dark) suggests the conservatory is being used as a living room, with a common activity being watching television. The peak from 3 to 6pm could be a play space for children returning from school. In energy terms it is irrational to heat a poorly insulated structure through the winter, and it is important to understand the lifestyle factors that drive demand. A sample size of at least 20 conservatories that are used every day would be needed to have more confidence in how the energy is used. The significance of electric heating being used where radiators are present is an important observation from this study and calls for further investigation.

Mining more deeply into the data reveals some detailed behaviour of one of the high users. The graph below shows a thermostatically controlled 2 kW heater, switching periodically to maintain a set temperature. However, at times the user intervenes by switching down to a 1kW setting for background heat, or switching off altogether at lunchtime.



This profile for a single day in January shows that this electric heater has three settings: 1800W, 900 W, and off. The heater has two power settings and a thermostat.

Other Evidence on Conservatory Heating

Although energy conservation was becoming an increasingly important factor in homeowners' decisions to build conservatories, a 2004 survey by UCL into conservatory use in London[47] revealed that they were being heated more often. Compared with a similar survey from 1991, the work found that conservatories are being heated for longer on average (74% of respondents noted that they heat their conservatories daily). It also revealed an increase in the use of central heating and, worryingly, an increase in conservatory air conditioning.

The research also suggested that these factors may be connected to the improvements in the thermal performance of dwellings over time. The improved building fabric for conservatories may encourage building users to use them throughout the year, requiring increased heating to maintain satisfactory internal conditions.

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[47] Pathan, Ayuh, et al. "Trends in domestic conservatory use: A comparison between the 1991 Conservatory Association survey and the UCL 2004 survey." NCEUB meeting. UCL, London. 19 April 2007.

It is clear that the heater is being used thoughtfully but without full knowledge or concern for the environmental implications. The conservatory is used over a 15 hour day and is an important part of the living space, a lifestyle which is promoted enthusiastically by the industry. Though it is not covered in this study, the prospect of summer air conditioning being added to the electrical demand should also be considered. Last but not least is the trend towards outdoor living: the availability of electric patio heaters is another feature of the same phenomenon.

Recommendations

■ Avoiding peak-rate electric heating in all conservatories might save an indicative 1.6 GW from the evening peak load.

■ A detailed study is required to reveal how electric heating is used alongside gas central heating in the winter period in households with high electricity use.

■ Consultation with the conservatory industry is necessary to stem the growth in electric heating, and if possible discourage winter use of conservatories.

Estimating possible savings

EFUS data suggests that 44% of 4 million conservatories, or 1.8 million, have electric heating. The HES sample size for heated conservatories is so small that this can only be indicative, but the five dwellings here used an average of 900W each during the evening peak. This means the total saving from avoiding heating during the evening peak might be:

900 W x 1.8 million = around 1.6 GW

■ Building Regulations should consider limits to the heat loss (and solar gain) in conservatories – for example, by setting a maximum area of glazing.

Appliances left on when not in use

The Departments would like to investigate how often householders leave appliances on when they are not being used, for example TVs left on when no-one is in the room, or appliances left on all night.

Many appliances can be usefully left on when there is no-one in attendance: washing machines, fridges, dishwashers and so on. However, for items like TVs, games consoles, radios, lights, desktop computers and monitors, leaving the appliance on (rather than off or in standby mode) may serve little purpose unless there is someone there to watch, listen or play. Lights are sometimes an exception because they may be left on to deter burglars, or for personal safety on stairs. (And there may be some exceptional cases for ICT that needs to update software or other tasks periodically.) We have investigated the use of these appliances.

Approach

We investigated night-time use separately from the phenomenon of appliances being left on in unoccupied rooms. For night-time use, we selected cases where appliances were left on for at least five hours per night, on average, between 11pm and 6am. We ignored power use below a threshold appropriate to the appliance, typically 3W for lights and light distribution circuits, and 15W for TVs, depending on the standby power use. We then investigated how many households left appliances on and how much power they used, on average.

For the other part of the analysis we selected households with appliances in more rooms than there were people in the house, and focused on periods when there were more rooms in use than people in the household. For example, if there were three TVs active in different rooms and three people living in the house, then they could all be watching independently. However, if there were three TVs on in different rooms but only two living people in the house then, unless they had guests, at least one of those TVs must be on with no-one watching. We ignored cases where the overlap in appliances was less than 20 minutes.

Analysis - night time use

We found 79 of the 250 households left lights and appliances on overnight, drawing significant power. This was more likely to be lighting than appliances, either independently monitored plug-in lamps, or on the lighting circuit (assuming all the power use on the lighting circuit is for lighting).

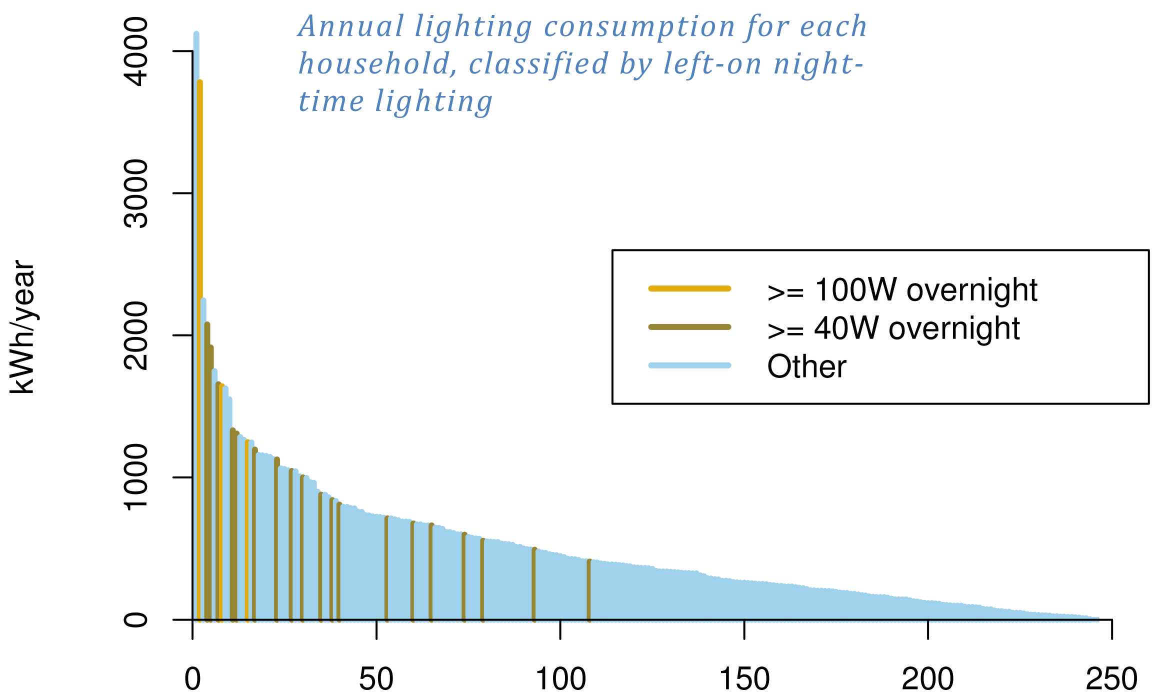
The table below shows how many households left lights on overnight, and which room the lights were in, where this is known. The small number of landing lights reflects that most hall and landing lights are on a lighting circuit, where the location is not known. In total, the households left on 2.9 kW of lighting, an average of 11.8 W per house (95% confidence interval for the mean is 9.0 to 14.5 W). This is equivalent to 23-37kWh/year for each household.

This suggests that if 1 million households could be persuaded to turn off all lights overnight, this would save from 9 to 14.5 MW, or 23-37 GWh over the year.

Room	Number of households	Mean night time power use (11pm-6pm) (W)
House (lighting circuit)	66	42
Lounge	4	20
Landing (lamps)	2	8
Bedrooms	7	14

The low wattage for overnight lighting in the table reflects the fact that in many cases the lamps are low-energy CFL bulbs rather than old-fashioned incandescents.

