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Determinants of high electrical energy demand in UK homes: Appliance ownership and use

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ABSTRACT

This paper provides an analysis of the appliance ownership and use factors contributing to high electrical energy demand in UK homes. The data were collected during a large-scale, city-wide survey, carried out in Leicester, UK, in 2009–2010. Annual electricity consumption and appliance ownership and use were established for 183 dwellings and an odds ratio analysis used to identify the factors that led to high electricity consumption. Many of the appliance ownership and use factors have not previously been studied for the UK domestic sector. The results of this study should be of key interest to government policy makers and energy supply companies interested in the underlying drivers of the highly positively skewed distribution of UK domestic electricity use. The study identifies those appliances that could be targeted for technical improvements or subjected to campaigns to encourage more energy efficient use in order to reduce electricity consumption among high demand households. This paper builds on earlier work by the current authors which identified the households (socio-demographic and dwelling characteristics) most likely to be high electricity consumers. The current work provides the basis for advice and guidance to those households that would enable them to, over time, reduce their electricity use.

1. Introduction

The UK domestic sector has experienced a general year-on-year rise in electricity use of around 1% since 1970. This expansion has been attributed to the increased ownership and use of electrical appliances [1]. The increase in electricity consumption for appliance use in the UK has been dramatic, increasing 211% from 1970 to 2011; an annual average growth rate of nearly 3% [1]. This has resulted in appliances' share of total domestic energy use increasing from less than 5% in 1970 to 13.9% in 2011.

This large growth has been attributed to increased ownership of appliances and increased use of appliances with, in particular, a greater use of cold appliances to store food [1]. These developments are the result of wider societal changes, such as, increased living standards and life expectancy, lifestyle changes, automation of jobs previously done by hand and increases in smaller and fragmented households [2,3]. The expansion of electricity consumption for appliances in the home is widely expected to continue [4–6].

To address energy conservation and climate change concerns, policymakers are now faced with the challenge of implementing measures to address this continuously evolving and increasingly energy intensive end-use. Therefore, there is growing interest, amongst the UK government and energy research community, in trying to understand the detail of electrical energy demand and in particular the factors that lead to the highly skewed distribution of UK domestic electricity use, in which the upper quartile of households uses almost half (48.5%) of the electricity supplied to the whole domestic sector [7–13]. High electricity consuming households also appear to be consuming more electricity over time, but in addition have the greatest potential for making energy savings [14,15]. It has been suggested that UK energy policy might focus on reducing the demand of these high consuming households in order to meet national energy reduction targets [11–15]. Therefore, understanding what drives high use in domestic buildings is important to support decisions about how to reduce electricity use and CO_2 emissions from this group.

This paper investigates the effects of appliance ownership (i.e. the presence and types of appliances in a home) and use (e.g., working hours per day, loads of clothes washing and drying per week, etc.,) on high electrical energy consumption in UK domestic buildings.

The data were collected during a large-scale, city-wide survey, undertaken in Leicester, UK, during 2009–2010, as part of the 4M

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project [16]. To the authors' knowledge, it was the first city-scale energy survey carried out in the UK.

Many previous studies worldwide have investigated the effects of appliance ownership and use on electricity consumption in domestic buildings [15,17–38]. A detailed international review and discussion of these effects is provided by Jones et al. [39]. In the UK however, only a few previous studies have been undertaken and these have primarily focused on the effects of ownership of office equipment and infotainment appliances, such as desktop and laptop computers, Wi-Fi routers, televisions (TVs) and set-top boxes.

From these UK studies, Baker and Rylatt [25] found that the ownership of desktop computers, TVs and set-top boxes were significant indicators of variations in the electricity consumptions of 148 UK households. Coleman et al. [40], in a study of 14 UK homes, found that on average around 23% of the households' electricity consumption was for office equipment and infotainment appliances and around 7% could be attributed to standby power modes. In a study of 72 UK dwellings, Firth et al. [11] identified four groups of appliances which were distinguishable by their temporal electricity use patterns: continuously on; in standby mode; in active use mode and cold appliances (fridges and freezers). Mansouri et al. [41] investigated the ownership and utilisation levels for some appliances among householders resident in the south-east of England. Terry and Palmer [42] examined how trends in ICT (i.e., desktop and laptop computers, monitors, printers and routers) use at home have affected household electricity consumption (daily electricity use, peak demand, base load, weekday vs. weekend use), as well as the potential for electricity savings from Wi-Fi routers.

This paper adds to the current UK literature and investigates the effects of appliance ownership and use of a broader range of appliances, which fell into seven distinct appliance categories: office equipment and infotainment, heating ventilation and air conditioning (HVAC), catering, washing, laundry, building and outdoors maintenance, and hygiene, beauty and leisure appliances. Many of the appliance ownership and use factors have not previously been studied for UK homes.

The current paper builds on earlier work by the same authors, which identified the socio-demographic and dwelling characteristics of households most likely to be high electricity consumers [7], and the current work now provides the basis for advice and guidance to those households that would enable them to, over time, reduce their electricity use.

2. Data and methods

2.1. Data collection: the 4M datasets

Initially, 1000 households living in the city of Leicester were approached to take part in the 4M study. Of these, 575 households subsequently completed a face-to-face survey which was conducted on behalf of the 4M team, between March and July 2009, by the National Centre for Social Research (NatCen). Households were selected randomly, after stratifying by percentage of detached homes and percentage of homes with no dependent children. This survey provided data about the ownership and use of major cooking appliances (electric oven, hob and range cooker) as well as electric showers.

During the initial household survey, participants were asked whether they would also like to take part in follow-up activities. Two follow-up activities have provided additional data for this paper. Firstly, regular electricity meter readings were taken in three phases between March 2009 and July 2010; 409 households agreed to provide meter readings. The first readings were taken during the NatCen house visit; the second was requested by letter; and the final reading was obtained by another house visit followed by a letter request, for those houses that could not be accessed when visited. The meter readings for each household were then used to obtain an annual electricity consumption figure for 2009; the method of doing this is described elsewhere in Ref. [7]. In total, annual electricity consumption values were obtained for 256 households. In addition to the meter readings, 241 households also signed a mandate which permitted access to their billed electricity use for 2009. Data was successfully obtained for 218 households, although this data was treated with caution as some meter 'readings' were actually just estimates. To verify that the residents were responsible for the electricity consumption in 2009, a check against their year of first residence was completed using data from the initial household survey. The data from both the meter readings and mandates were combined into a single dataset of 315 annual electricity consumptions. Where both meter reading and mandate data existed for a dwelling, the meter reading was used in preference.

Secondly, a self-reported, paper-based domestic appliance ownership and use survey was devised by the 4M team and administered to 504 households that had agreed to follow-up surveys. The survey was badged as part of the 'Living in Leicester' initiative to avoid any suggestion that energy demand was being studied. Households were asked to report the number of appliances they owned from a pre-defined list of the most common domestic appliances, give the size and type of their main TV, as well as openly report less common appliances. The survey also asked households to provide estimates of their use of desktop and laptop computers and TVs during weekdays and weekend days. They also reported the weekly number of loads of clothes washed, the temperature setting used and the weekly number of loads of clothes dried. Likewise the weekly dishwashing and temperature was reported. The survey was sent out by post in January 2010, followed by a reminder in February to those that had not yet responded. In total, 183 of the households returned a completed survey, giving a response rate of 36.3%. The data were manually input by the 4M researchers into an SPSS database. The appliance survey has provided the data about the ownership and usage patterns (except major cooking appliances and electric showers) for this paper.

It should be noted that this study is frequently based on self-reported data. This could lead to inaccuracies in the results obtained due to the participants' inability to accurately report data (recollection bias) and by their intentional incorrect reporting of information in order to conform to social norms or to please the researcher (social desirability bias).

