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Information, communication and entertainment appliance use – insights from a UK household study

Michael Coleman [a], Neil Brown [a], Andrew Wright [a], Steven K. Firth [b]

[a] The Institute of Energy and Sustainable Development, De Montfort University, The Gateway, Leicester, LE1 9BH, UK mjcoleman@dmu.ac.uk – nbrown@dmu.ac.uk – awright@dmu.ac.uk

[b] School of Civil and Building Engineering, Loughborough University, Loughborough, UK

S.K.Firth@lboro.ac.uk

Corresponding author: Michael Coleman Email: mjcoleman@dmu.ac.uk

Tel: +44 (0) 116 257 7981 Fax: +44 (0) 116 257 7977

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Abstract

Electricity consumption data for information, communication and entertainment (ICE) appliances (consumer electronics and ICT equipment) were collected from a sample of fourteen UK households to identify patterns of appliance use. Follow-up interviews were also undertaken to explore factors that influenced the electricity consumption recorded. Results support the current consensus that ICE appliance use can be a significant electricity end-use in UK homes, often from standby loads. On average, around 23% of the households' electricity consumption was from ICE appliance use and around 7% could be attributed to standby power modes. Key appliances that contributed to the sample's average electricity consumption are identified. Inconspicuous electricity consumption from network appliances (e.g. set-top boxes, routers) is an issue of particular concern due to policy gaps. The results support technical interventions, such as the implementation of minimum energy performance standards, and other design measures. Other initiatives are required to influence householder behaviour, such as the expansion of mandatory energy labelling, improved feedback information and the use of behaviour change campaigns.

1. Introduction

1.1 Background

The UK is committed to an 80% reduction in greenhouse gas emissions by 2050, compared to 1990 levels [1]. In 2010, around 32% of the UK's total energy demand was consumed by households [2]. Therefore, the UK Government has introduced initiatives to reduce domestic energy consumption, with a focus on improving the energy efficiency of homes (e.g. more stringent building regulations, improved insulation, the Green Deal) and encouraging the uptake of low carbon space and water heating systems [3]. This focus is reflected in the greater potential for reductions associated to space and water heating. In 2009, around 61.7% of domestic energy use was from space heating, 17.6% from water heating, 18.0% from lighting and appliances, and 2.7% from cooking appliances [2]. However, electricity consumption is much less dependent on physical characteristics of built form than space and water heating [4] (around 80% of UK heating systems use natural gas [5]) and there is concern over the continued rise in electricity demand from the use of appliances in UK homes [6]. In particular, there has been increased consumption from consumer electronics (e.g. televisions, DVD players, radios, etc) and information and communication technologies (ICT) (e.g. computers, printers, cordless telephones, etc). It is estimated that, in 2009, consumer electronics accounted for around a quarter of UK domestic electricity consumption, around 21 TWh, and ICT equipment accounted for a further 6.5 TWh [6].

In recent years the distinction between consumer electronics and ICT equipment has become ambiguous due to the convergence of appliance functions. Therefore, this study referred to the two appliance categories as information, communication and entertainment (ICE) appliances, following the rationale of previous work [7]. The growth of ICE appliance use has been evident throughout EU and OECD countries [8, 9] and policymakers are now faced with the challenge of implementing measures to deal with a continuously evolving and increasingly energy intensive electricity end-use. Work by de Almeida et al. highlights that it is essential to undertake energy monitoring studies to inform effective policies [9]. Such work can help to evaluate the effectiveness of existing policies and identify new patterns of consumption. Results from recent European monitoring campaigns [10, 11] have provided important insights into household electricity consumption, but these did not include UK homes.

Although it is important to undertake energy monitoring, it is also important to understand why patterns of electricity consumption occur by gathering behavioural data. One approach is to investigate energy use from a 'socio-technical' perspective. The term socio-technical was originally used by Emery and Trist [12] to describe work systems that incorporate complex interactions between people, machines and the work environment [13]. More recently, the term has been applied to energy systems that involve technological, social, physical, political, regulatory and cultural aspects of energy supply and consumption [14, 15]. Wall and Crosbie's study [16], into energy use from household lighting, contends that household energy use is a socio-technical phenomenon and that the formulation of strategies for energy demand reduction must consider the interactions between people and technology. To investigate this interaction Wall and Crosbie undertook energy monitoring to inform the collection of qualitative interview data that explored why patterns of energy use occurred. According to Lopes et al. [17] and Crosbie [18], energy monitoring provides the only method to accurately record patterns of electricity consumption, free from the influence of self-report bias. Thus, conducting interviews based on measured patterns of energy use can provide a more accurate investigation of factors that are most important for specific behaviours [16].

This study adopted this approach and undertook energy monitoring to objectively record households' patterns of ICE appliance use and conducted follow-up interviews to explore factors that influenced the electricity consumption recorded. The overarching aim was to improve knowledge and understanding of ICE appliance use within UK households. More specific objectives were to identify the proportion of household electricity consumption from ICE appliances, explore factors that influence ICE appliance use, and provide recommendations for policymakers to reduce CO_2 emissions.

2. Methodology

2.1 Description of sample

Fourteen households were recruited to take part in this study. The sample size reflects the practical constraints of monitoring household appliances [19] (e.g. over 220 individual appliances were monitored), and the type of intensive analysis commonly used in qualitative research, which make it difficult to target a large sample size [20]. The study used a 'snowball' sampling strategy; to select an initial participant(s), who in turn identifies other potential recruits [21, 22]. While rapid and cost effective, snowball sampling has other advantages – e.g. during early trials monitoring equipment was found to require field adjustments; initial participants from within the researcher's acquaintances minimised dwelling access problems. However, this approach can lead to a homogonous sample [23], so participants were asked to nominate households with a different composition to their own. Homes were also only selected if there was a relatively 'typical' range of appliance types (e.g. at least one television). Table 1 shows details of the households and that monitoring occurred between March 2008 and August 2009. The sampling approach gave a sample reasonably similar to the national stock[1] within the constraints of a small sample (although it does not follow that energy consumption will also be similar). However, the ICE appliance sector is a rapidly changing area due to continuous development and diversification of products and services [7, 8]. As a result, the monitoring occurred before the UK's digital broadcast switchover (during 2011) and none of the homes owned HD complex set-top boxes (which can receive high-definition broadcasts).

2.2 Monitoring of electricity consumption

Whole house electricity consumption and ICE appliances were monitored for two weeks. A single channel current logger (SPCmini manufactured by Elcomponent Ltd), was used on the incoming electricity supply, to record whole house electricity consumption. This proved impossible for Household 13, so consumption was based on 'start and finish' meter readings. Individual appliances were monitored, at five minutely intervals, using a system produced by Digital Living Limited. The system consists of twenty plug-in meters connected to a central data collection point (gateway), using a Power Line Carrier connection (i.e. via the dwelling's mains cabling). A LON converter is used to process the LONWORKS signal from the plug-in meters and electricity consumption is monitored at 1 Wh resolution. Data are transferred, on a daily basis, from the gateway, via a GSM modem, to a central server and are managed in an SQL database. Figure 1 shows a schematic of the system; the main advantages are that no additional wiring is required to begin monitoring, the system is relatively visually unobtrusive, and data can be accessed on a daily basis.

It must be recognised that the short monitoring periods are subject to the effects of seasonal variation and unusual influences on occupancy (e.g. from unusual weather events, school holidays, participants illness, etc). For instance, work by Bennich et al. [25] suggests that, in Sweden, audio and video appliances are used less frequently in summer months (e.g. from more time spent outdoors or on vacation), although computer loads remain relatively constant throughout the year. This study is also subject to the Hawthorn effect – when people know they are being observed they are likely to alter their behaviour [26]. Consequently, monitoring only occurred during 'typical' occupancy levels, householders were asked to

[1]The sample reflected some of the household diversity in the UK: one person 21% (UK 31%); Two or more unrelated 7% (UK 2%); Married/cohabiting couple no children 36% (UK 27%); Married/cohabiting couple with dependent children 14% (UK 22%); Married/cohabiting couple with non-dependent children 7% (UK 7%); Lone parent with dependent children 14% (UK 6%); Lone parent with non-dependent children 0% (UK 3%); Two or more families 0% (UK 1%). UK national figures gained from the ONS [24]

behave ‘normally’ and were informed that study aimed to investigate their appliance use, not energy conservation.