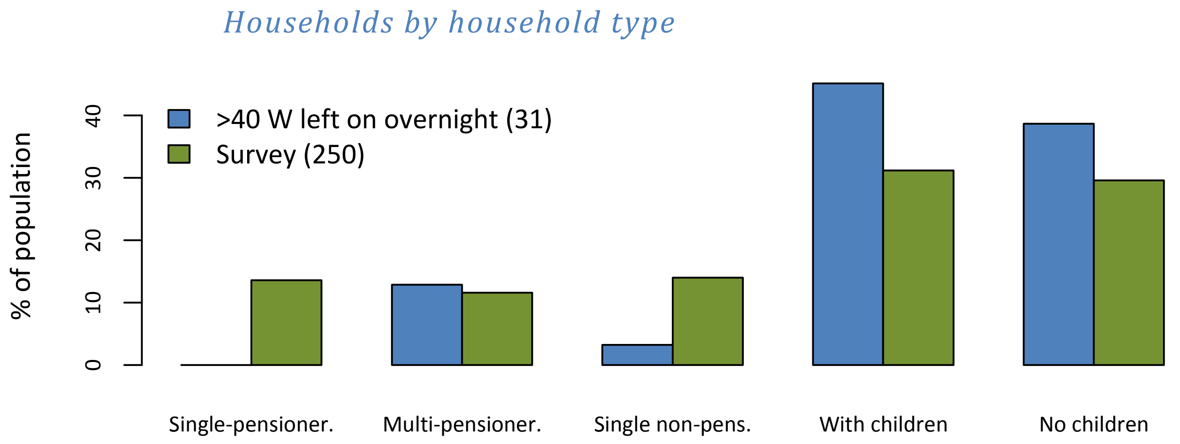
We also compared the total annual lighting electricity for each household with left-on overnight lighting. Households leaving lights on overnight were also likely to be high total lighting users. However, night-time lighting was never more than 20% of the total lighting use, and in 90% of cases it was less than 7%.

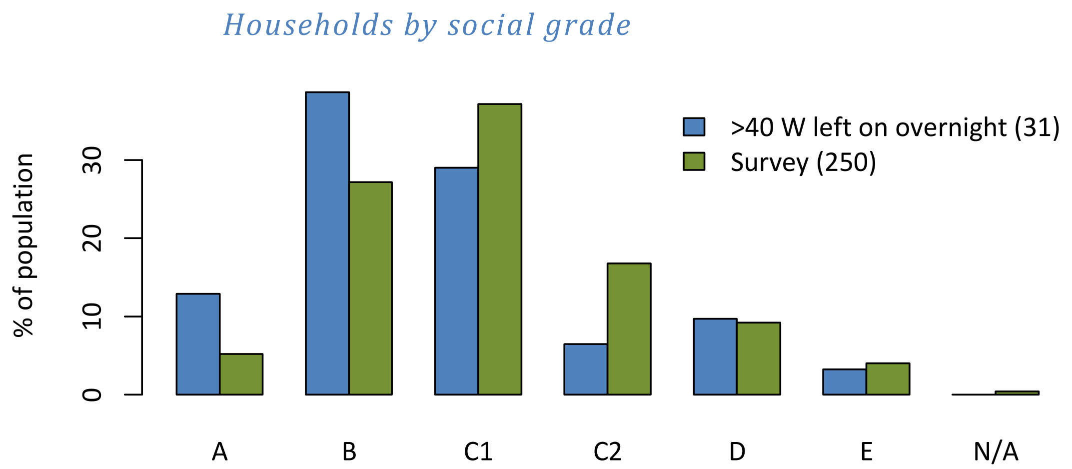


There were only 12 households leaving equipment other than lights on overnight, see table below. (Note this excludes appliances left on standby overnight, including computers in a power-saving mode. We also excluded six computers that were never switched off, assuming they act as servers and are required 24 hours/day. These used between 50 and 115W.) Averaged over all households, the power used was 2.1 W per dwelling (95% confidence interval 1.3 to 3.2 W per dwelling).

Appliance	Room	Number of households	Night time power use (11pm-6pm)
TV	Bedrooms and one in a study	4	32 – 91 W
Wii (excluding appliances using less than 5W)	Lounge or unknown	6	7 – 39 W
Computer (excluding those in power save mode and 6 computers that were never switched off)	Bedroom	1	115 W
Monitor	Study/Kitchen	2	28 – 84 W

Households using more than 40W overnight for lights and appliances were less likely to be single pensioners, and more likely to be of higher social grade, see charts below. This suggests that wealthier households are less concerned about avoiding unnecessary night-time use (or perhaps more concerned about security). Households with children are also a little more likely to leave lights on overnight.





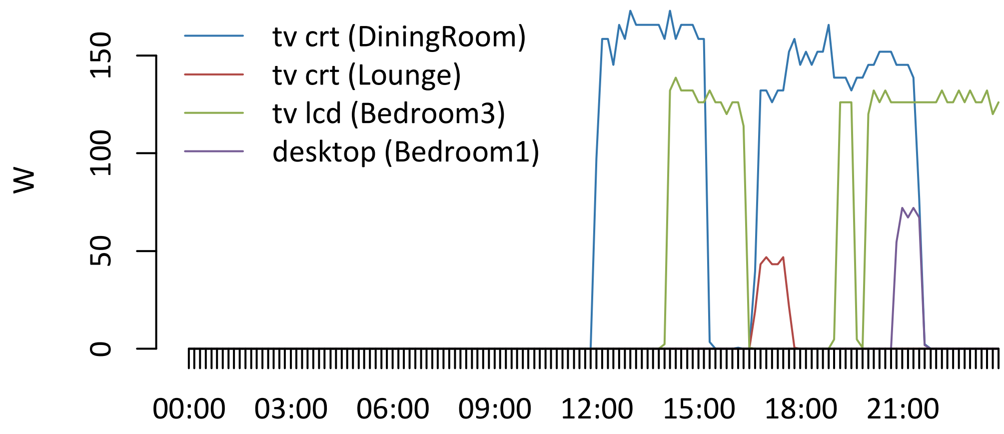
Analysis - Lights and appliances in different rooms

Out of the 250 households monitored, we found 124 (just under half) that we could investigate because we knew of appliances in more rooms than there were people in the house. We analysed three weeks' data for each of these houses (because we had at least three weeks of data for each household), and determined how many hours we could infer that there were appliances left on in an empty room. This is a lower bound only on the actual figure since:

- Where there was more than one person they could be in the same room (so we underestimated the number of appliances left on for larger households).
- It was not possible to include lights on lighting circuits since there was no information about their location. This means that we *underestimated* cases where lights were left on in unoccupied halls/stairs, and we were biased about the rooms where lights were left on: halls and corridors seldom have standard lamps (that plug into sockets).

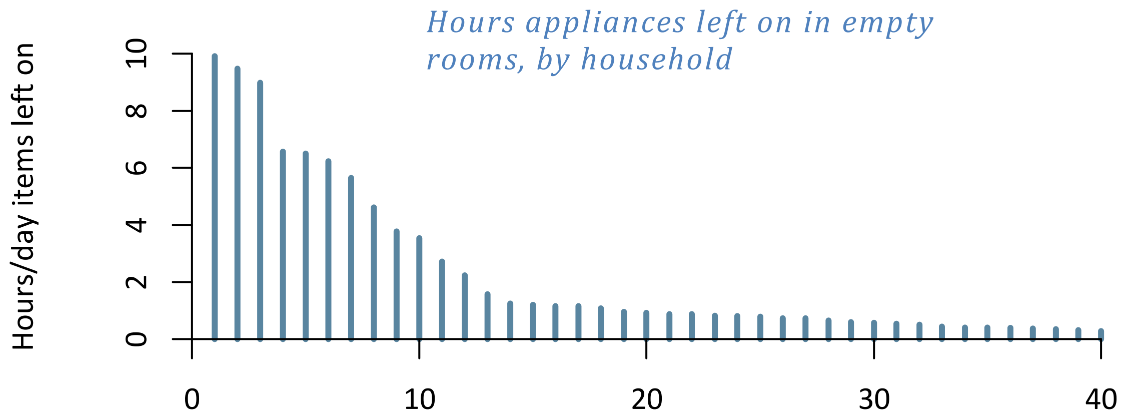
This profile shows an example day from one of the homes. The TV in the lounge was left on most of the day and evening, even when the TV and desktop computer in the dining room were in use. The lounge TV was also still on when the bedroom TV was in use in the evening.

This daily profile shows appliances active in several rooms, even though this is a single person household



We identified 18 households where appliances were left on in empty rooms for more than one hour per day. As before, we ignored computers that were always left on, and considered only those switched on and off at least daily. Monitors were included even if they were never switched off, because they do not need to be left on for computer servers to function.

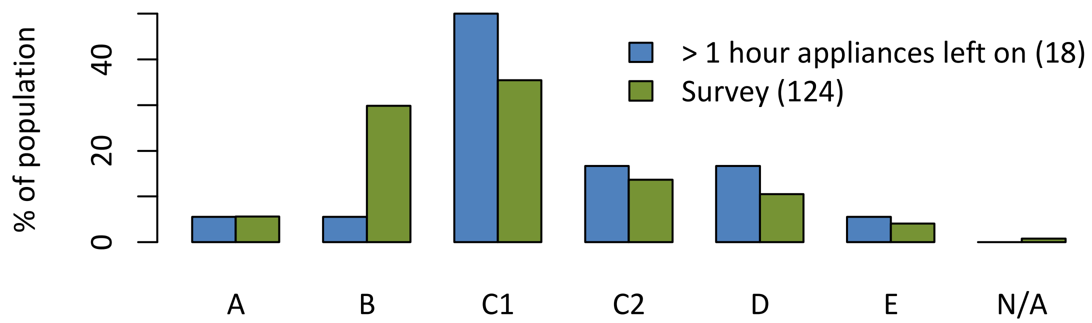
Of these 18, all but four were single person households - 27% of all the single person households in this analysis. The others were two-person households - 10% of these. The real figures are likely to be higher due to limitations of the method.