The final dataset used in this study consisted of: 575 records for the ownership and use of major cooking appliances and electric showers; 315 annual electricity consumptions (256 from meter readings and 59 from mandates); and 183 records of the ownership and use of domestic electrical appliances. Owing to the patchy responses by households to all three components, the total sample size in different sections of this paper fluctuates depending on which data are being analyzed. 183 households produced a complete dataset.

2.2. Stratification of households

The 315 homes for which annual electricity consumptions were available were stratified into three equally sized groups (thirds). The 105 lowest consuming households were classified as the 'low electrical demand group', the middle 105 as the 'medium electrical demand group', and the highest 105 as the 'high electrical demand group'. The stratification resulted in households with annual electricity consumptions below 2544 kWh being classified in the 'low electrical demand group', those between 2544 kWh and 4041 kWh in the 'medium electrical demand group' and those greater than 4,041 kWh in the 'high electrical demand group'. This method of stratification has previously been used by other researchers

Table 1
Appliance taxonomy used in the odds ratio analysis.

Appliance taxonomy
Office equipment and infotainment appliance category
IT appliances
Computer
Desktop computer
Laptop computer
Imaging
Printer
Scanner
Copier
Facsimile machine
Networking
Wireless router
DSL
Ethernet HUB
Telephony appliances
Telephone
Telephone with answering machine
Mobile phones
Entertainment appliances
Television
CRT television
LCD television
Plasma television
Set top boxes
Digital set top box
Satellite set top box
Cable set top box
Internet set top box
Video and recording
DVD player
VCR player
Blu-ray player
DVD with VCR
Portable DVD player
Audio
Stereo system
Digital radio
Analogue radio
Clock radio
Personal CD player
Turntable
Speakers
MP3 docking station
Home music studio
Home theatre system
Record player
Video console
Video console
HVAC appliance category
Electric blanket
Portable electric heater
Patio heater
Electric towel rail
Hot tub/Spa/Jacuzzi
Desk fan
Cooker hood
Extractor fan
Ceiling fan
Air conditioning
Catering appliance category
Major cooking appliances
Electric oven
Electric hob
Small cooking appliances
Microwave
Grill plate
Deep fryer
Toaster
Sandwich toaster
Slow cooker
Steamer
Kettle
Blender
Food mixer
Juicer
Food processor
Bread maker
Coffee maker
Ice cream maker
Preservation and cooling appliances
Refrigerator
Fridge-freezer
Upright freezer
Chest freezer
Beer and wine cooler
Washing appliance category
Dishwasher
Laundry appliance category
Iron
Washing machine
Washer-dryer
Tumble-dryer
Building and outdoors maintenance appliance category
Vacuum cleaner
Security systems (Alarm)
Power tools
Electric lawn mowers
Garden strimmer
Hedge trimmer
Shredder
Indoor aquarium
Outdoor aquarium
Vivarium
Plant propagator
Dehumidifier
Hygiene, beauty and leisure appliance category
Electric shower
Hair dryer
Hair straighteners
Hot air styler
Hair clippers
Shaver

[7,11–13,31], therefore the current study maintains comparability with the existing body of literature. Jones and Lomas [7] provide a detailed analysis of how the stratification of the 4M sample into high, medium and low electrical demand groups compares with the stratification reported by others.

Because the aim of this study is to understand the effects of appliance ownership and use on the probability of a household having a high electrical energy demand, the low and medium consumption groups were merged for analysis purposes.

2.3. Odds ratio method

Odds ratio (OR) analyses were used to examine the influence of ownership and use on the electrical energy demand of the 4M households. The odds ratio method has previously been used by Jones and Lomas [7] in a study of the socio-economic and dwelling characteristics affecting high electricity demand in UK homes. OR is a statistical method that can be used in analyses where the dependent variable is binary (i.e., high electricity consumer or not) and the independent variables used to explain variations in the dependent variable are categorical (e.g., whether a household owns a CRT, LCD or Plasma screen TV).

An OR is a measure of the association between an exposure and an outcome. The OR represents the odds that an outcome will occur given a particular exposure, compared to the odds of the outcome occurring in the absence of that exposure [43]. In other words, ORs are used to compare the relative odds of the occurrence of the outcome of interest (a household being a high electricity consumer), given exposure to a factor of interest (e.g., total number of electrical appliances owned, working hours of the main television each day, temperature of clothes washing, etc.,). The OR can also be used to compare the change in probability of a household having high electricity consumption based on a change in the appliance ownership or use factor, for example the change in probability if the number of televisions owned by a household increases from one to two.

For each appliance ownership and use factor, the OR was calculated to indicate the probability that a household will be a high electrical energy user relative to a reference household in the same category. The reference for each factor was chosen for one of two reasons; either the household did not have the factor (e.g., no desktop computer owned, no refrigerator) or, the factor represented the majority of the sample.

For a given factor, the OR was the number of households with high electricity demand (>4041 kWh pa) divided by the number with low or medium demand (<4042 kWh pa), divided by the same ratio for the reference group [44]. Eq. (1) below shows an example of the odds ratio calculation for the ownership of a tumble dryer.

$$OR = \frac{TD_H / TD_{LM}}{NTD_H / NTD_{LM}} = \frac{TD_H \times NTD_{LM}}{NTD_H \times TD_{LM}} = \frac{31 \times 99}{19 \times 34} = \frac{3069}{646} = 4.75 (95\%CI = 2.38, 9.48) \quad (1)$$

where OR = Odds ratio; TD_H = Number of homes with a tumble dryer and high electric demand; TD_{LM} = Number of homes with a tumble dryer and low or medium electric demand; NTD_H=Number of homes with no tumble dryer and high electric demand; NTD_{LM} = Number of homes with no tumble dryer and low or medium electric demand. The numerical values are in Table 2.

An OR value of 1 indicates that households with a given appliance ownership or use are just as likely to be high electrical energy consumers as the households in the reference group. An OR greater than 1 indicates a higher probability that a household would be a high user compared to the reference group, whereas a ratio below 1 indicates that the probability is lower than for the reference group. In addition, the higher the value of the OR, the more likely it is that the households would be high consumers compared to the reference group.

The 95% confidence interval (CI) associated with each OR describes the uncertainty in the estimate [43]. Eq. (2) shows the formula for calculating the 95% CI for the ownership of a tumble dryer. A narrow CI indicates that the effect is known more precisely, whereas a wider interval indicates that the uncertainty is greater, but there may still be enough precision to draw inferences about the effect. A CI spanning the value 1 (e.g., CI = 0.5, 1.5) indicates that the influence of the factor on high electricity consumption is unclear, however it would be incorrect to interpret a CI spanning the value 1 as indicating evidence for no association between the factor and high electricity consumption altogether, because the width of the CI is influenced by sample size and the variability in the data. Large sample sizes tend to give more precise OR estimates than smaller ones [44,45]. The CI was taken into consideration when interpreting the effects.

$$\begin{aligned} CI_{+95\%} &= e^{\ln OR + 1.96\sqrt{\frac{1}{TD_H}+\frac{1}{NTD_H}+\frac{1}{TD_{LM}}+\frac{1}{NTD_{LM}}}} = e^{\ln 4.75 + 1.96\sqrt{\frac{1}{31}+\frac{1}{19}+\frac{1}{34}+\frac{1}{99}}} = 9.48 \\ CI_{-95\%} &= e^{\ln OR - 1.96\sqrt{\frac{1}{TD_H}+\frac{1}{NTD_H}+\frac{1}{TD_{LM}}+\frac{1}{NTD_{LM}}}} = e^{\ln 4.75 - 1.96\sqrt{\frac{1}{31}+\frac{1}{19}+\frac{1}{34}+\frac{1}{99}}} = 2.38 \end{aligned} \quad (2)$$

where $CI_{\pm 95\%}$ = Upper and Lower 95% Confidence Interval; OR = Odds ratio; TD_H = Number of homes with a tumble dryer and high electric demand; TD_{LM} = Number of homes with a tumble dryer and low or medium electric demand; NTD_H = Number of homes with no tumble dryer and high electric demand; NTD_{LM} = Number of homes with no tumble dryer and low or medium electric demand.