2.3 Appliance categories and identification of power modes

To identify patterns of ICE appliance use in the homes, electricity consumption was attributed to individual appliance types and four broad categories of appliance: (i) video (e.g. televisions, STB, DVD, etc); audio (e.g. Hi-Fi equipment, radios, etc); computing (e.g. desktop computers, laptops, monitors, routers, printers, etc); telephony (cordless telephones, answer-phones). Mobile telephones and other small portable devices were excluded from the monitoring for practical reasons (e.g. limited number of loggers, concerns that they would not be charged from the same socket). Where possible, appliance electricity consumption was apportioned to power modes. The increased complexity of appliance functions has led to a large number of different power modes. For example, Jones and Harrison [27] describe eleven measurements required to cover operational modes of a STB. Other definitions have also emerged to specifically deal with the increased networking of appliances [28]. This study took a relatively broad approach to power mode classification, informed by other studies [29,30]. These are shown in Table 2 and reflect the operating modes outlined in IEC 62087 (BS EN 62087:2009) [31].

Data for each dwelling and appliance were processed by spreadsheet, calculating key values of electricity consumption (e.g. total consumption, values for power modes, minutes of use, etc) and producing charts and summary tables. For some appliances, automatically calculating power mode electricity consumption was hampered by the 1 Wh resolution of the monitoring equipments’ data storage, which could result in five minutely intervals displaying a zero value, despite an appliance consuming electricity in a low power mode. In such cases, the measured consumption was not missing, but would accumulate over several samples to form a 1 Wh increment. As a result, for some appliances, the different power mode loads of an appliance could show different numbers of zero values followed by similar peaks. For example, a 1 W load would result in a 1 Wh measurement, in one five minutely interval, per hour, whereas a 6 W load would result in a single zero value followed by a 1 Wh measurement. Therefore, a moving average, which smoothed the 1 Wh peaks in the data (by averaging the electricity consumption values of cells before and after a given timestamp), was used to assist extensive manual screening of the data, to correctly attribute electricity consumption to power modes for each measurement interval.

Most appliances’ active and standby power modes were easily identifiable (e.g. televisions, computer monitors, games consoles) and others often remained in the same power mode during the monitoring (e.g.

STBs, VCRs, DVD players, routers, printers and audio equipment). Figure 2 shows the electricity consumption of three appliances, for a day, at one of the homes. The active power consumption of a television and desktop computer can clearly be seen, along with the effect of the 1 Wh resolution, which results in peaks of consumption for the passive and off standby loads respectively. For clarity, the complex STB consumption is shown with the use of the moving average, which spreads energy consumption over the measurement intervals.

For some appliances it was impossible to attribute a specific power mode to the consumption, due to missing data (e.g. very long time intervals) or from appliances showing similar active and standby power mode consumption (this mainly effected telephony equipment). For such cases, these data were removed from power mode calculations by categorising as ‘unknown’. In other cases it was possible to identify an appliance on standby, but not the specific standby power mode. Such data were categorised as ‘unclassifiable standby’, to include the data in standby consumption totals.

As found in the UK Market Transformation Programme (MTP) investigation of home computers [32], determining when computers entered standby power modes, from automatic power management settings, was problematic due to computers operating in a wide range of power loads while active. Standby power for laptop computers can also be influenced by batteries state of charge [30]. Therefore, ultimately, some standby use from computers may have been reported as active consumption, and results presented should be viewed as conservative.

As illustrated in Figure 2, many network appliances (e.g. STBs, AV boosters, routers, and modems) often remained in an active power mode, even when the accompanying television or computer was not being used. The categorisation of such energy consumption can be a contentious issue. Technically an appliance, such as an STB, is in the active power mode irrespective of whether the associated television is also active. However, previous studies have included active STBs and routers in standby calculations. For example, EES [30,33] highlight that the inclusion of continuously active appliances, such as STBs, in their standby calculations, reflects the appliances’ very significant and relatively stable electricity consumption over time. Similarly, a report by Grinden and Feilberg [34], from the REMODECE project, highlights that routers and STBs were included in standby calculations, whereby “standby is calculated as the consumption in the hours when the associated PC or TV is <u>not</u> in use” ([34] p7). This provides a means to identify energy consumption from these appliances that is not being fully utilised by householders. This study has followed a similar approach and has included electricity consumption from active network appliances (e.g. STBs, AV boosters, routers, and modems) in active standby values, when the associated equipment (e.g. television, computers) were not active.

2.4 Household interviews

Energy monitoring accurately details patterns of electricity use, but to convert these data into more useful information there is a need to gain insights into the behaviour of the people causing the consumption. Semi-structured interviews were used to gather these data from each household and covered two key forms of behaviour. The first series of questions explored householders' appliance use (i.e. the extent to which appliances are used in the different power modes). Charts and tables were used to show the energy monitoring results and provided a basis for the discussion. Figure 3 shows a useful chart that allowed participants to see their specific use of appliances (this approach was informed by [16]).

These charts were provided for the appliances over both weeks and showed when appliances were off, in a standby power mode, or were active. The second series of questions concentrated on why appliances were adopted in the home; the power requirements of appliances can affect electricity consumption significantly. Two social psychology theories facilitated the development of interview questions. The Theory of Interpersonal Behaviour [35, 36] offered a framework to focus questions on patterns of appliance use and Diffusion of Innovations Theory [37] was used to help explore adoption decisions. The theories were used to inform and focus the interviews, but not to constrain them, so the questions were kept relatively broad and open-ended to allow data to emerge freely, in participants' own words. The key constructs from the theories were also used to assist the data analysis, which was completed through template analysis (see King [38]).

3. Results

Figure 4 shows a 24 hour profile of ICE appliance usage by category and total, averaged across all days of measurement and all households. It should be interpreted with caution due to the small sample size and for the reasons discussed subsequently. It shows that for these households, audio and telephony make up a virtually constant, small load. Computing usage varies only slightly due to a lot of equipment being active permanently (reasons for this are discussed in subsequent sections). Video shows the greatest diurnal variation (though with substantial baseload), with peaks evident in the morning, at lunchtime and, as would be expected, a larger peak in the late evening. Overall, the baseload makes up well over half the total 24 hour energy use.

3.1 Electricity consumption by appliance type

The average electricity consumption per appliance type (i.e. overall electricity consumption, for each appliance type, divided by number of appliances) is shown Table 3, which suggests that more recent technologies (e.g. LCD televisions, HDD complex STBs, HDD recorders, digital radios, cordless telephones) are more energy intensive than older technologies (e.g. CRT televisions, simple STBs, VCRs, analogue radios). This is reflected in higher power loads and/or more frequent active use. However, it is apparent that LCD televisions have lower standby loads and laptops could offer energy savings over desktop computers and monitors.

Figure 5 shows the average household two week electricity consumption for the thirty-six types of appliances monitored (i.e. overall electricity consumption, for each appliance type, divided by number of households). The average household values incorporate the ownership levels (presented in Table 4), which illustrates the average number of appliances per household found in the sample. It is evident that desktop computers and televisions consumed the most electricity, mostly in the active mode. It is also apparent that network appliances (i.e. appliances with the purpose to maintain connection to networks, such as STBs, routers modems, and telephones) have become a significant end-use; they account for around 22% of average household ICE appliance electricity consumption and a significant portion of standby consumption due to equipment frequently being left continuously in an energy consuming state. Around 37% of average household ICE appliance standby consumption was from network appliances. Probable standby consumption from telephony appliances is excluded from this value (due to being classed as 'unknown'), but it is likely that the majority of consumption was from standby; some households reported that handsets were rarely used owing to the more frequent use of mobile telephones.

Audio and printing equipment, and video play and record equipment (e.g. DVD players, VCRs, etc) also accounted for a significant amount of standby consumption, again due to appliances often being left on standby continuously. For example, around 91% of printing appliances electricity consumption was from standby consumption and VCRs and DVD players consumed 96.2% and 88.4% respectively of their electricity on standby. Around 96% of integrated-Hi-Fi systems' electricity consumption was also from standby, on average accounting for around 14% of total standby consumption.