We computed for each dwelling the average daily energy ‘wasted’. We calculated a best case, assuming that when there were appliances active in more rooms than people, the lowest power room was the one that was empty. Conversely, our worst case assumed the room consuming highest power was empty. In the profile shown above, the dining room TV is switched on after the lounge TV and it is likely that the occupant remained in the dining room and left the lounge TV unattended. In this case the lounge TV uses nearly three times as much power, so the actual power wastage is closer to the worst case than the best case.

Persuading the 18 households to turn off their unattended lights and appliances would save from 62 to 250 kWh/year for each household. Taking into account all the households that we could analyse, the average savings would be 10 to 44 kWh/year. However, because of the under-estimates, total savings would doubtless be higher.

Households in social grade B were less likely to leave appliances on than average. This difference was statistically significant.



The table below shows the appliances that are most often left on in the worst eight households (by hours). Bedroom TVs are often left on, along with desktop computers and monitors. Hall and landing lights feature in three of the top eight, even though there are few lamps (not on lighting circuits) in these areas – only 23 out of 609 (4%) lamps with known locations. It is likely that there are many more households leaving lights on in these areas that we cannot detect, because they are not attached to monitored sockets. Over for all households, the average total installed wattage in the hall and landing was 111W.

Top 8 households leaving lights and appliances on in unoccupied rooms

Household	Hours left on in empty rooms/day	Electricity wasted (kWh/day)	Most common combinations of appliances, with typical power use
Single pensioner grade C2	9.9	0.27 – 1.63	TV in lounge (115W) and often 30 W lights 30 – 40W lights in the kitchen/diner
Single non-pensioner grade D	9.5	0.53 – 1.70	TV in lounge (50W) plus light (35W) desktop (130W) and monitor (20W) in study, kitchen TV (12W)
Single pensioner grade C1	9.0	0.30 – 1.27	Lights in dining room (30W) TV and lights in lounge (112 -180 W) Sometimes bedroom TV (50W)
Single pensioner grade C1	6.6	0.08 – 0.76	Lights (80W), TV (60W) and monitor (20W) in lounge Lights in dining room (12W)
Single pensioner grade B	6.5	0.68 – 1.43	Light in hall (90W) Desktop and monitor in study (130W)
Single pensioner grade C1	6.2	0.20 – 0.46	TV in kitchen (20W) Lights in lounge (26W) Landing lights (32W)
Two pensioners grade D	5.6	0.06 – 1.33	TV and lights in lounge (240W) Hall light (10W) Landing light (10W) Bedroom TV (135W)
Single pensioner grade C2	4.6	0.13 – 0.51	Kitchen TV 90W Lounge lights (13 – 83 W)

The impact of lights being left on is expected to reduce over time as more households install low energy light bulbs. However, appliances are left on too, so we repeated the analysis for just the appliances. This time we found only six households out of 61 left equipment on for at least 1 hour/day on average, wasting 38 to 135 kWh/year. Averaged over all of the 61 households that could be analysed, the wastage was 6 to 20 kWh/year.

There was only a little overlap between the households leaving lights on overnight and those leaving appliances on in unoccupied rooms: three households were in the top 20 for both.

Recommendations

■ Many households leave some nights on all night – using 9 to 14.5 W per house on average, or 23 to 37 kWh/year. The highest users of night-time lights also have high lighting electricity use generally, so policies that reduce lighting energy would also reduce night-time lighting use.

■ There is evidence that lights, TVs and computers are left on unnecessarily in some households – at least 18 out of 124 did so for at least 1 hour per day on average, including 27% of single person households. The real numbers must be higher because our method was biased against larger households and relied on incomplete knowledge of lights. TVs were often left on in bedrooms and kitchens, but excluding lights we only identified six out of 61 households leaving appliances on more than 1 hour per day.

■ We found potential savings of at least 10 to 44 kWh/year from turning off appliances that are not being used, averaged over all the 124 households in our analysis. (The range is due to not knowing which room is unoccupied, and therefore which appliances are not needed. A further study with presence sensors could provide more accurate information if necessary. This could also eliminate the bias in our analysis towards single person households.) About half of the wasted electricity was due to lighting – in practice the real wastage must be much more than this because our analysis was limited to lights plugged into sockets.

Rebound effects from more efficient products

The Departments would like to investigate whether households that buy more efficient appliances tend to use them more. If so, this would at least partly offset the energy saving from greater efficiency – a form of 'rebound effect'. The Departments wish to quantify the effect, if this is possible.

Approach

If householders use products more after buying a more efficient model this implies two things. First, that newer appliances are more efficient, and second, that among the newer appliances, more efficient ones are used more. This led to a two-stage analysis – identifying newer appliances with better efficiencies, and looking for evidence that such appliances are more heavily used.

For both newness and efficiency, and efficiency and usage, we used linear regression to look for trends. This requires a 'scalar' value for both parameters: a continuous numerical value, rather than cruder categories. Age and usage (measured in frequency of use or hours/day) are naturally scalar. However, energy efficiency (in terms of energy ratings) are not, so we coded the energy efficiency ratings as A++=1, A+=2, A=3, B=4 and so on. This allowed us to carry out linear regression and to calculate 'coefficients of determination' (R^2, which shows how good a predictor one variable is of another).

Analysis

Washing and drying appliances

For these appliances we used the number of cycles per week as a measure of use. This varies considerably between households: even excluding the extreme 20% of households, the range was from 1.5 cycles per week to 10 cycles per week. We used energy rating as a measure of efficiency.

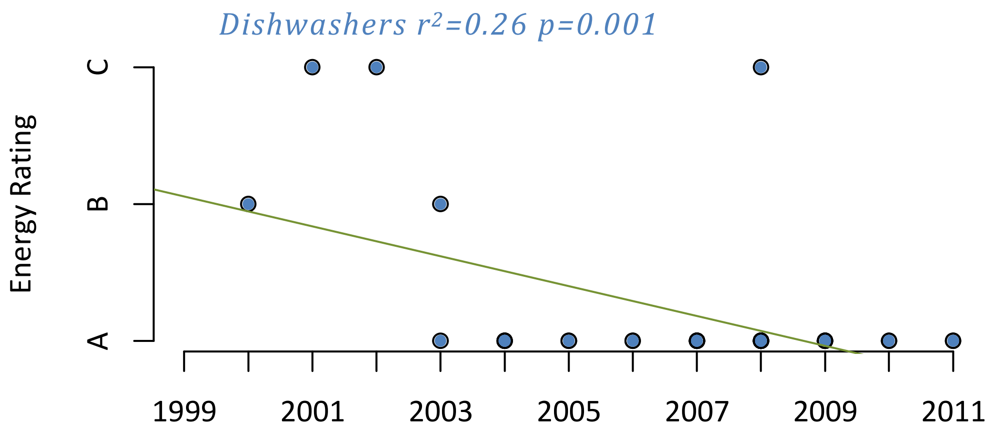
Therefore the appliance sample was restricted to only appliances where we knew both the age and energy rating: less than half the total number of appliances. For washer-dryers we could only use 7 out of 22 that were monitored.

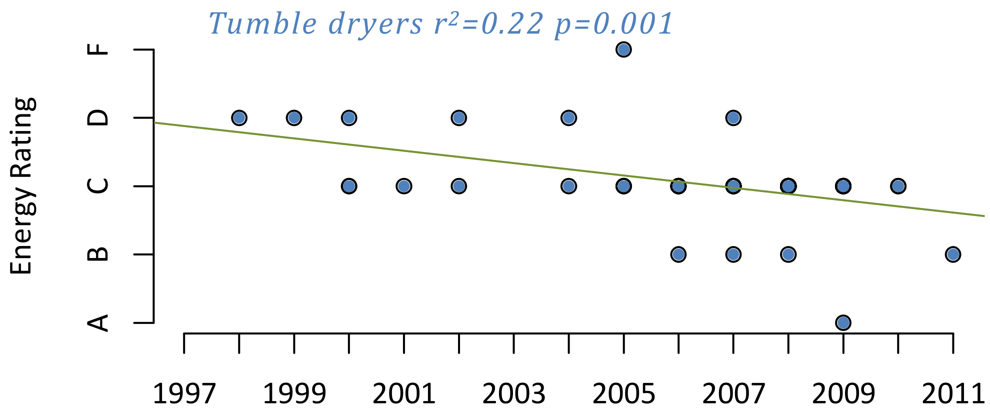
We found improved efficiency with newness for all washing appliances except washer dryers, for which there were too few to confirm a trend. For the other appliance types, we found an improvement of about one energy grade per 10 years of age. However, we did not find any significant trend of more use with efficiency for any of the appliance types – suggesting that there is no rebound effect for washing appliances.