2.4. Appliance taxonomy

To structure the OR analyses, the appliance ownership and use factors were categorised with regard to the appliance type addressed, using a modification of the appliance taxonomy initially developed by Marjanovic et al. [46]. The hierarchical taxonomy provided a four tiered structure that subdivided the appliances into a number of clear and systematically grouped categories (Table 1). At the highest level the appliances were grouped into seven appliance categories (office equipment and infotainment, HVAC, catering, washing, laundry, building and outdoors maintenance and hygiene, beauty and leisure). Appliance categories were further divided into 10 subgroups (e.g., IT, telephony, entertainment appliances, etc.,). The IT and entertainment appliance subgroups only were further categorised into appliances with similar functions (e.g., computer, networking, television, etc.,). At the lowest level of the appliance taxonomy, the appliances in the homes were classified into 91 different appliance types.

3. Results and discussion

The results of the OR analysis are presented in Table 2. For each appliance category, the appliance types covered by the survey are listed and for many of these an indication of their use is also provided. The OR analysis was undertaken for 10 subgroups of appliance types (IT, telephony, entertainment, HVAC, small cooking, preservation and cooling, washing, laundry, building and outdoor maintenance and hygiene, beauty and leisure appliances), 15 individual appliance types and 17 appliance use patterns.

The number of households that owned the stated number of appliances or used their appliances with the frequency stated is given. Often, the total for all number of homes across all ownership levels is 183, because all households provided a response to that part of the appliance survey.[1] Of these, a total of 133 were low-medium electricity consuming households and 50 high consumption households. Sometimes, not all households answered a question, this was most often the case with frequency of use questions, and so the total is less than 183; an OR was still undertaken.[2]

Table 2 then gives the OR result and the 95% CI. Where the probability of the OR arising by chance is less than 1%, 5% or 10% this is indicated, with the 1% and 5% probabilities emboldened. The 95% CI indicates the range of values that the OR could be if a different sample of households were used in the study. If the 95% CI is narrow, the effect of the appliance ownership and use factor on high electricity demand is known more precisely and there is high confidence in the result obtained. A 95% CI that spans the value 1 indicates that the effect of the factor is less clear and should be treated with more caution.

[1] For example, 50 homes had 0–1 IT appliances (27% of 183), 24 had 2 (13%), 50 had 3 (27%), 28 had 4 (15%), 14 had 5 (8%), and 17 had 6 or more (10%); total 183.

[2] For example: 46 households used their main desktop computer on a weekday for 0–2 h (54% of 84), of which 35 were in the low-medium electricity consumption group and 11 in the high consumption group; 19 use their main computer for 2–4 h (23%), 11 low-medium and 8 high; and 19 for more than 4 h (also 23%), 12 low-medium and 7 high; total 84.

Table 2
Number of households with the stated ownership and use of appliances and the odds ratio results.

Factors	Households and percentage	Number of homes		Odds ratio (95% CI)
		<4041 kWh per annum (low-medium group)	>4041 kWh per annum (high group)	
All appliances				
Households owning stated number of appliances				
30 or less	108 (59%)	97 (73%)	11 (22%)	Reference
31–35	23 (13%)	17 (13%)	6 (12%)	**3.11** (1.02, 9.54)*
36–40	23 (13%)	8 (6%)	15 (30%)	**16.53** (5.72, 47.76)***
41–45	15 (8%)	6 (5%)	9 (18%)	**13.23** (3.96, 44.21)***
46+	14 (7%)	5 (3%)	9 (18%)	**15.87** (4.51, 55.88)***
Office equipment and infotainment appliance category				
IT appliances				
Households owning stated number of IT appliances				
0–1	50 (27%)	43 (32%)	7 (14%)	Reference
2	24 (13%)	19 (14%)	5 (10%)	1.62 (0.45, 5.75)
3	50 (27%)	38 (29%)	12 (24%)	1.94 (0.69, 5.43)
4	28 (15%)	18 (14%)	10 (20%)	**3.41** (1.13, 10.37)**
5	14 (8%)	7 (5%)	7 (14%)	**6.14** (1.65, 22.94)***
6+	17 (10%)	8 (6%)	9 (18%)	**6.91** (1.99, 23.95)***
Households owning stated number of desktop computers				
0	89 (49%)	68 (51%)	21 (42%)	Reference
1	82 (45%)	61 (46%)	21 (42%)	1.11 (0.55, 2.24)
2–3	12 (6%)	4 (3%)	8 (16%)	**6.48** (1.77, 23.67)***
Households using the main desktop computer for the stated number of hours on weekdays				
0–2 h	46 (54%)	35 (60%)	11 (42%)	Reference
2–4 h	19 (23%)	11 (19%)	8 (31%)	2.31 (0.74, 7.20)
4+ h	19 (23%)	12 (21%)	7 (27%)	1.86 (0.59, 5.88)
Households using the main desktop computer for the stated number of hours on weekend days				
0–2 h	35 (43%)	27 (49%)	8 (31%)	Reference
2–4 h	21 (26%)	15 (27%)	6 (23%)	1.35 (0.39, 4.63)
4+ h	25 (31%)	13 (24%)	12 (46%)	**3.12** (1.02, 9.48)***
Households owning stated number of laptop computers				
0	88 (48%)	76 (57%)	12 (24%)	Reference
1	68 (37%)	46 (35%)	22 (44%)	**3.03** (1.37, 6.69)***
2–3	27 (15%)	11 (8%)	16 (32%)	**9.21** (3.46, 24.54)***
Households using the main laptop computer for the stated number of hours on weekdays				
0–2 h	46 (55%)	33 (66%)	13 (40%)	Reference
2–4 h	17 (21%)	7 (14%)	10 (30%)	**3.63** (1.14, 11.56)**
4+ h	20 (24%)	10 (20%)	10 (30%)	2.54 (0.86, 7.52)*
Households using the main laptop computer for the stated number of hours on weekend days				
0–2 h	38 (45%)	26 (51%)	12 (36%)	Reference
2–4 h	21 (25%)	13 (25%)	8 (24%)	1.33 (0.44, 4.07)
4+ h	25 (30%)	12 (24%)	13 (40%)	2.35 (0.83, 6.65)
Telephony appliances				
Households owning stated number of telephony appliances				
0–1	40 (22%)	35 (26%)	5 (10%)	Reference
2	57 (31%)	51 (38%)	6 (12%)	0.82 (0.23, 2.91)
3	47 (26%)	31 (23%)	16 (32%)	**3.61** (1.19, 11.01)**
4	23 (13%)	12 (9%)	11 (22%)	**6.42** (1.85, 22.26)***
5+	16 (8%)	4 (4%)	12 (24%)	**21.00** (4.83, 91.26)***
Entertainment appliances				
Households owning stated number of entertainment appliances				
0–5	79 (43%)	66 (50%)	13 (26%)	Reference
6–10	89 (49%)	60 (45%)	29 (58%)	**2.45** (1.17, 5.15)**
11+	15 (8%)	7 (5%)	8 (16%)	**5.80** (1.79, 18.81)***
Households owning stated number of televisions				
1	74 (42%)	63 (49%)	11 (23%)	Reference
2	57 (32%)	44 (34%)	13 (28%)	1.69 (0.69, 4.12)
3	33 (19%)	16 (12%)	17 (36%)	**6.09** (2.39, 15.52)***
4–5	12 (7%)	6 (5%)	6 (13%)	**5.73** (1.56, 21.02)***
Main television type				
CRT	73 (42%)	61 (48%)	12 (26%)	0.47 (0.21, 1.05)*
LCD	75 (43%)	53 (42%)	22 (47%)	Reference
PLASMA	25 (15%)	12 (10%)	13 (27%)	**2.61** (1.03, 6.61)**
Main television size				
<32"	66 (43%)	55 (49%)	11 (26%)	REFERENCE
32"–39"	62 (40%)	43 (38%)	19 (44%)	2.21 (0.95, 5.13)*
40"+	27 (17%)	14 (13%)	13 (30%)	**4.64** (1.72, 12.55)***