3.2 Variations in household electricity consumption

The two week electricity consumption of the fourteen households is summarised in Table 5 and ranked by total ICE appliance electricity consumption. The mean and median whole house consumptions were 165.1

and 181.3 kWh respectively, while for ICE consumption, the mean and median were 38.3 and 27.4 kWh respectively. The mean whole house electricity consumption was comparable to 2008 UK government averages[2]. However, there were very wide variations; whole house consumptions varied by a factor of 3.4, and ICE appliance consumption by a factor of 14.5. One household (H7) had an exceptionally high ICE usage, nearly three times that of the next highest household. On average, around 23% of the households' electricity consumption was from ICE appliance use and around 7% can be attributed to ICE appliance standby power modes (this standby figure excludes probable standby consumption from telephony equipment, for reasons described previously). It is also apparent that total ICE appliance electricity consumption is generally less variable than whole house consumption for this sample, which could suggest that ICE appliance ownership and use is similar in most homes. However, homes with similar total ICE appliance consumption (e.g. households 3, 11, 8 and 5) often have very different electricity use in respect to the types of appliances and power modes.

The variation in appliance electricity consumption can be viewed in more detail in Figure 6, which allocates the households' two week electricity consumption into the main broad appliance categories active and standby consumption for clarity. Variations in households' ICE electricity consumption occurred due to a combination of: (i) the number of appliances owned by households; (ii) the types of appliances owned by households; (iii) the power requirements of the appliances in the different power modes; (iv) the different patterns of use. For example, the five households that did not own complex STBs (households 1, 5, 8, 10 and 14) were amongst the six homes with the lowest video appliance electricity consumption. However, behaviour is also important. For instance, Household 11 owned a complex STB, but the appliance was only used briefly during the two weeks of monitoring and disconnected at the mains socket when not in use. In this home computing equipment was used frequently and was often left on standby. The standby consumption in this home was largely due to equipment left in the off standby mode (e.g. two desktop computers, an LCD monitor) and also a multipurpose printer, router and modem frequently left in active standby.

Notably, there was very high ICE appliance electricity consumption in household 7 (a one person household). Although this appliance use appears to be very atypical, high consumption in households has also been captured in other residential energy studies [11,40]. Household 7 accounted for 29.5% of the total

[2]The UK government estimated that, in 2008, the average annual electricity consumption for households located in the UK was 4478 kWh [39]. When this value is divided into 50 weeks (to allow two weeks holiday) and multiplied for the duration of this study's monitoring period, this equates to around 179.1 kWh per two weeks.

ICE appliance electricity consumption recorded from the sample, largely due to the continuous active use of computing appliances (including three desktop computers, two external hard drives and a laptop). This was a key factor for the high base load from computing appliances shown in Figure 4. As a result of this household's consumption, some of the important variations in electricity consumption were lost in the average values. For instance, standby accounted for over 45% ICE appliance electricity consumption in half of the homes (average percentage was 38% and nearly 70% in household 6) and some appliance types' consumption, that appeared to be less significant to the 'average' household, was actually an important end-use in several homes (e.g. audio equipment).

For nine out of the fourteen households, video appliance use was the predominant form of ICE appliance electricity consumption. Perhaps unsurprisingly, televisions were generally the most significant end-use. For the eleven households that used STBs, on average, around 33% of the electricity consumed by the STBs and the associated televisions was attributable to the STBs. This compares reasonably well to an estimate made by Turner [41] who contends that STBs are wrongly perceived as power hungry devices, because "over any 24 hour period 70-80% of the energy consumption is due to the TV, not the STB" ([41] p3). However, in five households (3, 4, 6, 7 and 12), STBs accounted for between 44% and 65%, of the STB and associated television, suggesting that in many homes STBs could be as significant as the televisions used with them.

Figure 6 also shows that computing appliances were a significant end-use in many homes, particularly in households with higher ICE appliance electricity consumption. In half of the homes (2, 14, 4, 5, 6, 9 and 10), standby consumption from computing appliances was higher than active consumption, accounting for between 67% (household 10) and 94% (household 6) of computing appliance electricity consumption in these homes. In six of the households (14, 4, 5, 6, 9 and 10) the 'off' standby power mode was responsible for between 20% and 30% of the households' computing appliance consumption.

Audio appliances left on standby were particularly significant to five of the households (3, 5, 8, 10 and 14). In households 5 and 14 integrated Hi-Fi's resulted in over 4% and 6%, respectively, of their two week whole house electricity consumption. This indicates that simple changes to behaviour could have a significant impact on some homes electricity consumption. Simply disconnecting integrated Hi-Fi systems from the mains socket could reduce two week ICE appliance electricity consumption in households 3, 5, 8, and 14 by between 18.6% and 23%.

3.3 Key factors that influenced patterns of electricity consumption

In all fourteen interviews, participants described a variety of ways that society influenced the increased ownership and use of ICE appliances, such as social norms, commercial pressure, more flexible working patterns, and the need to communicate and maintain social networks. Access to the Internet was often viewed as a necessity. Working from home was an important factor; households 9, 12 and 13 all included someone who worked extensively from home and in five of the six households with the highest computing appliance electricity consumption (9, 10, 11, 12 and 13), at least one member worked regularly from home. In household 9, this led to the ownership of a commercial standard printer/copier with a high power load.

In common with other studies [42-44] participants described the parallel and simultaneous use of appliances, to pursue different personal interests and preferred forms of entertainment. Participants often explained that the wider range of digital services facilitated this use. Responses also described the 'background' use of appliances to develop a more comfortable atmosphere in the home (e.g. provide a sense of company or influence the ambience of the home). As a result, appliances would be left active without all of their functions being utilised (e.g. televisions used for audio or with the volume turned down).

There was also evidence of 'social television'. For instance, householder 4 would communicate with a friend via his laptop about television programmes they were both watching. This type of behaviour is a rapidly growing activity, with social network sites (e.g Twitter and Facebook) and media groups (e.g. broadcasters and newspapers) providing text based platforms to discuss programmes as they are broadcast [45]. Social television has the potential to fundamentally alter appliance use, with services providers developing more interactive experiences that include audio and visual communication [45,46].

Three participants (from households 4, 6 and 8) reported that the simultaneous use of their televisions and computers had been facilitated by the mobility of laptops and a wireless Internet connection. Previously, these householders had used desktop computers away from living areas (e.g. in an office room) and other entertainment equipment. A member of household 5 also explained that the potential to view television, in the home's more comfortable lounge, was a factor for wanting a laptop. Therefore, despite laptops offering improved energy efficiency, they can also facilitate more energy intensive behaviour, by encouraging the use of other equipment at the same time (e.g. televisions, STBs, audio equipment).

Householders also reported behaviours that reduced their energy consumption due to factors, such as environmental concern, financial cost, and concern over fire. The effects of behaviour were apparent in the monitoring data. For example, the members of household 1 routinely disconnected their appliances after active use, largely due to environmental and financial motivations. In household 2 video and computing appliances (including a complex STB) were regularly disconnected overnight or when the house was unoccupied. Similarly, members of household 9 frequently disconnected video and audio appliances from the mains supply to reduce standby consumption. However, in the majority of homes, this type of behaviour was not applied to all their appliances, all of the time. For instance, in households 9 and 11 computing appliances were often left on standby. Thus, intentions to save energy were not always strong enough to override other motivations, such as convenience (e.g. time and effort to turn appliances on and off), concerns over loss of settings, pleasure and comfort. Practical issues and equipment configurations were also important. In half of the homes the way appliances were connected to other appliances resulted in wasted electricity consumption. For example, in four homes, broadcast signals could only be received by televisions when VCRs and DVD players were active or on standby. In the majority of homes, groups of appliances were also powered by a single mains socket through the use of an extension cable or a block socket splitter. As a result, appliances that were not actually being used were often on standby. Other issues that influenced standby consumption included restricted access to sockets, appliance controls and the lack of visibility that appliances were on standby (e.g. participants often incorrectly believed appliances, without lights or displays, were not on standby), however, lights did trigger some energy saving behaviour.

Knowledge was also important. For example, in twelve of the homes, participants indicated that they did not have a clear understanding of the amount of electricity consumed by ICE appliances, and the large majority of householders were unaware of the extent of standby consumption in their homes. Only three participants (from households 4, 10 and 12) reported that they knew how to activate computers' power management settings. Two other participants reported knowledge of power management settings (from household 7 and 10), but they deactivated the settings to protect unsaved work and maintain Internet connection. The importance of knowledge was also reflected in participants reactions to the information presented to them. Householders in nine of the interviews said that they intended to alter their behaviour due to participating in the study. Typically, responses related to the reduction of standby consumption and two householders even disconnected appliances at the interview stage.