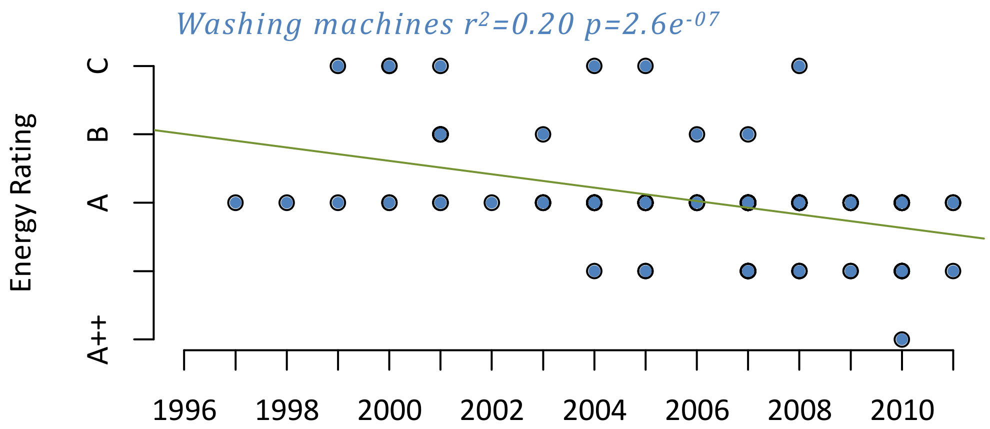
The following charts show the trends of improving energy rating with newness, and the results are summarised in the table beneath.

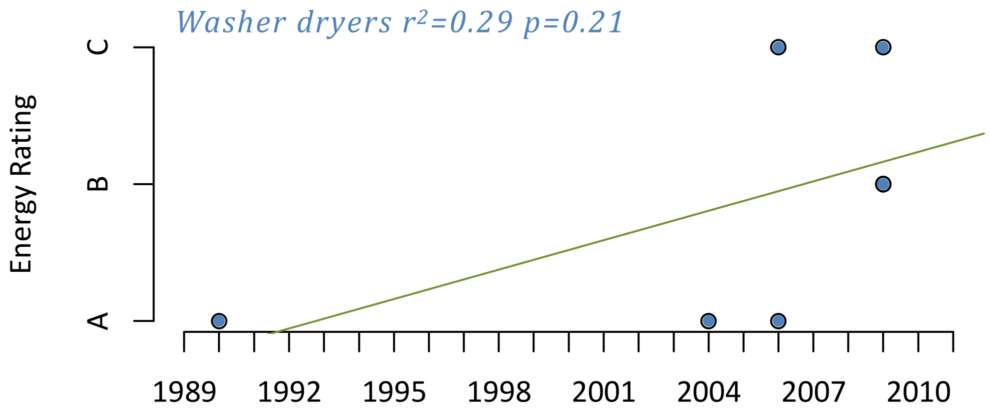
The charts include the coefficient of determination, R^2, which shows how closely two parameters are linked (where 1 is a perfect correlation, and 0 is none). The charts also include the p-value, which here means the probability of the null hypothesis: that there is no relationship between y and x and therefore that the slope of the line is zero.

This probability is calculated from the estimate and standard error of the slope. The standard error of the slope is akin to the standard error of the mean in a t test: from a set of samples you can calculate a mean and standard error of the mean, from a set of sample points you can calculate a mean slope and a standard error of the slope. From this you can calculate the likelihood that the slope is 0, i.e. that the y values are completely independent of the x values and the distribution of y is the same for all values of x. In the cases below the probability that the slope is 0 is extremely small.





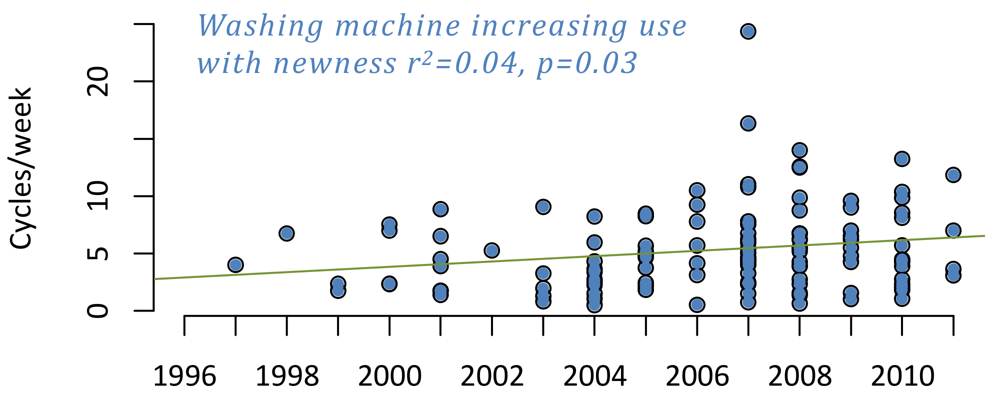




Appliance	Number in sample	Significance of efficiency trend*	Extra grade/year	Significance of use trend*	Extra uses/ week/grade in appliances bought 2004 or later)
Dishwashers	39	**0.001**	**0.1**	0.9	-
Washing machines	122	**2.6^{e-07}**	**0.1**	0.7	-
Tumble dryers	51	**0.001**	**0.1**	0.7	-
Washer dryers	7	0.22	-	-	-

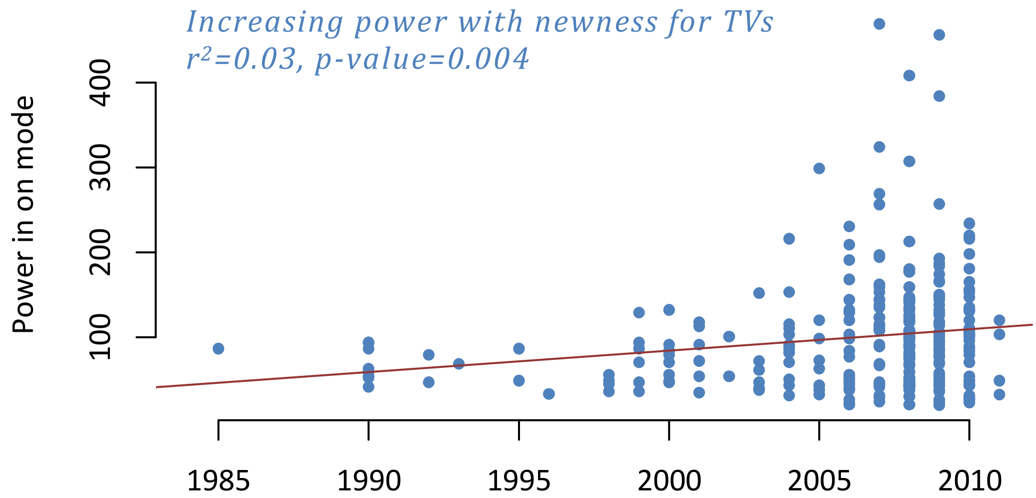
* The significance columns show the p-value, which is the likelihood that the observed trend is caused by random variation. If this is less than 0.05 – i.e. there is only a 5% chance that the trend is produced merely by chance – then we consider the trend is significant, see box on p185. These are shown blue here.

We also looked for significant trends relating use and newness and we found that heavily used washing machines tend to be newer ($p < 0.05$). This may be because they wear out and are replaced more often, or because households that run the washing machine frequently choose to upgrade their appliance. However this trend was weak, and did not suggest any rebound effect. We did not find any significant trend relating use and newness for the other appliance types.