Table 2 (*Continued*)

Factors	Households and percentage	Number of homes		Odds ratio (95% CI)
		<4041 kWh per annum (low-medium group)	>4041 kWh per annum (high group)	
Households using the main television for the stated number of hours on weekdays				
0–2 h	14 (8%)	11 (9%)	3 (6%)	0.58 (0.14, 2.37)
2–4 h	48 (28%)	36 (30%)	12 (26%)	0.71 (0.29, 1.71)
4–6 h	50 (30%)	34 (27%)	16 (34%)	Reference
6–8 h	20 (12%)	17 (14%)	3 (6%)	0.38 (0.10, 1.47)
8–10 h	15 (9%)	12 (10%)	3 (6%)	0.53 (0.13, 2.15)
10+ h	22 (13%)	12 (10%)	10 (22%)	1.77 (0.63, 4.95)
Households using the main television for the stated number of hours on weekend days				
0–4 h	38 (22%)	30 (25%)	8 (17%)	0.55 (0.20, 1.54)
4–6 h	40 (24%)	27 (22%)	13 (28%)	Reference
6–8 h	33 (20%)	23 (19%)	10 (21%)	0.90 (0.33, 2.44)
8–10 h	27 (16%)	20 (16%)	7 (15%)	0.73 (0.25, 2.15)
10+ h	31 (18%)	22 (18%)	9 (19%)	0.75 (0.31, 2.35)
HVAC appliance category				
Households owning stated number of HVAC appliances				
0	37 (21%)	32 (24%)	5 (10%)	Reference
1	44 (24%)	39 (29%)	5 (10%)	0.82 (0.22, 3.09)
2	41 (22%)	28 (21%)	13 (26%)	2.97 (0.94, 9.38)
3	29 (16%)	18 (14%)	11 (22%)	**3.91** (1.17, 13.05)**
4	17 (9%)	10 (8%)	7 (14%)	**4.48** (1.16, 17.27)**
5+	15 (8%)	6 (4%)	9 (18%)	**9.60** (2.37, 38.87)***
Catering appliance category				
Major cooking appliances				
Households owning stated number of major cooking appliances				
None	144 (46%)	108 (51%)	36 (34%)	Reference
Electric oven and/or electric hob and/or electric range cooker	171 (54%)	102 (49%)	69 (66%)	**2.03** (1.25, 3.30)***
Households using the electric oven for the stated number of hours on weekdays				
0–0.5 h	40 (26%)	33 (30%)	7 (16%)	0.54 (0.19, 1.52)
0.5–1 h	46 (30%)	33 (30%)	13 (30%)	Reference
1–2 h	36 (23%)	23 (21%)	13 (30%)	1.43 (0.56, 3.66)
2–3 h	13 (8%)	10 (9%)	3 (7%)	0.76 (0.18, 3.22)
3+ h	19 (13%)	11 (10%)	8 (17%)	1.85 (0.61, 5.63)
Households using the electric oven for the stated number of hours on weekend days				
0–0.5 h	25 (17%)	22 (21%)	3 (7%)	0.30 (0.08, 1.13)*
0.5–1 h	39 (26%)	29 (27%)	10 (22%)	0.75 (0.30, 1.88)
1–2 h	54 (36%)	37 (35%)	17 (38%)	Reference
2–3 h	21 (14%)	12 (11%)	9 (20%)	1.63 (0.58, 4.61)
3+ h	12 (7%)	6 (6%)	6 (13%)	2.18 (0.61, 7.74)
Households using the electric hob for the stated number of hours on weekdays				
0–0.5 h	38 (26%)	29 (28%)	9 (21%)	0.91 (0.34, 2.41)
0.5–1 h	51 (35%)	38 (37%)	13 (30%)	Reference
1–2 h	23 (16%)	10 (9%)	13 (30%)	**3.80** (1.35, 10.72)**
2+ h	35 (23%)	27 (26%)	8 (19%)	0.87 (0.31, 2.38)
Households using the electric hob for the stated number of hours on weekend days				
0-0.5 h	33 (22%)	25 (24%)	8 (18%)	1.05 (0.37, 2.97)
0.5–1 h	47 (32%)	36 (35%)	11 (25%)	REFERENCE
1–2 h	37 (25%)	20 (19%)	17 (39%)	**2.78** (1.09, 7.09)**
2+ h	31 (21%)	23 (22%)	8 (18%)	1.14 (0.40, 3.25)
Small cooking appliances				
Households owning stated number of minor cooking appliances				
1–3	62 (34%)	51 (38%)	11 (22%)	0.52 (0.24, 1.15)
4–6	96 (52%)	68 (51%)	28 (56%)	Reference
7+	25 (14%)	14 (11%)	11 (22%)	1.91 (0.77, 4.71)
Preservation and cooling appliances				
Households owning stated number of preservation and cooling appliances				
0-1	89 (49%)	75 (56%)	14 (28%)	Reference
2	68 (37%)	48 (36%)	20 (40%)	**2.23** (1.03, 4.84)**
3+	26 (14%)	10 (8%)	16 (32%)	**8.57** (3.23, 22.72)***
Households owning stated number of refrigerators				
0	99 (54%)	77 (58%)	22 (44%)	Reference
1+	84 (46%)	56 (42%)	28 (56%)	1.75 (0.91, 3.37)*
Households owning stated number of fridge-freezers				
0	65 (36%)	48 (36%)	17 (34%)	Reference
1+	118 (64%)	85 (64%)	33 (66%)	1.10 (0.55, 2.17)

Table 2 (*Continued*)