Energy consumption was also an issue largely excluded from purchase decisions due to limited knowledge of appliances power requirements. The large majority of householders were completely unaware of current voluntary energy labelling schemes (e.g. Energy Star and the Energy Saving Trust's Energy Saving Recommended scheme). For some householders, the lack of mandatory energy labelling conveyed the message that different appliance models would consume similar amounts of electricity. In contrast, householders in twelve of the interviews reported awareness of mandatory energy labels for cold and wet appliances, which had influenced past decisions to purchase more energy efficient appliances in ten of these homes. Participants in nine of the households also stated that mandatory energy ratings for ICE appliances would influence them to purchase more energy efficient products.

4. Discussion

The results, and the diversity between households, suggest that, to reduce electricity consumption, initiatives need to address the impact of all appliance types, in the different power modes. One clear approach is through better product design; this has been the focus of recent UK and EU policy via the Eco-design of Energy-using Products Directive (2005/32/EC), which was recast and enlarged in 2009 (Eco-design of Energy-related Products Directive – 2009/125/EC). Since the completion of this study's monitoring, a number of minimum energy performance standards (MEPS) have come into force, in the UK, via the Eco-design Directive, which set specific active and standby power requirements for many ICE appliances [47]. The results from this study provide justification for the implementation of MEPS. The substitution of many of the appliances monitored in this study, with appliances that comply with the Eco-design Directive, would undoubtedly help to reduce households' standby consumption and the introduction of stringent MEPS for televisions and computers active power modes could significantly reduce households' electricity consumption. Minimising standby power loads could also help address situations where factors, such as convenience and restricted access to sockets, inhibit the disconnection of appliances.

The significance of network appliances, in the domestic setting, reflects current concerns regarding policy gaps and growing energy consumption from networked equipment [48]. Results support calls for the improved integration of power management for networked appliances, and network infrastructures, such as requirements for auto power down functions and the implementation of standardised communication interfaces and protocols for both consumer electronics and ICT equipment [48,28].

The use of appliances to create a comfortable atmosphere suggests that energy saving functions could also be developed for 'background' use. For example, a television used for exclusively audio or visual purposes does not require all functions to be powered. A more 'functional' approach needs to be taken towards appliance design, as suggested by [48,49]. This approach stipulates that appliances should be set specific power requirements for the performance of particular functions, and reflects the multi-functional nature (and multiple power states) of devices.

The association of standby consumption to appliance lights and displays also highlights the role of design; greater standardisation of controls could assist energy saving intentions, as discussed by others [50,51]. In many of the homes participants believed that they were preventing standby power consumption by using switches on appliances. The inclusion of hard-off switches, (which disconnect appliance components from the mains supply), combined with non-volatile memory to retain settings, could support these intentions and would mitigate access difficulties involved in switching appliances off at the mains socket.

Social and behavioural issues must also be addressed. The study has highlighted that simple curtailment behaviours (e.g. disconnecting appliance at the mains sockets) could make relatively significant reductions in some households' ICE electricity consumption. These behaviours are important because it will take time for more efficient appliances to be adopted by households. New patterns of appliance use can also develop rapidly. Crosbie [44] found that service providers, marketing and service infrastructures had a significant influence on the formation of new more energy intensive television practices. Similar findings from this study, such as simultaneous use of appliances, social pressures to own equipment (e.g. commercialism, modern lifestyles, etc), the potential influence of social television, and more frequent working from home, also need to be addressed.

In various countries, the adoption and use of laptops, instead of desktop computers, is viewed as a positive step to reduce energy consumption [6,9,11,47]. This study also found that laptops provide improved efficiency, but in some cases, these mobile technologies encouraged the simultaneous use of other appliances. Policymakers should be aware that improving the uptake of energy efficient products has the potential for the rebound effect – i.e. the development of more energy intensive patterns of use, and highlights an issue worthy of further research.

There is the need to improve people's understanding of appliance power requirements and how to use them more efficiently. Measures could include; awareness campaigns, the inclusion of power management into ICT educational courses, and clearer information supplied with appliances. Importantly, the expansion of mandatory energy labelling (beyond the recent inclusion of televisions) to other consumer electronics and ICT equipment could help consumers to make more energy efficient purchase decisions.

This study also provides a degree of support for improved feedback through smart metering and in home displays [52-54]. It was apparent that the information presented to participants raised awareness of appliance electricity consumption and, in cases, prompted action. However, many feedback systems only provide information from dwellings' mains supply and it may be difficult for households to identify inconspicuous, but significant, power loads (e.g. network appliances, standby consumption). This implies that additional mechanisms may be needed to disaggregate electricity consumption and help households interpret information. A current UK study[3], exploring the use of wireless technologies to provide appliance level feedback, also aims to disaggregate energy consumption to individual building occupants. Such an approach may be useful to future energy monitoring studies, because it also identifies wasted active power mode electricity consumption (i.e. when no one is utilising active appliances).

5. Conclusions

An investigation into the electricity consumption from ICE appliances (consumer electronics and ICT equipment) has been undertaken in a sample of UK homes. Despite the small sample size, the socio-technical perspective informs observed patterns of consumption with insights into why the patterns of use occurred. Usage patterns varied widely between households, in both size and make-up, but the average (mean) household electricity consumption from ICE appliances was 38.3 kWh (median 27.4 kWh). The average value equates to around 23% of average whole house electricity consumption (median 18%). Of this, standby power modes accounted for 11.5 kWh, which equates to around 30% of ICE consumption and around 7% of average whole house electricity consumption. This supports the current consensus that ICE appliances have become a significant domestic electricity end-use and that much of this consumption can be attributed to standby [6,8,9,11].

Desktop computers and televisions were the most significant electricity consuming appliances, with the majority of their electricity consumption from the active power mode. However, appliances that appear less significant to the average household can be an important end-use in many homes. Audio appliances (e.g. integrated Hi-Fi's) printers, and play and record equipment (e.g. VCRs, DVDs, etc) were significant end-uses, largely from standby consumption. Improved product design could help to improve energy efficiency, by reducing equipment power loads and facilitating people's intentions to save energy.

Network appliances (e.g. STBs, routers, modems and telephony equipment) accounted for a significant portion of average household ICE appliance electricity consumption. Computers that were continuously active and connected to the Internet, in one of the homes, were also responsible for a large portion of the sample's electricity consumption. Measures to address policy gaps and growing energy consumption from

[3] Reduction of Energy Demand in Buildings through Optimal Use of Wireless Behaviour Information (Wi-be) Systems (EP/I000259/1).

networked equipment should be explored, such as improved power management and standardised communication interfaces and protocols.

Policymakers should also be aware that more flexible working patterns can increase domestic energy consumption, and although laptops provide improved efficiency, these technologies can encourage the simultaneous use of other appliances. The emergence of new services could also influence household electricity consumption (e.g. social television). These are areas that warrant future research. Additional initiatives to raise awareness (e.g. education, information campaigns, and feedback devices) are needed to encourage energy saving behaviour and the expansion of mandatory energy labelling to ICE appliances could be an effective approach to promote the purchase of more energy efficient products.

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Figure 1 Diagram of the appliance monitoring system.