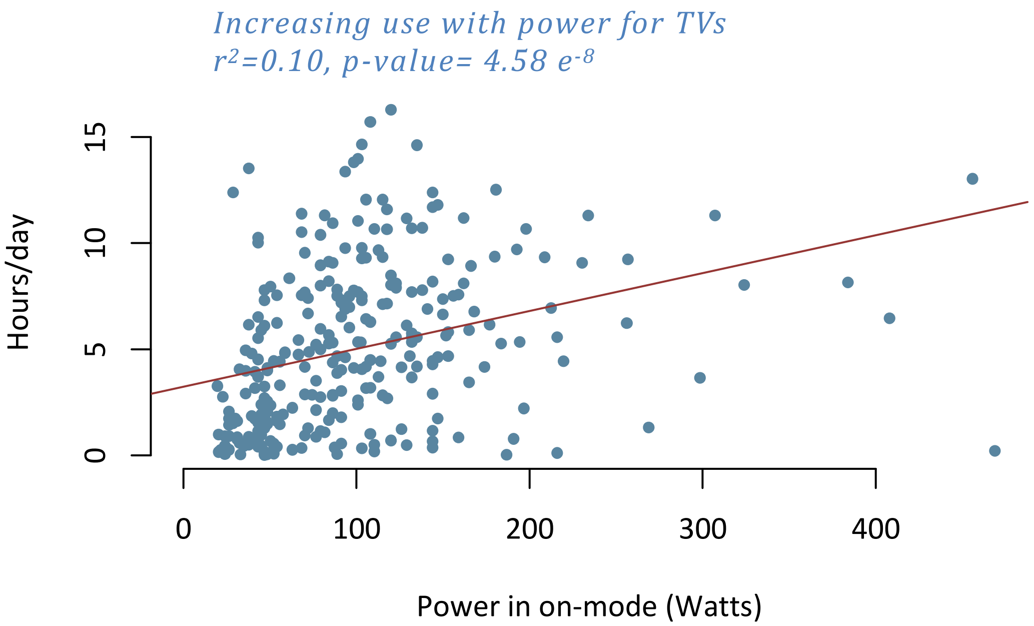


TVs

Although energy ratings are now defined for TVs, these only came into effect in 2012 and so no energy ratings are available for the TVs in the survey. The efficiency of a TV relates the power user to the screen area, since a large part of the energy use is in making the screen bright. However, larger TVs do not provide more functionality (in contrast to larger washing machines enabling larger loads) so we ignored size and considered power directly instead of power per unit screen area. If households replace a TV with one consuming less power and then use it more, then that would be a rebound effect.



In fact power use for TVs *increases* with newness ($p < 0.01$). We also looked for more use for TVs with lower power consumption but found the opposite: higher power TVs were used more.



Appliance	Number in sample	Significance of power trend	Increasing power Watts per year	Significance use with efficiency	Extra hours/day (W)
TVs	280	**0.004**	**2.5**	**4.6×10^{-8}**	**0.2**

Other Evidence on Rebound Effects

Reviews of domestic energy consumption in the UK[48,49,50,51] have highlighted trends towards rising ownership of all appliance types. There are also more and more households owning multiple appliances. For example, the average number of TVs per household increased from 1.84 in 2001 to 2.36 in 2006, and ownership of cold appliances increased by 10% from 1995 to 2001. As well as increasing ownership, research also points towards increased appliance usage. For instance, research by GfK found that average daily TV viewing has risen by 13% from 1995 to almost 4 hours daily in 2005. The net result is that residential electricity consumption in the UK for lighting and appliances rose by 2% per year between the 1980s and the early 2000s.

[48] Boardman, Brenda, et al (2005). The 40% House. Oxford: ECI.
[49] Boardman, Brenda (2004). Achieving energy efficiency through product policy: the UK experience. Environmental Science & Policy 7.3: 165-176.
[50] Bertoldi, Paolo, and Atanasiu, Bogdan (2007). Electricity consumption and efficiency trends in the enlarged European Union. IES-JRC. European Union.
[51] Boyny, J. (2006) CE and IT: Market continuously driven by new technologies and by the development of changing consumer approach. Proceedings of 4th International Conference on Energy Efficiency in Domestic Appliances and Lighting (EEDAL 06), 21-23 June 2006, London.

Recommendations

We found no evidence of a rebound effect from increased appliance efficiency so we have no recommendations. Our main observations are:

■ The energy ratings of new washing machines, tumble dryers and dishwashers are improving by about 1 grade per 10 years.

■ The trend was for new TVs to use more power rather than less (though now that energy ratings are required this may change).

Seasonality trends in non-heating appliances

The Departments would like to understand how the use of appliances varies through the seasons of the year. We have already shown that there are marked differences in use in several appliance categories, notably in cooking, refrigeration and laundry/dishwashers. The Departments now want us to explore these trends in more detail, drilling down into specific appliances, for example washing machines versus tumble dryers, rather than just laundry. They wish to see whether there are different seasonality trends for individual appliances.

Approach

Our method used data from the 26 households that were monitored for a whole year. First, we calculated electricity use on each day for each appliance type, averaging the total usage across all households monitored for that appliance. Second, we extended the data to cover two full years (i.e. two complete seasonal cycles, rather than just one cycle, like the raw data). Third, we used linear regression with a formula based on sin/cos functions to match the yearly cycle as closely as possible.

(The approach is similar to our calculation of seasonality factors for the different categories of appliance. However In this case we used the daily average figures in kWh, whereas for the seasonality adjustment we divided each day by the overall average to obtain an adjustment factor, between 0 and 1, for the day.)

As well as using the daily energy use, we also looked at frequency of use to see whether any variations were due to the number of times the appliance was used, or the energy used for each cycle.

Since the sample size is small some individual households with extreme patters of use can skew the average figures. In some cases we drill down to individual households to examine differences in behaviour.

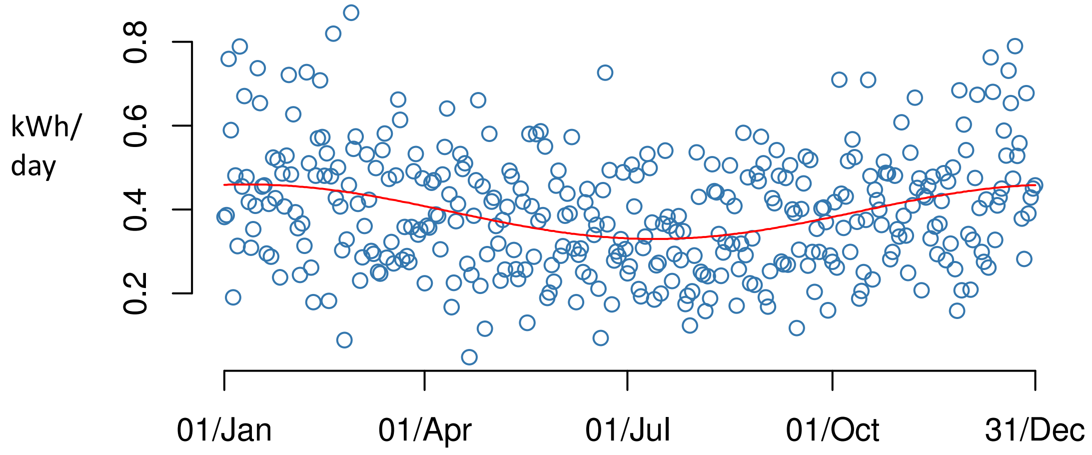
Analysis

Washing appliances

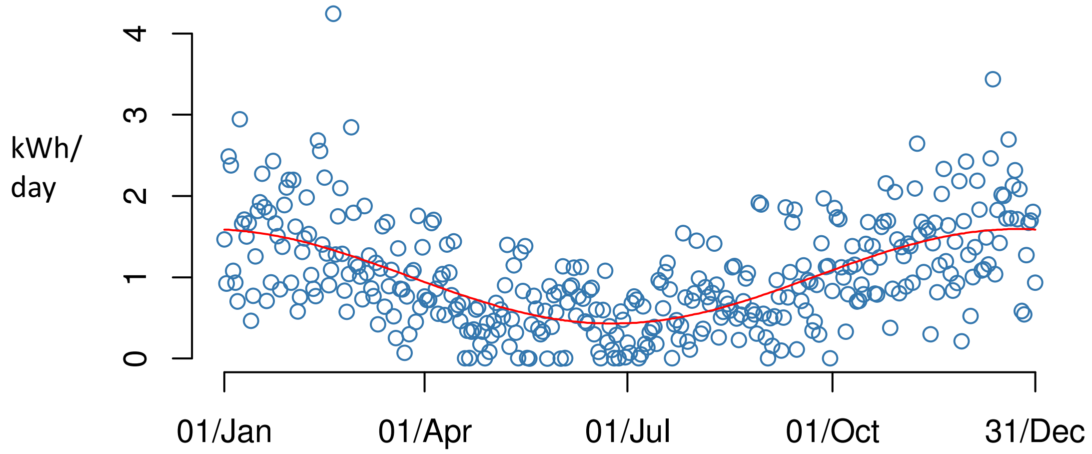
We calculated the daily energy use through the year for the three main washing appliances: washing machines, tumble dryers and dishwashers. The charts show that there was little variation through the year for dishwashers and washing machines, but very large differences for the tumble dryer.

In each of these charts, each point represents the average daily energy use for all the households with that appliance monitored on that day.