Factors	Households and percentage	Number of homes		Odds ratio (95% CI)
		<4041 kWh per annum (low-medium group)	>4041 kWh per annum (high group)	
Households owning stated number of upright freezers				
0	136 (74%)	108 (81%)	28 (56%)	Reference
1+	47 (26%)	25 (19%)	22 (44%)	**3.39** (1.67, 6.89)***
Households owning stated number of chest freezers				
0	148 (81%)	108 (81%)	40 (80%)	Reference
1+	35 (19%)	25 (19%)	10 (20%)	1.08 (0.48, 2.45)
Washing appliance category				
Households owning stated number of washing appliances				
0	139 (76%)	111 (83%)	28 (56%)	Reference
1	44 (24%)	22 (17%)	22 (44%)	**3.96** (1.93, 8.16)***
Households owning stated number of dishwashers				
0	139 (76%)	111 (83%)	28 (56%)	Reference
1	44 (24%)	22 (17%)	22 (44%)	**3.96** (1.93, 8.16)***
Households using the dishwasher for the stated number of loads per week				
0	7 (16%)	4 (19%)	3 (14%)	0.34 (0.05, 2.13)
1-2	12 (28%)	9 (43%)	3 (14%)	***0.15*** (0.03, 0.81)**
3-4	8 (19%)	3 (14%)	5 (22%)	0.75 (0.13, 4.49)
5+	16 (37%)	5 (24%)	11 (50%)	Reference
Temperature of dishwashing				
40 °C or less	8 (26%)	4 (31%)	4 (22%)	0.44 (0.07, 2.74)
41–59 °C	13 (42%)	4 (31%)	9 (50%)	Reference
60 °C or more	10 (32%)	5 (38%)	5 (28%)	0.44 (0.08, 2.46)
Laundry appliance category				
Households owning stated number of laundry appliances				
1–2	116 (63%)	96 (72%)	20 (40%)	Reference
3+	67 (37%)	37 (28%)	30 (60%)	**3.89** (1.97, 7.69)***
Households owning stated number of washing machines				
0	21 (11%)	16 (12%)	5 (10%)	Reference
1	162 (89%)	117 (88%)	45 (90%)	1.23 (0.43, 3.56)
Households owning stated number of washer-dryers				
0	165 (90%)	120 (90%)	45 (90%)	Reference
1	18 (10%)	13 (10%)	5 (10%)	1.03 (0.35, 3.04)
Households owning stated number of tumble dryers				
0	118 (64%)	99 (74%)	19 (38%)	Reference
1	65 (36%)	34 (26%)	31 (62%)	**4.75** (2.38, 9.48)***
Households undertaking the stated number of loads of clothes washing per week				
1–2	76 (42%)	67 (52%)	9 (18%)	Reference
3	41 (23%)	27 (21%)	14 (28%)	**3.86** (1.49, 9.97)***
4	16 (9%)	12 (9%)	4 (8%)	2.48 (0.66, 9.37)
5+	46 (26%)	23 (18%)	23 (46%)	**7.44** (3.01, 18.39)***
Temperature of clothes washing				
30 °C or less	47 (28%)	36 (29%)	11 (24%)	0.68 (0.31, 1.52)
31–40 °C	97 (58%)	67 (55%)	30 (65%)	Reference
41 °C or more	24 (14%)	19 (16%)	5 (11%)	0.59 (0.20, 1.72)
Households undertaking the stated number of loads of clothes drying per week in Summer				
0	40 (59%)	28 (76%)	12 (39%)	Reference
1–2	18 (26%)	6 (16%)	12 (39%)	**4.67** (1.42, 15.35)**
3+	10 (15%)	3 (8%)	7 (22%)	**5.44** (1.20, 24.70)**
Households undertaking the stated number of loads of clothes drying per week in Winter				
0	9 (13%)	6 (16%)	3 (9%)	Reference
1–2	25 (36%)	20 (52%)	5 (16%)	0.50 (0.09, 2.73)
3	12 (17%)	6 (16%)	6 (19%)	2.00 (0.33, 11.97)
4+	24 (34%)	6 (16%)	18 (56%)	**6.00** (1.13, 31.74)**
Building and outdoors maintenance appliance category				
Households owning stated number of building and outdoors maintenance appliances				
0–1	54 (30%)	45 (34%)	9 (18%)	Reference
2	52 (28%)	44 (33%)	8 (16%)	0.91 (0.32, 2.57)
3	27 (15%)	13 (10%)	14 (28%)	**5.38** (1.90, 15.24)***
4	18 (10%)	14 (11%)	4 (8%)	1.43 (0.38, 5.36)
5+	32 (17%)	17 (12%)	15 (30%)	**4.41** (1.63, 11.96)***

Table 2 (*Continued*)

Factors	Households and percentage	Number of homes		Odds ratio (95% CI)
		<4041 kWh per annum (low-medium group)	>4041 kWh per annum (high group)	
Hygiene, beauty and leisure appliance category				
Households owning stated number of hygiene, beauty and leisure appliances				
0	68 (37%)	54 (41%)	14 (28%)	Reference
1	65 (36%)	49 (37%)	16 (32%)	1.26 (0.56, 2.85)
2	33 (18%)	20 (15%)	13 (26%)	**2.51** (1.01, 6.25)**
3+	17 (9%)	10 (7%)	7 (14%)	2.70 (0.87, 8.36)*
Households owning stated number of electric showers				
0	154 (49%)	112 (53%)	42 (40%)	Reference
1+	161 (51%)	98 (47%)	63 (60%)	**1.71** (1.07, 2.76)**
Households using the electric shower for the stated number of showers per week				
0	14 (9%)	10 (10%)	4 (6%)	Reference
1–10	80 (50%)	57 (58%)	23 (37%)	1.01 (0.29, 3.54)
11–20	47 (29%)	27 (28%)	20 (32%)	1.85 (0.51, 6.77)
21+	20 (12%)	4 (4%)	16 (25%)	**10.00** (2.03, 49.30)***

Note: Reference represents the reference category. Odds ratios in **bold** indicate that the factor increases the likelihood that a household will be a high electricity consumer (lower bound of CI greater than unity), whereas those in ***bold italics*** indicate that a household is less likely to be a high consumer (upper bound of CI less than unity).

* Significant at the 10% level.

** Significant at the 5% level.

*** Significant at the 1% level.

Some salient observations from the OR analysis follow. In particular, to highlight where ownership or use means there is a significantly increased likelihood of a household being a high electricity consumer; where significant means at the 1% or 5% level. Similarities and differences from the observations of others are identified.

3.1. Appliance ownership

A household's ownership of electrical appliances alone will not directly affect electricity consumption, however, the number and types of appliances owned will define the physical infrastructure in which electricity consumption can occur. In other words, the greater number of appliances owned, the more opportunities that exist for electricity use. This was clear in the OR results, because in general, as the total number of appliances owned, as well as the ownership levels of specific appliances increased so too did the likelihood of high electrical energy demand.

The OR analysis indicated that households which owned more than 30 appliances (the mean number of appliances owned by respondents to the appliance survey) were significantly more likely to be high electrical energy consumers. Ownership of more than 36 appliances appears to be a strong influencing factor, indicated by the lower bound of the CIs all being well above unity.

In the IT appliances subgroup, the OR results showed that households owning four or more IT appliances or two or three desktop computers were significantly more likely to be high electricity consumers. For laptop computers, it was observed that as ownership levels increased, so too did the likelihood of high electrical energy demand. These findings are consistent with a number of previous studies [15,20,25,29]. This result may relate to the fact that desktop computers have a relatively high annual electricity use (166 kWh) in an average UK home [10]. In addition, owning a desktop or laptop computer almost certainly increases the ownership of other compatible IT appliances, such as printers, scanners and routers, all of which will further contribute to a higher total household electricity use.

In the telephony appliances subgroup, the OR results indicated that households with three or more telephony appliances were significantly more likely to be high electrical energy users than those with none or one.

The OR results for ownership of entertainment appliances showed that the more entertainment appliances owned, the higher the probability that a household will have a high electricity demand. More specifically, households owning three or more TVs were significantly more likely to be high consumers. Other earlier studies have also concluded that homes with a TV have significantly higher electricity consumption [15,19,25,28–30,38]. The greater probability of high electrical energy consumption can probably be attributed to the simultaneous use of TVs by different occupants. Also, households with more than two televisions may use these for purposes other than just watching TV, such as a display screen for a video games console or a desktop computer.

The similar probability of high consumption by households owning either one or two televisions could indicate that the electricity consumption for TV use is simply split between the two devices. In fact, a second TV with lower power consumption than the main TV could reduce electricity use by transferring some TV use to the lower power consuming device.

The choice of the main television screen type was also observed to have a significant impact on the likelihood of high consumption. Households owning a plasma screen were more likely to be high electricity consumers than those with an LCD screen. No variation in probability was identified between households with CRT and LCD screens. This finding is perhaps explained by the higher mean operational power demand of plasma screens (246 W) compared to CRT (57 W) and LCD (97 W) screens [10]. In addition, the reduced probability of high consumption among dwellings with a CRT as opposed to a plasma screen TV could highlight a possible income effect, as CRT TVs are no longer manufactured; households that own them are unlikely to have recently replaced their main television. Also, the ownership of an older style CRT screen may be associated with older or retired residents. The current authors' earlier research found a strong effect of income and age on high electricity use [7].