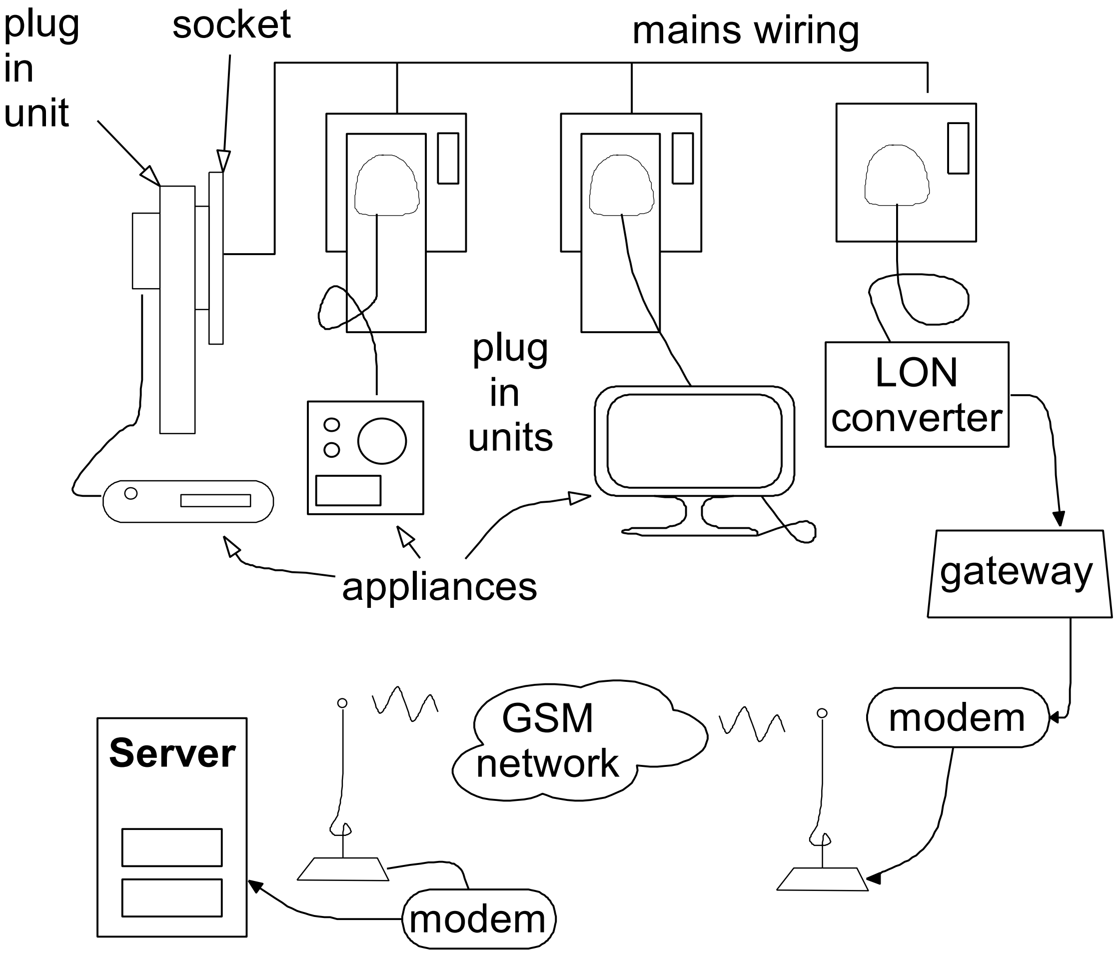
Figure 2 Electricity consumption profiles for three appliances, over a 24 hour period, at household 13.

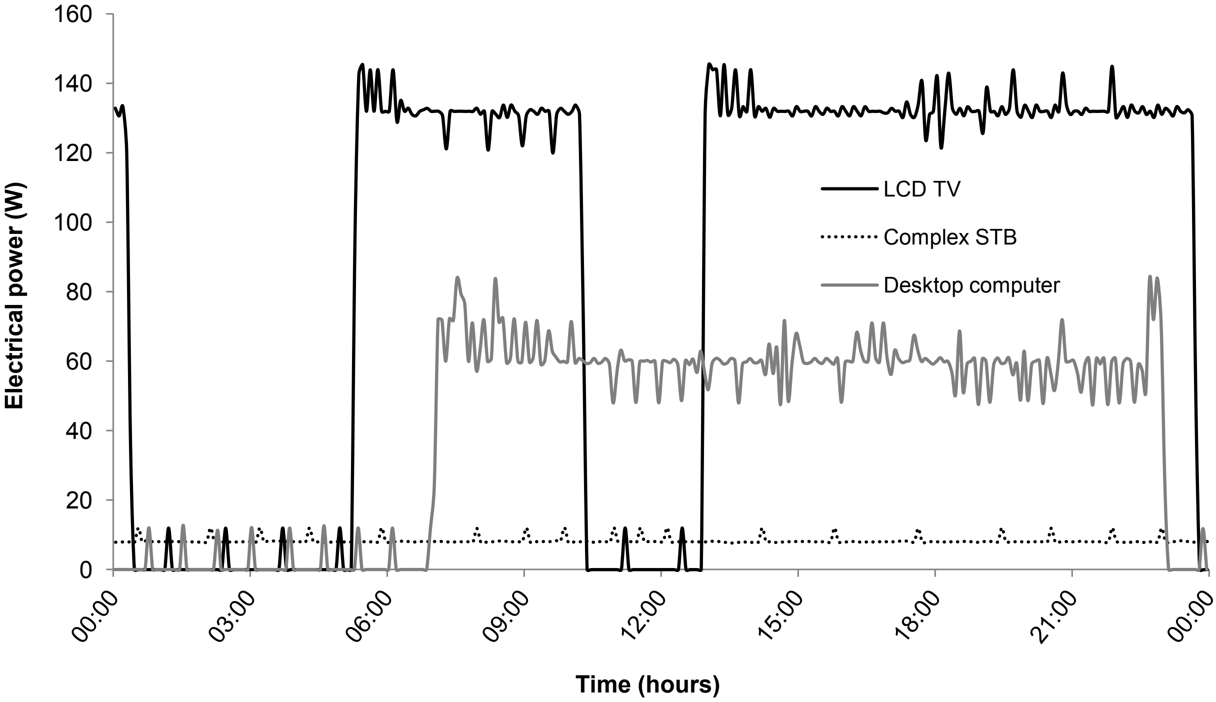
Figure 3 Example of patterns of use chart from household 13 for four video appliances.

Figure 4: Profile of ICE appliance use by category over 24 hours, averaged over all days for 14 households in study.

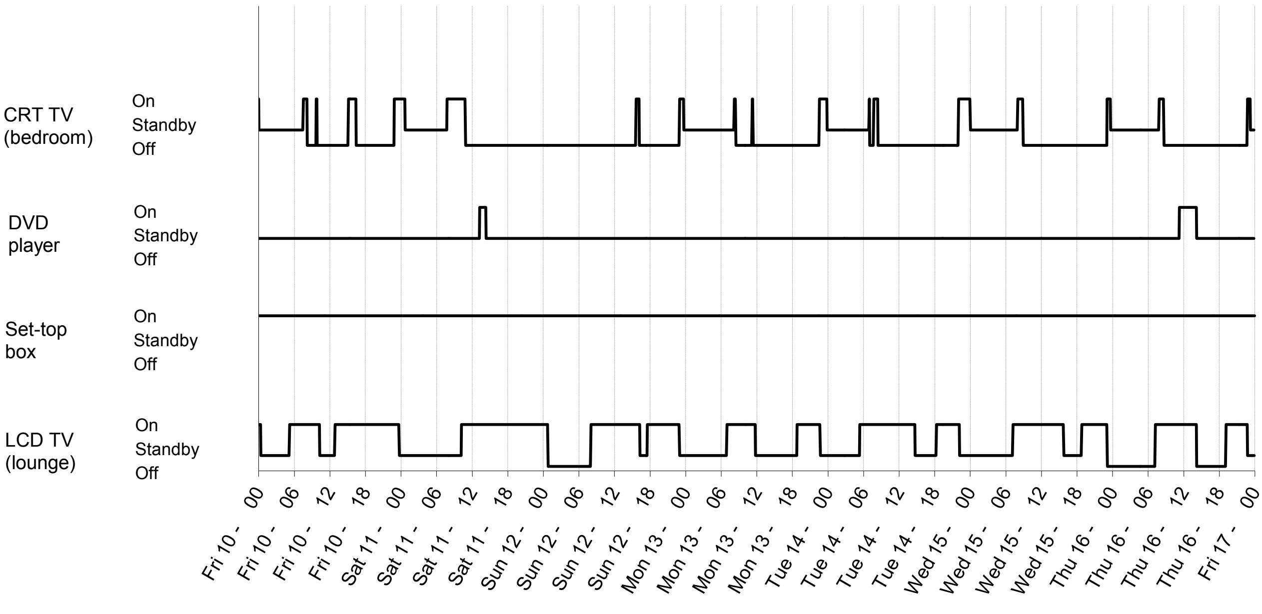
Figure 5: Average household two week electricity consumption from different ICE appliances power modes. Note: active standby values for network appliances (STBs, router, modem, AV trans/receiver and AV booster) include electricity consumption from active appliances, when the associated equipment (e.g. television, computers) were not active.