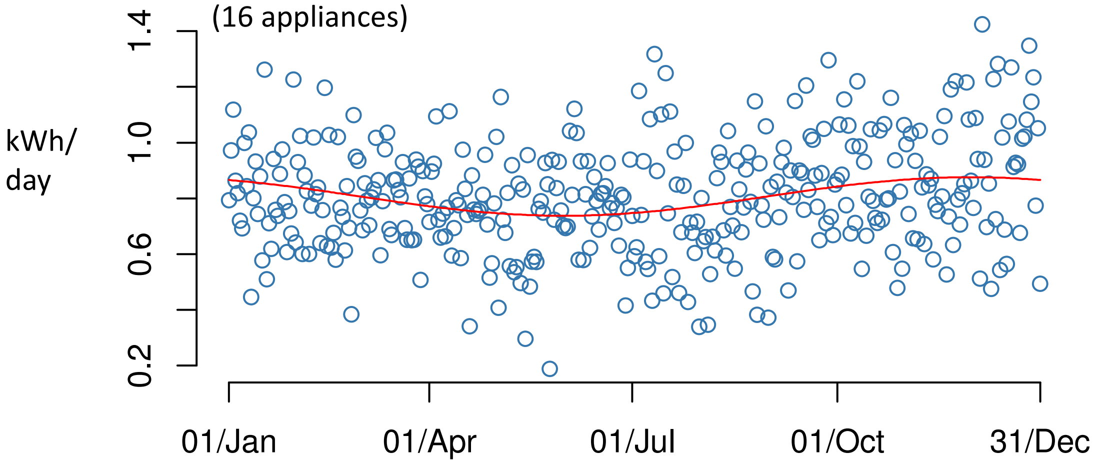
Seasonality curve for washing machines
(22 appliances)



Seasonality curve for tumble dryers
(11 appliances)

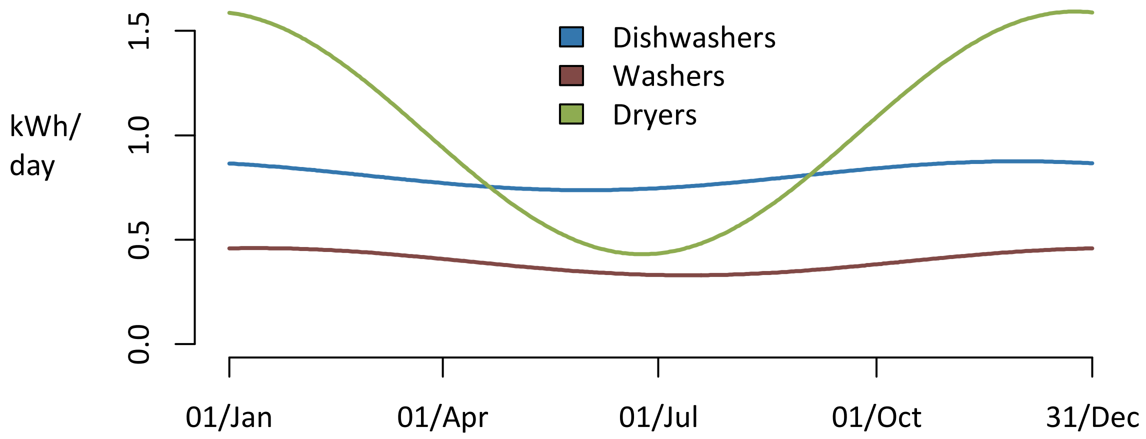


Seasonality curve for dishwashers
(16 appliances)



These results are summarised in the chart and table below.

Daily energy use for washing appliances through the year

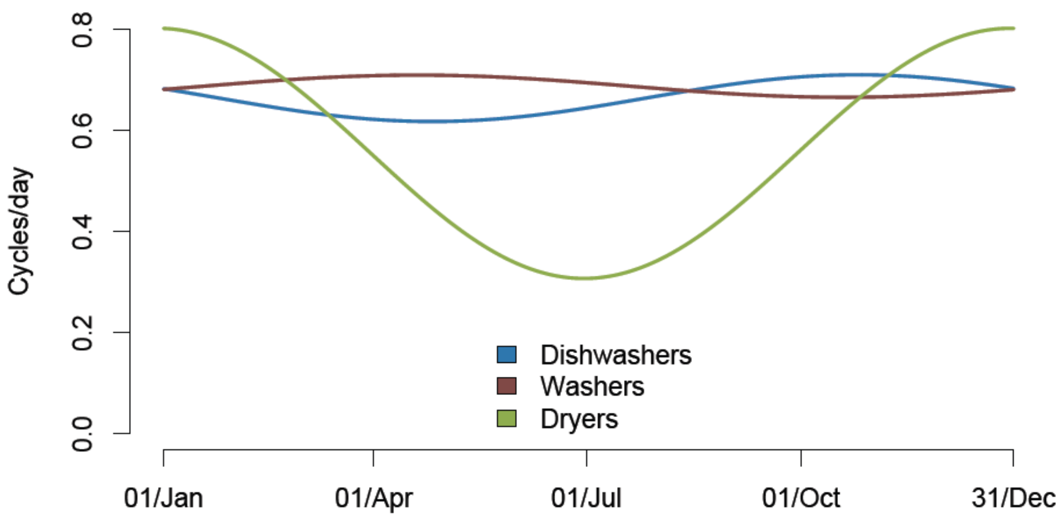


Appliance	Households in sample	Mean (kWh/day)	Peak day	Trough day	Range (max-min/mean)
Dishwashers	16	0.81	30/Nov	31/May	17%
Washing machines	22	0.39	12/Jan	13/Jul	33%
Tumble dryers	11*	1.01	24/Dec	24/Jun	115%

*Three more households had tumble dryers that were not monitored, so overall 54% of households had tumble dryers. Four had washer-dryers.

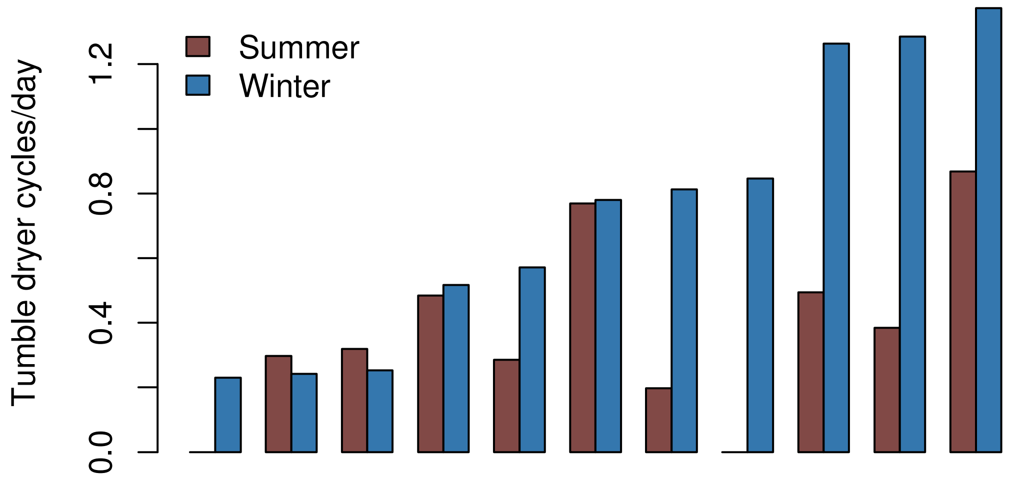
We looked at seasonal trends in use for tumble dryers, to see if the lower energy consumption in summer was due to being used less often or to less energy per use. We found that dryers were used less in summer, and the seasonal range in use was 90%, which accounts for most of the 115% range in energy consumption. The remaining difference could be because we wear heavier clothes in winter that retain more water when washed and therefore require more energy to dry.

Frequency of use for washing appliances through the year



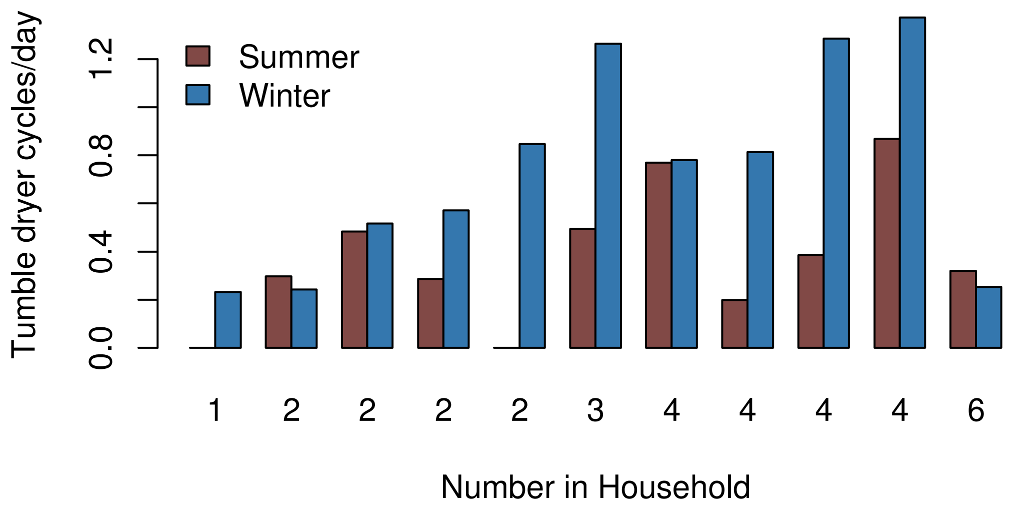
We also compared the frequency of use by each household in summer (13 weeks starting from June 22nd) versus winter (13 weeks starting from Dec 22nd). This showed that about half the households used their tumble dryers much less often in summer – but others did not. The households that used their tumble dryer most often in winter were more likely to avoid using it in summer. Conversely, households that did little washing were more likely to continue using a tumble dryer even in summer – possibly because they spend little time or money on washing, so they put little effort into avoiding dryer use.