The size of the main television was also found to have a significant influence on electrical energy demand. The increased likelihood of high electricity use among homes with a main television 40" or larger is likely to be related to the screens' high operational power consumption. Also larger TVs generally have a higher purchase price, which could indicate that the homes possessing TVs 40" or larger have a greater wealth, which has been shown to positively affect electricity consumption [7,18,47].

In the HVAC appliance category, the ownership of three or more HVAC appliances was found to have a significant influence on the probability of a household being a high electricity user.

In the major cooking appliances subgroup, the OR results showed that cooking with electricity, doubled the probability of being a high electricity consumer compared to using alternative fuel types. In this case, electric cooking refers to ovens, hobs and range cookers. On the contrary, the ownership of small cooking appliances had no significant effect on high electricity consumption. This may indicate that the annual electricity use of such appliances, kettles, microwaves and toasters, etc., is similar regardless of the overall total electricity consumption of a dwelling. Furthermore, supplementary appliances, like slow cookers, food processors and bread makers may be used infrequently and therefore consume little or no additional electricity.

In the preservation and cooling appliances subgroup, the OR results indicated that as the number of preservation and cooling appliances increases, so too does the probability of being a high electricity consumer. The OR results also showed that upright freezers were the only single preservation and cooling appliance that significantly increases the likelihood of a dwelling having high electricity consumption. This result suggests that, with the exception of upright freezers, multiple ownership of preservation and cooling appliances is responsible for driving the highest domestic electricity consumptions. This is because preservation and cooling appliances are widely owned and contribute to a similar baseline electricity use.

Households with a dishwasher were almost four times more likely to be high electricity consumers. The significant positive relationship between dishwasher ownership and electricity demand has been consistently found by previous researchers [15,24,28,29–31,34,38]. The increased likelihood relates to the additional electricity consumption, around 294 kWh per year in the average UK home [10], resulting from automating rather than manually dishwashing. Also, households that wash dishes by hand, with the exception of homes with electric water heating, do not consume any electricity for this task as the hot water is probably provided by a gas fuelled boiler. Furthermore, as a dishwasher is a non-essential appliance, dwellings choosing to own the device may have higher household incomes or have a greater number of occupants generating more dirty dishes etc. Both of these socio-economic characteristics were previously observed to increase the likelihood of high consumption [7].

In the laundry appliance category, the OR results revealed that homes with three or more laundry appliances were significantly more likely to be high electricity users. In addition, the ownership of a tumble dryer increased the probability of high electrical demand. This can be attributed to the additional electricity use required for drying clothes, which for the average UK home equates to 394 kWh per annum [10]. The high impact of tumble dryer ownership on electrical energy demand has been the focus of extensive research [15,24,29,30–32,38]. The ownership of a tumble dryer might also be associated with family size and composition. The number of occupants and presence of children and teenagers have previously been found to have a significant impact on high electrical energy consumption [7].

Households owning three or five or more building and outdoors maintenance appliances were significantly more likely to have a high electrical energy demand.

In the hygiene, beauty and leisure appliance category, the ownership of an electric shower was found to significantly increase the likelihood of high electricity consumption. Despite being used for only a short time, as electric showers are likely to have the highest power consumption of any household electrical end-use (typically 7–11 kW), it is perhaps understandable that dwellings with at least one electric shower should have a greater likelihood of high electrical energy demand, compared to those without any. Also, households without an electric shower, probably heat the hot water used for showering with a gas fuelled boiler, thereby further limiting electricity consumption.

3.2. Appliance use

The number of appliances owned by a household only partially reflects the effects of domestic appliances on household electricity consumption. It is also necessary to consider the duration of appliance use by the building occupants. Previously, Bedir et al. [18] found that that the frequency of use of appliances explained 37% of the variance in electricity consumption between domestic buildings, however, it has been acknowledged by other researchers [18,22,29,37] that little research has been undertaken to assess the influence of appliance use on the total electrical energy demand of residential buildings.

Only households using their main desktop computer for more than four hours on a weekend day or main laptop for more than two hours on a weekday were more likely to be high consumers. The lack of a more general relationship between the use of the main desktop and laptop computer and high electricity consumption may be attributed to the variations in power demands of different models of desktop and laptop computer and the proportion of time in which the appliances are defined as working but are actually operating in standby power modes.

The working hours of the main television had no influence on the likelihood that a dwelling would have high electricity consumption. The lack of influence of the occupants' use of the main television is consistent with the earlier ownership results that showed that only homes with three or more TVs had an increased probability of high electricity consumption. In addition, the absence of an effect could relate to variations in the power consumptions of the main TV, whereby, a lower powered, smaller CRT TV could have a higher number of working hours, but have less electricity use, than a higher powered, larger plasma screen TV used for a shorter duration.

The OR results found that, in general, the number of hours an electric oven is used each day had no effect on the probability of high electricity use. Similar results were obtained for the effect of the working hours of the electric hob. This result is perhaps unexpected as the OR result for electric cooking demonstrated a significant effect on high electrical energy use in residential buildings. The current finding may be explained by the variable power demands of different oven and hob types. Also, the current results do not take into account the specific cooking practices of the occupants, for example, the working hours do not reflect the number of electric hobs used (normally up to four) or the temperature settings chosen; these additional factors will have a significant effect on the electricity consumed.

The OR results showed that the likelihood of a household being a high electricity consumer was unaffected by the amount of dishwashing and the temperature settings chosen. Earlier research however, has shown a significant correlation between the duration of use of the dishwasher and electricity demand [18,29]. The current conflicting results could be attributed to the fact that, frequency of use, rather than duration of use was requested by the appliance survey. The frequency of dishwashing loads may not be indicative of the actual operative hours. Occupants undertaking more loads of dishwashing on a quick wash setting may use less electricity than those using the dishwasher less but on an intensive wash setting. Furthermore, the number of loads of dishwashing does not stipulate the temperature chosen to wash the dishes. Households using the dishwasher more, but at a cooler washing temperature could feasibly use less electricity.

Regarding the unclear effect of the choice of dishwasher temperature settings on the probability of high consumption, a possible explanation may again relate to the lack of information about the occupants' operation of the dishwasher, as the impact of a higher temperature setting may be negated by less use. Also, the temperature settings data are probably subject to self-report error, firstly, occupants may use multiple temperature settings, therefore does the temperature indicated reflect an average or the most recent temperature used. Secondly, dishwashers can have very diverse programming interfaces, some may stipulate the temperature in degrees centigrade, but others numerically on a scale from 1 to 5, or even descriptively (e.g. hot, cold or economy), the latter classifications will make it difficult for the occupants to report the exact temperature without referring to the user manual.

In general, the OR results showed that as households do more clothes washing, their probability of being a high consumer increases. The temperature selected for clothes washing had no clear effect, which may be due to lack of specificity in the responses or self-reporting error (see dishwashing above). The same also applied to the loads of clothes drying per week in the summer, but only households undertaking four or more loads of drying per week in the winter were more likely to be high consumers. This may indicate that whilst some winter use of drying appliances is quite common in UK homes, summer use is much less so; using a dryer or washer-dryer in the summer, rather than drying laundry outside, is likely to lead to high electricity consumption.

Households taking more than twenty-one electric showers each week were found to have a significantly increased probability of high electricity use. This result can almost certainly be attributed to the high power demand of electric showers (typically 7–11 kW). Moreover, the number of showers taken is likely to be correlated with the number of occupants residing in a dwelling and whether the family composition includes children and teenagers; these are both factors that have been previously been shown to have a significant effect on the likelihood of high electrical energy demand [7].