Figure 6 Variation in two week ICE appliance electricity consumption for the fourteen homes, separated into active and standby electricity consumption, for the main categories of appliances (‘unknown’ electricity consumption includes telephony appliances). Note: standby values include electricity consumption from active network appliances (e.g. STBS, modems, routers), when the associated equipment (e.g. television, computers) were not active.

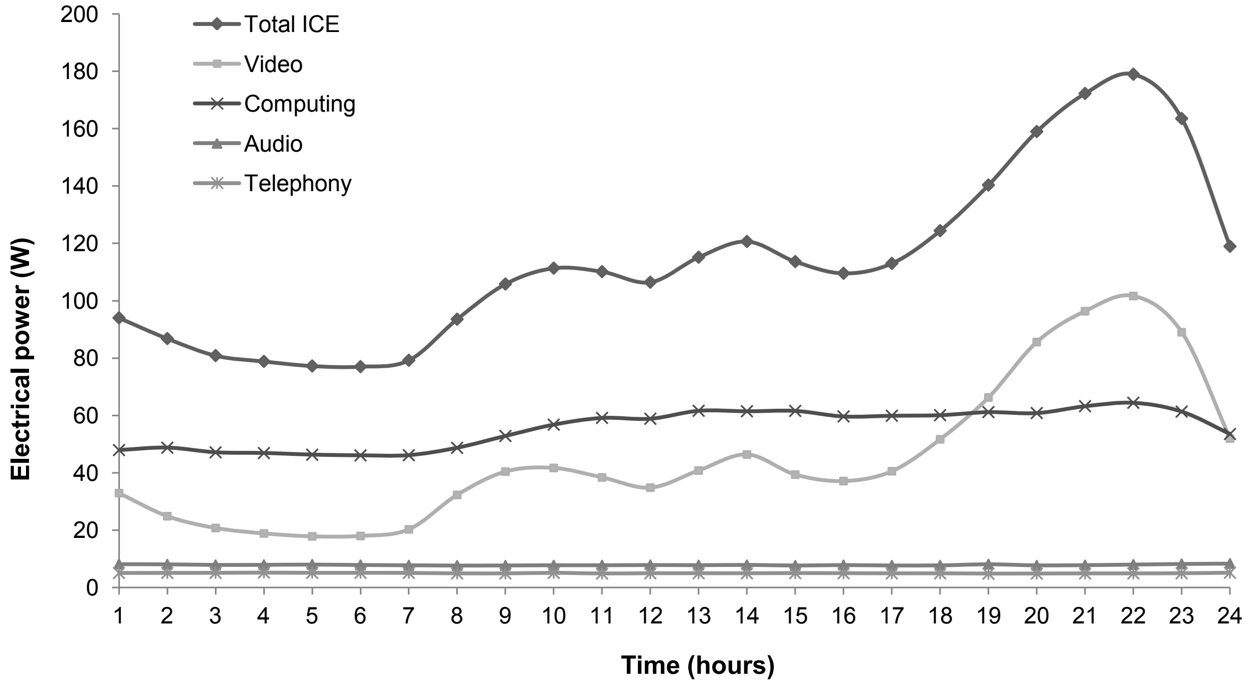

plug in unit
socket
mains wiring
plug in units
LON converter
appliances
gateway
GSM network
modem
Server
modem



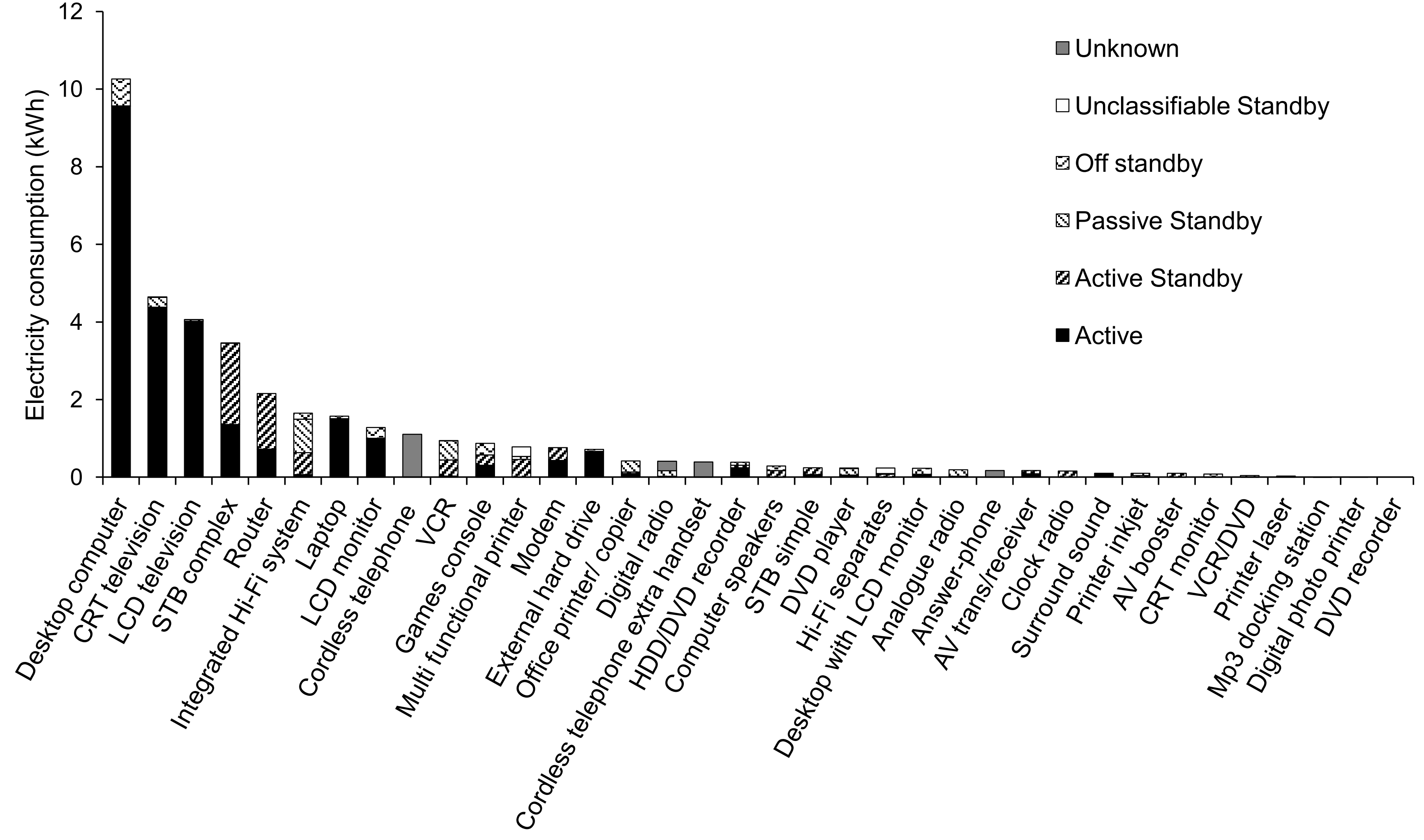
160
140
120
100
80
60
40
20
0
Electrical power (W)
LCD TV
Complex STB
Desktop computer
00:00
03:00
06:00
09:00
12:00
15:00
18:00
21:00
00:00
Time (hours)