Frequency of use for tumble dryers by household in summer and winter



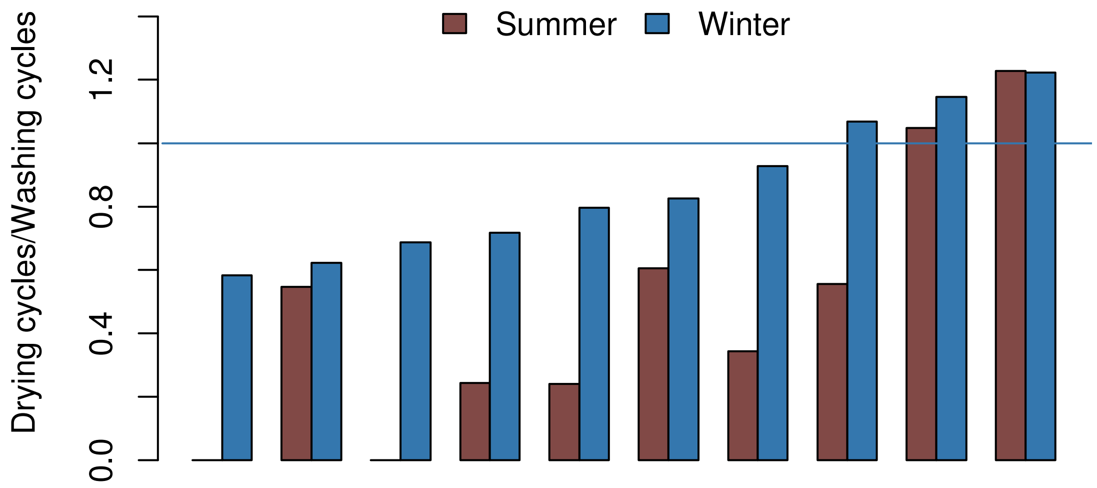
We looked for a relationship between seasonality in drying with household size and found nothing significant, though with such a small sample that is hardly surprising. The chart below shows the same data ordered by household size.

Frequency of use for tumble dryers by household, in summer and winter, by number in household



Finally we compared the relative frequency of washing and drying between households, in winter and in summer. In winter this ranged from 0.5 at the low end, meaning the dryer was used only after half the washes, to 1.2 at the high end – meaning the dryer was used more often than the washing machine. From inspection of house profiles, some extra drying cycles are probably due to the first run not being quite long enough to dry the clothes. However one household (a pensioner couple) sometimes ran the tumble dryer on days when they did not use the washing machine at all – perhaps after a hand wash. In five households the ratio was much lower in summer, meaning that they used alternative drying methods more often.

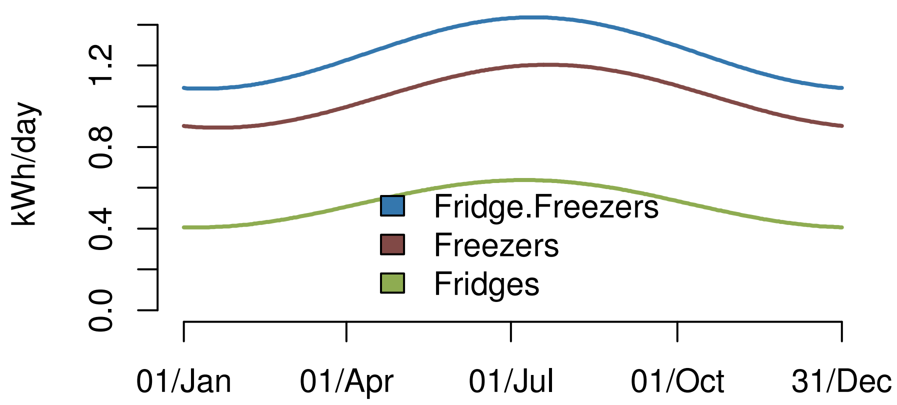
Ratio of dryer use to washing machine use in summer and winter



Cold appliances

Fridges and freezers use more energy in the summer than in the winter. The difference is larger for fridges because the energy used depends on the difference between the internal temperature and the ambient temperature: for a freezer running at least 35°C below room temperature an extra 5°C of cooling makes less difference than a fridge running at only 20°C below ambient. However, the seasonal difference for all appliances demonstrates the importance of keeping them in a cool place and well ventilated.

Variation in energy use by cold appliances through the year



Appliance	Households in sample	Mean (kWh/day)	Peak day	Trough day	Range (max-min/mean)
Fridge freezer	14	1.26	13/Jul	12/Jan	28%
Freezers	17	1.05	21/Jul	20/Jan	29%
Fridges	10	0.52	9/Jul	07/Jan	45%

NB. For this analysis we excluded two fridges that showed anomalous results:

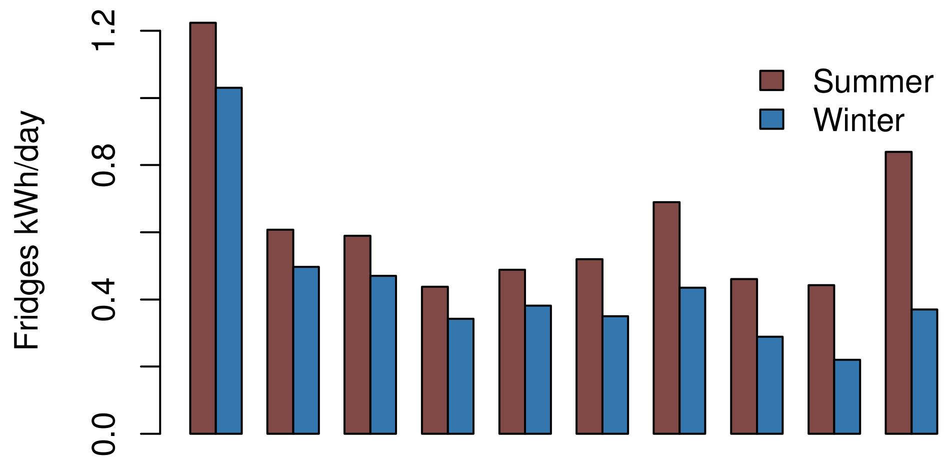
- One appeared to malfunction during the year (showing a rapid increase in energy use during January, and remaining high to the end of the monitoring period)
- One appeared to be replaced during the year (showing an abrupt fall in energy use)

Other Evidence on Fridges

Experimental results from two sample fridge freezers in Malaysia[52] showed that with each degree increase in ambient temperature the appliance uses an extra 47-53 Wh/day of electricity.

We compared the summer and winter energy consumption for each fridge. The difference between summer and winter varies significantly between households, suggesting that some are in cooler locations than others (in summer or winter). Four fridges used more than 50% more in summer time than in winter. Either they get very hot in summer or they are in a very cool place in winter.

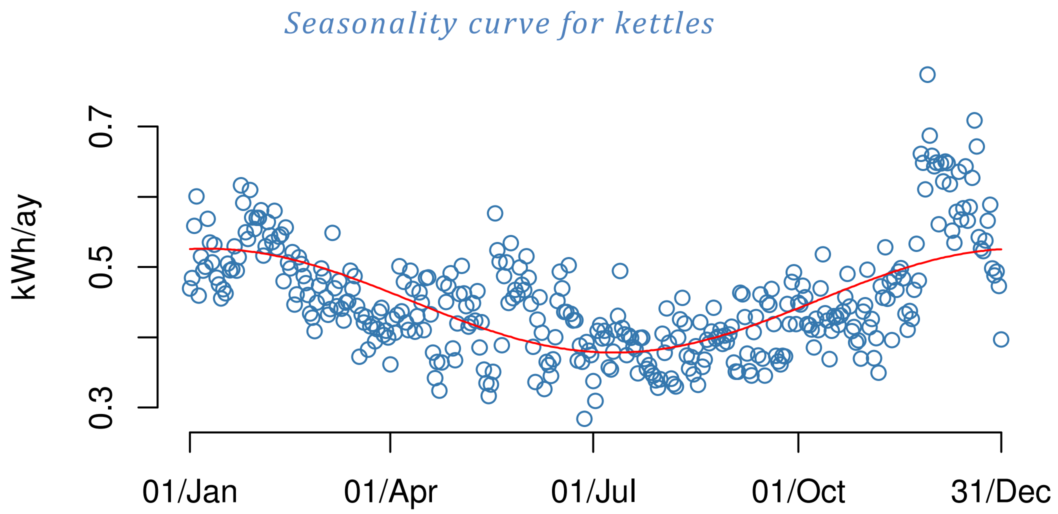
Energy use by fridges in summer and winter



[52] Saidur, R., Masjuki, H.H. and Choudhury, I.A. (2000) Role of ambient temperature, door opening, thermostat setting position and their combined effect on refrigerator=freezer energy consumption, Energy Conversion and Management, 43, 845-854.