4. Applications for the research

The results of this study should be of key interest to government policy makers and energy supply companies interested in the underlying drivers of the highly skewed distribution of UK domestic electricity use. The study identifies the appliance ownership and use factors responsible for driving the highest electricity consumptions in UK houses. These appliances or use characteristics could be targeted to reduce electricity demand amongst the user group.

Two main avenues for demand reduction exist. Firstly, technical improvements can be made to increase the energy efficiency of the appliances responsible for high electrical energy use, by decreasing the power required to deliver services or functions. The findings of this study support the introduction of minimum energy performance standards (MEPS). Although MEPS already exist for some appliance types (e.g., refrigerators, washing machines and televisions), a number of appliances identified to be contributing to high electricity consumption are currently exempt from this policy. Therefore, the range of appliances for which MEPS are required could be extended, in addition to, continuous improvement from appliance manufacturers in line with the development of new technology. Secondly, motivating more energy efficient behaviour amongst the occupants of high demand homes; which would include influencing both peoples' appliance use (e.g., switching off standby, reducing duration of operation) as well as their purchasing behaviours (e.g., buying more energy efficient appliances).

The previous paper by the current authors [7] identifies the households most likely to be high electricity consumers (socio-demographic and dwelling characteristics), this paper provides the basis for advice and guidance to those households that would enable them to, over time, reduce their electricity use.

5. Limitations and future research

This study has contributed to an improved understanding of the appliance ownership and use factors driving high electrical energy consumption in UK homes. The results were obtained based on a relatively small sample size (183 dwellings), in a single UK city and therefore extrapolating the results to the wider population of UK homes may not be appropriate. A larger national-scale study of appliance ownership and use would therefore be a valuable extension to the current work and could also be used to validate the findings of the current study.

The reliability of the self-report data provided by the survey respondents is an overarching concern for all appliance use surveys. The accuracy of the data may be affected by both the respondents' inability to report their usage reliably but also by intentionally adjusting their actual usage to appear more energy efficient. For example, the participants of the survey may have understated their actual main television working hours because they did not want to feel judged or reveal their actual behaviour to the researchers. Also, given the energy-related nature of the appliance survey, the participants could have been aware of the underlying motives of the researchers and may have chosen to report more energy efficient behaviors, such as, washing laundry at a cooler temperature (e.g., 30 °C).

The measurement of appliance usage, rather than adopting self-reported usage, would remove reporting bias, especially if ownership was based on an independent in-house survey. Such an approach is relatively straight forward for a small number of homes and short monitoring periods, but it can be prohibitively expensive for a large number of homes, with many monitored appliances and long monitoring periods (for example to record annual energy usage). Throughout the results and discussion, the current authors have, where possible, compared the results obtained in this study with those of others to highlight where consistent results have been obtained. Where variations from previous studies have been identified, possible explanations have been suggested but these results should be treated with more caution and further research is required for corroboration.

This paper has investigated two of the three factors that influence appliance electricity consumption (appliance ownership and use). The power demands of the appliances in different power modes (i.e., active and standby) will also determine the amount of electricity that is used. It is therefore recommended that further research might involve an appliance monitoring study to capture the impact of this additional factor. Such a survey would also improve our understanding of the temporal nature of appliance use in high consuming households and the ability for load shifting of this high demand to smooth demand on the supply network. This information would be of particular interest to energy supply companies for the future planning of the UK energy supply network with increased low carbon power generation.

6. Conclusions

This paper provides an analysis of the appliance ownership and use factors contributing to high electrical energy demand in UK homes. The data were collected during a large-scale, city-wide, survey carried out in Leicester, UK, during 2009–2010, as part of the 4M project. To the authors' knowledge, it is the first city-scale energy and appliance survey carried out in the UK. An odds ratio (OR) analysis was used to investigate the effects of the appliance ownership and use factors on the electricity consumption of the

183 UK houses. Many of the appliance ownership and use factors have not previously been studied in the UK context.

The results from the study suggest that households owning more than thirty appliances have an increased probability of having a high electrical energy demand. More specifically, households likely to be high electricity consumers own: four or more items of IT equipment; more than five entertainment items; an electric oven, hob or range; two or more preservation and cooling appliances; or three or more laundry appliances.

With respect to the ownership of specific appliances, households likely to be high consumers own: two or three desktop computers; one or more laptop computers; three or more TVs; a main plasma screen TV; a main TV 40″ or larger; an upright freezer; a dishwasher; a tumble dryer; or an electric shower.

The OR findings for appliance use showed that households are likely to be high consumers if they use their: main desktop computer for more than four hours each day at the weekend; main laptop computer for more than two hours each day during weekdays; electric hob between one and two hours on a weekday and at the weekend; washing machine for five or more loads each week; clothes dryer once or more each week in the summer or four or more times each week in the winter; or take more than twenty-one electric showers each week.

A previous paper by the current authors identified the households most likely to be high electricity consumers (socio-demographic and dwelling characteristics), this paper provides the basis for advice and guidance to those households, by policy makers and energy companies, that would enable them to, over time, reduce their electricity use.