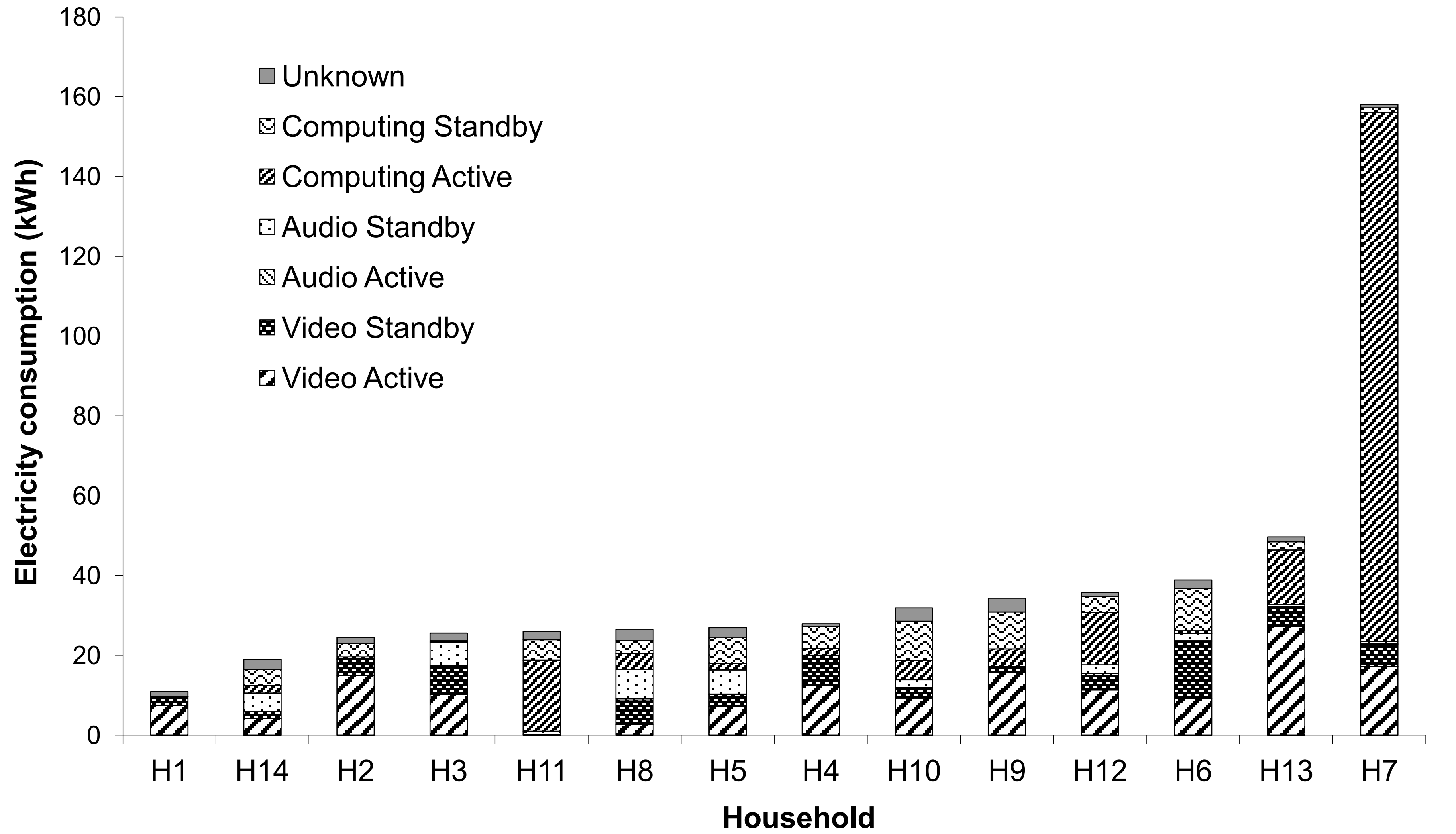
CRT TV (bedroom)
DVD player
Set-top box
LCD TV (lounge)
On
Standby
Off
Fri 10 - 00
Fri 10 - 06
Fri 10 - 12
Fri 10 - 18
Sat 11 - 00
Sat 11 - 06
Sat 11 - 12
Sat 11 - 18
Sun 12 - 00
Sun 12 - 06
Sun 12 - 12
Sun 12 - 18
Mon 13 - 00
Mon 13 - 06
Mon 13 - 12
Mon 13 - 18
Tue 14 - 00
Tue 14 - 06
Tue 14 - 12
Tue 14 - 18
Wed 15 - 00
Wed 15 - 06
Wed 15 - 12
Wed 15 - 18
Thu 16 - 00
Thu 16 - 06
Thu 16 - 12
Thu 16 - 18
Fri 17 - 00



Total ICE
Video
Computing
Audio
Telephony
Electrical power (W)
0
20
40
60
80
100
120
140
160
180
200
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Time (hours)



Electricity consumption (kWh)
0
2
4
6
8
10
12
Unknown
Unclassifiable Standby
Off standby
Passive Standby
Active Standby
Active
Desktop computer
CRT television
LCD television
STB complex
Router
Integrated Hi-Fi system
Laptop
LCD monitor
Cordless telephone
VCR
Games console
Multi functional printer
Modem
External hard drive
Office printer/ copier
Digital radio
Cordless telephone extra handset
HDD/DVD recorder
Computer speakers
STB simple
DVD player
Hi-Fi separates
Desktop with LCD monitor
Analogue radio
Answer-phone
AV trans/receiver
Clock radio
Surround sound
Printer inkjet
AV booster
CRT monitor
VCR/DVD
Printer laser
Mp3 docking station
Digital photo printer
DVD recorder



Unknown
Computing Standby
Computing Active
Audio Standby
Audio Active
Video Standby
Video Active
Electricity consumption (kWh)
0
20
40
60
80
100
120
140
160
180
H1
H14
H2
H3
H11
H8
H5
H4
H10
H9
H12
H6
H13
H7
Household

Table 1 Summary of participating households

Household	**Household type**	**Occupied weekdays daytime**	**Occupation of household reference person**[a]	**Dwelling type**	**Monitoring start date**
H1	Married couple	Yes	Retired	3-bed semi	6/3/2008
H2	Married couple, two dependent children	Yes	Employed full time	3-bed detached	18/07/2008
H3	Married couple	Yes	Employed full time	3 bed-semi	16/11/2008
H4	One person (male)	No	Employed full time	3-bed semi	23/11/2008
H5	Lone parent, one dependent child	Yes	Unemployed	3-bed semi	2/12/2008
H6	Married couple	Yes	Retired	4-bed detached	25/2/2009
H7	One person (male)	No	Employed full time	3-bed end terrace	1/3/2009
H8	Lone parent, one dependent child	No	Employed full time	3-bed mid-terrace	14/3/2009
H9	Married couple, one non-dependent child	Yes	Employed full time	3 bed semi	21/3/2009
H10	Cohabiting couple	No	Employed part time	4-bed mid-terrace	12/5/2009
H11	Two unrelated adults	Yes	Employed part time and self employed part time	3 bed mid-terrace	12/6/2009
H12	Married couple, two dependent children	Yes	Self employed	3-bed detached	30/6/2009
H13	Cohabiting couple	No	Employed full time	1-bed apartment	3/7/2009
H14	One person (female)	Yes	Retired	3-bed semi	20/8/2009

[a] Household reference person is the occupant responsible for the property. In cases of shared responsibility the occupant with the highest income is the reference person.

Table 2 Power mode definitions

Power mode	**Description**
Active	The power used when the appliance is performing its primary function (e.g. when a television is on and providing images and/or sound).
Active standby	The power used when the appliance is on, but not performing its main function (e.g. when a DVD recorder is on but not recording or playing).
Passive standby	The power used when the appliance is not performing its main function, but is in a state waiting to be switched on or is performing a secondary function (e.g. when a television has been switched off by the remote control).
Off standby	Off standby mode is when an appliance, that has an off switch, is connected to a power source, but is not waiting or performing any function. It can only be activated when the power switch on the appliance is activated (e.g. when a computer monitor is switched off, but still plugged into the mains power supply).