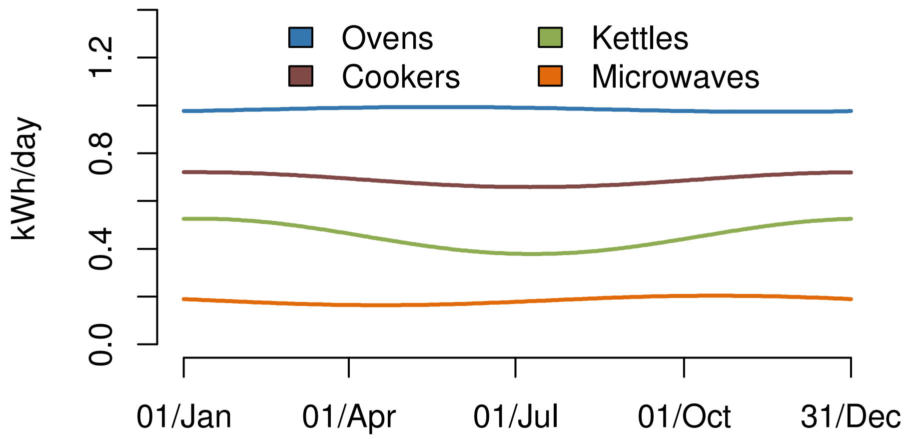
Cooking appliances

Use of cookers and ovens varies little through the year but kettles are used less in summer and more in winter.



NB. We excluded electric hobs from this analysis because there was only one household monitored for a year.

Appliance	Households in sample	Mean (kWh/day)	Peak day	Trough day	Range (max-min/mean)
Ovens	5	0.98	19/May	18/Nov	2%
Cookers	14	0.67	07/Jan	9/Jul	9%
Kettles	23	0.45	09/Jan	10/Jul	32%
Microwaves	23	0.18	18/Oct	18/Apr	22%



Recommendations and observations

■ Some households continue to use tumble dryers through the whole year, even in summer. Making more use of outdoor clothes lines could save up to 1 kWh/day/household April to October, and some of this could come from the peak period.

■ Fridges and, to a lesser extent, freezers, use considerably more energy in the summer than in the winter. Placing them in a cold place could save 0.1 kWh/day per appliance (based on half the difference between summer and winter energy use).

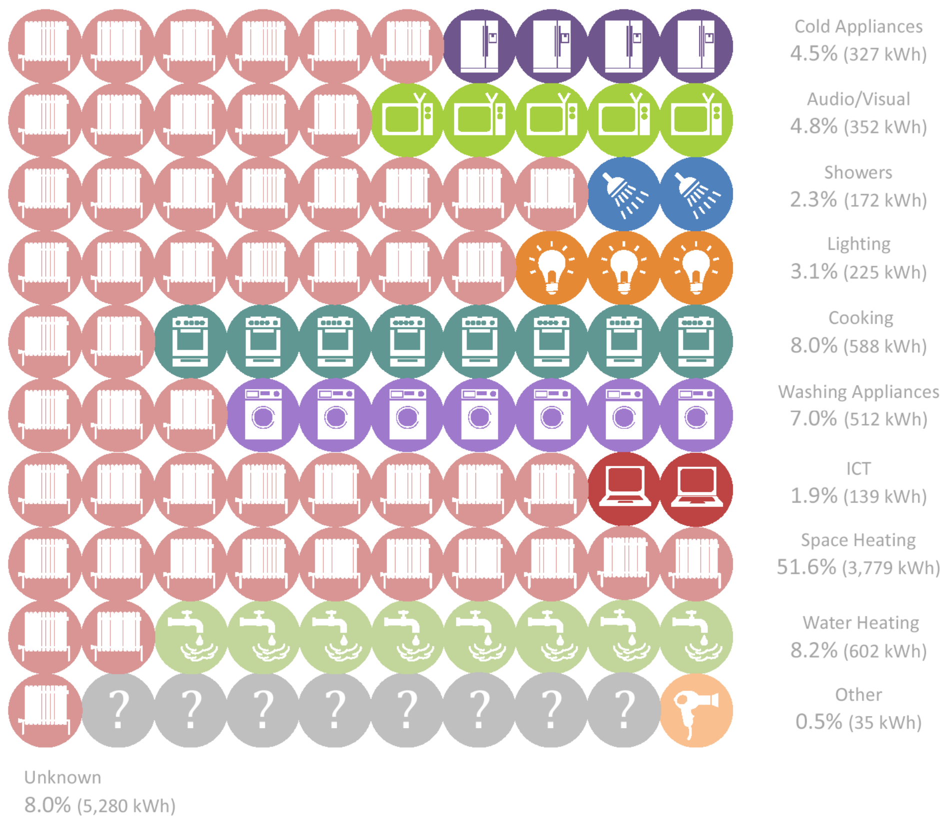
■ Replacing cold appliances (and especially fridges) with modern, efficient equipment would lead to bigger savings in summer than winter – savings about a third higher in summer.

■ Seasonal patterns of use are much less pronounced for cooking appliances than for refrigeration and washing appliances. Nearly all of the observed seasonal variation in 'cooking' energy comes from increased use of kettles in winter.

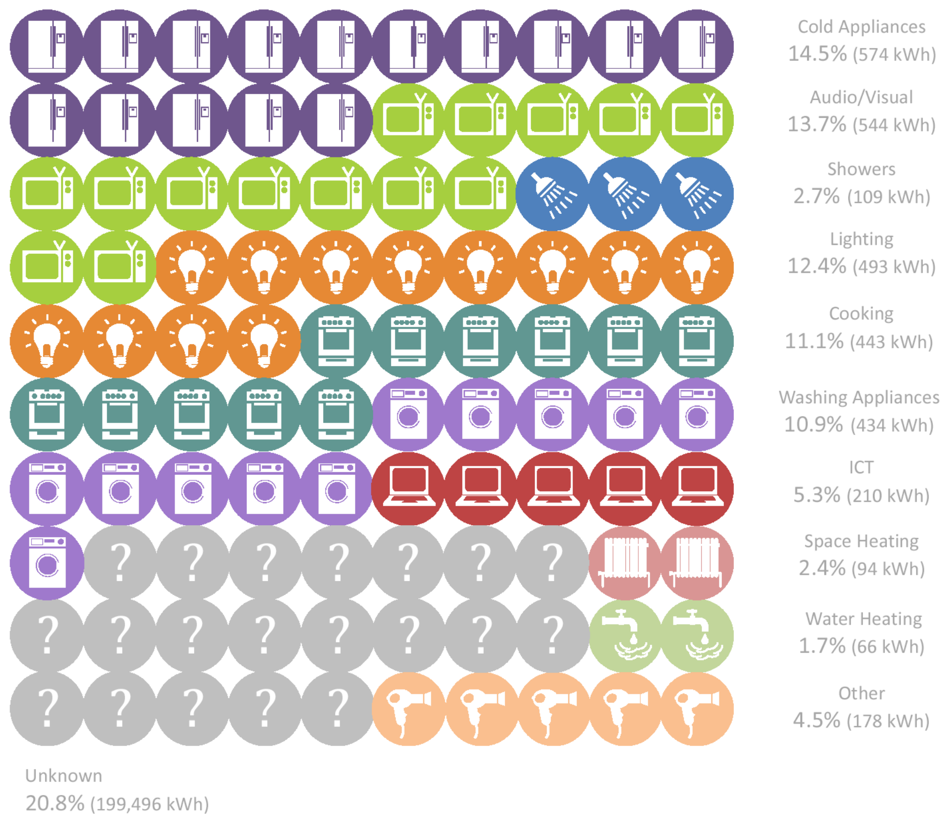
■ Increased uptake and use of tumble dryers would make a bigger impact on winter electricity use than in the summer. (Around three times as much energy used in December-January as in July.)

■ Conversely, there are much weaker seasonal patterns of use for dishwashers and washing machines.

Average electricity breakdown over year
9 homes with primary electric heating



Average electricity breakdown over year
241 homes without primary electric heating



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