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References

[1] DECC, (Department for Energy and Climate Change), United Kingdom Housing Energy Fact File 2012 [online], Publication URN: 12D/354. Available at URL: https://www.gov.uk/government/uploads/system/uploads/attachmentdata/file/201167/ukhousingactfile2012.pdf/>, 2012 (accessed 25.09.15).
[2] B. Boardman, S. Darby, G. Killip, M. Hinnells, C.N. Jardine, J. Palmer, G. Sinden, 40% House [online], Environmental Change Institute, University of Oxford, UK. Available at URL: http://www.eci.ox.ac.uk/research/energy/downloads/40house/40house.pdf/>, 2005 (accessed 17.11.15).
[3] H. Herring, Electricity use in minor appliances in the UK, Energy 20 (7) (1995) 705–710.
[4] EST. (Energy Saving Trust), The Elephant in the Living Room: How Our Appliances and Gadgets are Trampling the Green Dream: An Update to the Rise of the Machines, EST, Publications London, 1–36, Available at URL: http://www.energysavingtrust.org.uk/Publications2/corporate/Research-and-insights/The-elephant-in-the-living-room/>, 2006 (accessed 25.09.15).
[5] IEA. (International Energy Agency), Gadgets and Gigawatts: Policies for Energy Efficient Electronics IEA Publications, SBN 978-92-64-05953-5, France 2009 Available at URL: http://www.iea.org/publications/freepublications/publication/gigawatts2009-1.pdf/> (accessed 17.11.15).
[6] EST (Energy Saving Trust), The rise of the machines: a review of energy using products in the home from the1970 to today, EST Publications, London, (2006).
[7] R.V. Jones, K.J. Lomas, Determinants of high electrical energy demand in UK homes: Socio-economic and dwelling characteristics, Energy Build. 101 (8) (2015) 24–34.
[8] BRE (Building Research Establishment), Research Project: Analysis of energy use and carbon emissions from high consumption households [online] BRE: Contract N(304702, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/48192/3152-research-project-high-consumption.pdf 2008 (accessed 25.09.13).
[9] DECC (Department for Energy and Climate Change, Raw data of distribution analysis of domestic electricity and gas consumption in Great Britain 2011 [Personal communication].
[10] J.P. Zimmermann, M. Evans, J. Griggs, N. King, L. Harding, P. Roberts, C. Evans, Household Electricity Survey A study of domestic electrical product usage [online]. Intertek Report R66141 2012, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/208097/10043_R66141HouseholdElectricitySurveyFinalReportissue4.pdf (accessed.25.09.14).
[11] S.K. Firth, K.J. Lomas, A.J. Wright, R.D. Wall, Identifying trends in the use of domestic appliances from household electricity consumption measurements, Energy Build. 40 (5) (2008) 926–936.
[12] A.J. Summerfield, R.J. Lowe, H.R. Bruhns, J.A. Caeiro, J.P. Steadman, T. Oreszczyn, Milton keynes energy park revisited: changes in internal temperatures and energy usage, Energy Build. 39 (7) (2007) 783–791.
[13] A.J. Summerfield, A. Pathan, R.J. Lowe, T. Oreszczyn, Changes in energy demand from low-energy homes, Build. Res. Inf. 38 (1) (2010) 42–49.
[14] S.K. Firth, K.J. Lomas, A.J. Wright, Targeting household energy-efficiency measures using sensitivity analysis, Build. Res. Inf. 38 (1) (2010) 25–41.
[15] F. McLoughlin, A. Duffy, M. Conlon, Characterising domestic electricity consumption patterns by dwelling and occupant socio-economic variables: an Irish case study, Energy Build. 48 (2012) 240–248.
[16] K.J. Lomas, M.C. Bell, S.K. Firth, K.J. Gaston, P. Goodman, J.R. Leake, A. Namdeo, M. Rylatt, D. Allinson, Z.G. Davies, J.L. Edmondson, F. Galatioto, J.A. Brake, L. Guo, G. Hill, K.N. Irvine, S.C. Taylor, A, Tiwary, 4 M: measurement; modelling; mapping and management—the carbon footprint of UK cities, in: Low Carbon Cities: Proceedings of International Society of City and Regional Planners, ISOCARP 2010 The Hague, Netherlands, 2010, pp. 168–191.
[17] D.R. Carlson, H. Scott Matthews, M. Bergés, One size does not fit all: averaged data on household electricity is inadequate for residential energy policy and decisions, Energy Build. 64 (2013) 132–144.
[18] M. Bedir, E. Hasselaar, L. Itard, Determinants of electricity consumption in Dutch dwellings, Energy Build. 58 (2013) 194–207.
[19] A. Kavousian, R. Rajagopal, M. Fischer, Determinants of residential electricity consumption: using smart meter data to examine the effect of climate, building characteristics, appliance stock, and occupants' behavior, Energy 55 (2013) 184–194.
[20] S. Zhou, F. Teng, Estimation of urban residential electricity demand in China using household survey data, Energy Policy 61 (2013) 394–402.
[21] A. Carter, R. Craigwell, W. Moore, Price reform and household demand for electricity, J. Policy Model. 34 (2) (2012) 242–252.
[22] T.F. Sanquist, H. Orr, B. Shui, A.C. Bitter, Lifestyle factors in U.S. residential electricity consumption, Energy Policy 42 (2012) 240–248.
[23] D. Wiesmann, I. Lima Azevedo, P. Ferrão, J.E. Fernández, Residential electricity consumption in Portugal: findings from top-down and bottom-up models, Energy Policy 39 (5) (2011) 2772–2779.
[24] E. Leahy, S. Lyons, Energy use and appliance ownership in Ireland, Energy Policy 38 (8) (2010) 4265–4279.
[25] K.J. Baker, R.M. Rylatt, Improving the prediction of UK domestic energy-demand using annual consumption-data, Appl. Energy 85 (6) (2008) 475–482.
[26] K. Louw, B. Conradie, M. Howells, M. Dekenah, Determinants of electricity demand for newly electrified low-income African households, Energy Policy 36 (8) (2008) 2812–2818.
[27] G.K.F. Tso, K.K.W. Yau, Predicting electricity energy consumption: a comparison of regression analysis, decision tree and neural networks, Energy 32 (9) (2007) 1761–1768.
[28] K. Genjo, S. Tanabe, S. Matsumoto, K. Hasegawa, H. Yoshino, Relationship between possession of electric appliances and electricity for lighting and others in Japanese households, Energy Build. 37 (3) (2005) 259–272.
[29] F. Bartiaux, K. Gram-Hanssen, Socio-political factors influencing household electricity consumption: a comparison between Denmark and Belgium, What Works & Who Delivers?: Proceedings of the ECEEE 2005 Summer Study, European Council for an Energy Efficient Economy [online] (2005) 1313–1325 (accessed 25.09.14). http://www.eceee.org/library/conferenceproceedings/eceeeSummerStudies/2005c/Panel6/6131bartiaux/paper.
[30] B.M. Larsen, R. Nesbakken, Household electricity end-use consumption: results from econometric and engineering models, Energy Econ. 26 (2) (2004) 179–200.
[31] K. Gram-Hanssen, C. Kofod, K.N. Petersen, Different everyday lives: different patterns of electricity use breaking out of the box, Proceedings of the American Council for an Energy Efficient Economy 2004 Summer Study (2004) 774–785 (accessed 25.09.14). http://www.eceee.org/library/conferenceproceedings/ACEEEbuildings/2004/Panel7/p77/paper.
[32] D.S. Parker, Research highlights from a large scale residential monitoring study in a hot climate, Energy Build. 35 (9) (2003) 863–876.

[33] G.K.F. Tso, K.K.W. Yau, A study of domestic energy usage patterns in Hong Kong? Energy 28 (15) (2003) 1671–1682.
[34] B. Halvorsen, B.M. Larsen, Norwegian residential electricity demand—a microeconomic assessment of the growth from 1976 to 1993, Energy Policy 29 (3) (2001) 227–236.
[35] P. Tiwari, Architectural, demographic, and economic causes of electricity consumption in Bombay, J. Policy Model. 22 (1) (2000) 81–98.
[36] L. Nielsen, How to get the birds in the bush into your hand: results from a Danish research project on electricity savings, Energy Policy 21 (11) (1993) 1133–1144.
[37] J.C. Cramer, N. Miller, P. Craig, B.M. Hackett, Social and engineering determinants and their equity implications in residential electricity use, Energy 10 (12) (1985) 1283–1291.
[38] M. Parti, C. Parti, The total and appliance-specific conditional demand for electricity in the household sector, Bell J. Econ. 11 (1) (1980) 309–321.
[39] R.V. Jones, A. Fuertes, K.J. Lomas, The socio-economic, dwelling and appliance related factors affecting electricity consumption in domestic buildings, Renew. Sustain. Energy Rev. 43 (2015) 901–917.
[40] M. Coleman, N. Brown, A. Wright, S.K. Firth, Information, communication and entertainment appliance use—insights from a UK household study, Energy Build. 54 (2012) 61–72.
[41] I. Mansouri, M. Newborough, D. Probert, Energy consumption in UK households: impact of domestic electrical appliances, Appl. Energy 54 (3) (1996) 211–285.
[42] N. Terry, J. Palmer, Trends in home computing and energy demand, Build. Res. Inf. 44 (2) (2016) 175–187.
[43] M. Szumilas, Explaining odds ratios, J. Am. Acad. Child Adolesc. Psychiatry 19 (3) (2010) 227–229.
[44] A. Agresti, An Introduction to Categorical Data Analysis, 2nd ed, John Wiley & Sons, New Jersey, 2007.
[45] A. Field, Discovering Statistics Using SPSS: (and Sex, Drugs and Rock'n'roll), 2nd ed., Sage Publications Ltd., London, UK, 2005, ISBN 978-1849204088.
[46] L. Marjanovic, M.J. Coleman, H. Bruhns, A. Summerfield, A. Wright, Appliances taxonomy across both domestic and non-domestic building sectors, ASHRAE Trans. 114 (Part 1) (2008).
[47] I.G. Hamilton, P.J. Steadman, H. Bruhns, A.J. Summerfield, R. Lowe, Energy efficiency in the British housing stock: energy demand and the homes energy efficiency database, Energy Policy 60 (2013) 462–480.