Table 3 Average two week electricity consumption by ICE appliance type

			Average energy over 2 week period				Average power, by mode			
Appliance category	**Appliance**	**Number of appliances (Total)**	**Active (kWh)**	**Standby (kWh)**	**Unknown (kWh)**	**Total (kWh)**	**Active (W)**	**Active standby (W)**	**Passive standby (W)**	**Off standby (W)**
Video	LCD television	8	7.0	0.1	0.0	7.1	102.3	-	1.1	-
Video	STB complex	10	1.9	2.9[b]	0.003	4.8	17.8	15.8[b]	-	-
Video	CRT television	21	2.9	0.2	0.01	3.1	67.3	-	3.8	0.0
Video	HDD/DVD recorder	2	1.7	1.0	0.0	2.7	25.0	3.7[a]	4.6[a]	-
Video	VCR	8	0.06	1.58	0.005	1.6	16.8	12.4	4.9	-
Video	Games console	10	0.4	0.8	0.0	1.2	42.9	38.4	8.8	2.0
Video	AV trans/receiver	2	0.6	0.6[b]	0.0	1.2	3.6	3.6[b]	-	-
Video	STB simple	3	0.3	0.8[b]	0.0	1.1	6.2	6.2[b]	-	-
Video	AV booster	2	0.06	0.6[b]	0.0	0.7	2.1	2.1[b]	-	-
Video	VCR/DVD	1	0.04	0.56	0.0	0.6	13.9[a]	-	1.7[a]	-
Video	Surround sound	3	0.5	0.0	0.0	0.5	20.1	-	-	-
Video	DVD player	9	0.04	0.33	0.0	0.37	17.2	-	2.3	-
Video	DVD recorder	1	0.0	0.0	0.0	0.0	-	-	-	-
Telephony	Answer-phone	2	0.0	0.0	1.2	1.2	-	-	-	-
Telephony	Cordless telephone	14	0.0	0.0	1.1	1.1	-	-	-	-
Telephony	Cordless telephone extra handset	6	0.0	0.0	0.9	0.9	-	-	-	-
Computing	Desktop computer	17	7.9	0.6	0.0	8.5	77.0	-	3.5[a]	2.8[a]
Computing	Office printer/ copier	1	1.3	4.6	0.0	5.9	75.6[a]	17.4[a]	14.0[a]	-
Computing	Desktop with LCD monitor	1	1.1	2.1	0.0	3.2	98.6[a]	-	-	6.5[a]
Computing	Modem	4	1.5	1.2[b]	0.0	2.7	7.9	7.9[b]	-	-
Computing	External hard drive	4	2.3	0.2	0.0	2.5	13.8	-	-	1.1
Computing	Router	13	0.8	1.5[b]	0.0	2.3	7.6	7.7[b]	-	-
Computing	Laptop	11	1.9	0.1	0.0	2.0	31.6	20.2[a]	11.4	2.2
Computing	Multi functional printer	7	0.02	1.5	0.0	1.6	12.7	7.6	-	3.1[a]
Computing	LCD monitor	13	1.1	0.3	0.0	1.4	24.8	-	6.6	1.8
Computing	Computer speakers	7	0.01	0.6	0.0	0.6	9.5	3.4	-	5.0[a]
Computing	CRT monitor	2	0.005	0.6	0.0	0.6	28.0[a]	-	-	3.4[a]
Computing	Printer laser	1	0.3	0.1	0.0	0.4	52.6[a]	5.1[a]	-	-
Computing	Printer inkjet	6	0.004	0.2	0.0	0.2	11.7	2.3	-	1.3
Computing	Digital photo printer	1	0.0	0.1	0.0	0.1	-	-	-	0.3[a]
Audio	Integrated Hi-Fi systems	12	0.1	1.8	0.0	1.9	19.5	16.5	12.6	3.1
Audio	Digital radio	5	0.1	0.4	0.7	1.2	6.1	-	2.1	-
Audio	Clock radio	3	0.0	0.7	0.0	0.7	-	2.2	-	-
Audio	Analogue radio	4	0.1	0.6	0.0	0.7	5.7	-	3.7	-
Audio	Hi-Fi separates	7	0.02	0.5	0.0	0.5	-	-	-	-
Audio	Mp3 docking station	3	0.02	0.04	0.0	0.06	5.1	0.5[a]	-	-

[a] Only one appliance monitored in power mode; [b] Standby values include electricity consumption from active appliances, when the associated equipment (e.g. television, computers) were not active.

Table 4 Average household two week electricity consumption from different ICE appliances, ranked by appliance category and percentage of whole house consumption

Appliance category	**Appliance**	**Number of appliances (Total)**	**Average ownership level**	**Total (kWh)**	**Total standby (kWh)**	**Standby: % whole house (%)**	**Total: % whole house (%)**
Video	CRT television	21	1.5	4.65	0.25	0.15	2.82
Video	LCD television	8	0.6	4.06	0.04	0.025	2.46
Video	STB complex	10	0.7	3.45	2.09[a]	1.27[a]	2.09
Video	VCR	8	0.6	0.94	0.90	0.55	0.57
Video	Games console	10	0.7	0.87	0.56	0.34	0.53
Video	HDD/DVD recorder	2	0.1	0.39	0.15	0.09	0.24
Video	STB simple	3	0.2	0.24	0.17[a]	0.10[a]	0.15
Video	DVD player	9	0.6	0.24	0.21	0.13	0.14
Video	AV trans/receiver	2	0.1	0.17	0.08[a]	0.05[a]	0.10
Video	Surround sound	3	0.2	0.10	0.00	0.00	0.06
Video	AV booster	2	0.1	0.10	0.09[a]	0.05[a]	0.06
Video	VCR/DVD	1	0.07	0.04	0.04	0.02	0.03
Video	DVD recorder	1	0.07	0.00	0.00	0.00	0.00
Telephony	Cordless telephone	14	1.0	1.11	-	-	0.67
Telephony	Cordless telephone extra handset	6	0.4	0.40	-	-	0.24
Telephony	Answer-phone	2	0.1	0.17	-	-	0.11
Computing	Desktop computer	17	1.2	10.26	0.70	0.43	6.22
Computing	Router	13	0.9	2.16	1.43[a]	0.87[a]	1.31
Computing	Laptop	11	0.8	1.58	0.08	0.05	0.95
Computing	LCD monitor	13	0.9	1.28	0.30	0.18	0.78
Computing	Multi functional printer	7	0.5	0.78	0.77	0.47	0.47
Computing	Modem	4	0.3	0.76	0.33[a]	0.20[a]	0.46
Computing	External hard drive	4	0.3	0.71	0.05	0.03	0.43
Computing	Office printer/ copier	1	0.07	0.42	0.33	0.20	0.26
Computing	Computer speakers	7	0.5	0.29	0.28	0.17	0.18
Computing	Desktop with LCD monitor	1	0.07	0.23	0.15	0.09	0.14
Computing	Printer inkjet	6	0.4	0.10	0.10	0.06	0.06
Computing	CRT monitor	2	0.1	0.08	0.08	0.05	0.05
Computing	Printer laser	1	0.07	0.03	0.01	0.01	0.02
Computing	Digital photo printer	1	0.07	0.01	0.01	0.005	0.005
Audio	Integrated Hi-Fi systems	12	0.9	1.65	1.58	0.96	1.00
Audio	Digital radio	5	0.4	0.41	0.15	0.09	0.25
Audio	Hi-Fi separates	7	0.5	0.24	0.23	0.14	0.14
Audio	Analogue radio	4	0.3	0.19	0.17	0.10	0.11
Audio	Clock radio	3	0.2	0.16	0.16	0.10	0.10
Audio	Mp3 docking station	3	0.2	0.01	0.008	0.005	0.01
All	**Total**	**224**	**16**	**38.3**	**11.5**	**7.0**	**23.2**

[a] Standby values include electricity consumption from active appliances, when the associated equipment (e.g. television, computers) were not active.

Table 5 Households' two week whole house and ICE appliance electricity consumption

House -hold	Whole house (kWh)	Total ICE appliance (kWh)	Total ICE % of whole house	Total ICE active (kWh)	Total ICE unknown (kWh)	Total ICE standby (kWh)	ICE standby % of total ICE appliance	ICE standby % of whole house
H1	70.9	10.9	15.4	7.4	1.3	2.3	20.8	3.2
H14	73.2	19.0	25.9	6.0	2.5	10.4	55.1	14.3
H2	176.9	24.4	13.8	15.7	1.5	7.2	29.5	4.1
H3	162.8	25.6	15.7	10.6	1.9	13.0	51.0	8.0
H11	93.8	25.9	27.6	18.0	2.0	5.9	22.8	6.3
H8	185.6	26.5	14.3	6.8	2.9	16.8	63.4	9.1
H5	147.4	26.9	18.2	8.8	2.3	15.7	58.6	10.7
H4	69.7	27.9	40.1	14.2	0.8	13.0	46.4	18.6
H10	232.3[a]	31.9	13.7	14.0	3.3	14.6	45.7	6.3
H9	195.3	34.3	17.6	20.2	3.5	10.6	30.9	5.4
H12	200.0	35.7	17.9	24.9	1.0	9.8	27.5	4.9
H6	261.3	38.8	14.9	10.0	2.1	26.7	68.7	10.2
H13	203.1[b]	49.7	24.5	40.9	1.2	7.6	15.2	3.7
H7	238.6	158.0	66.2	150.0	0.8	7.2	4.6	3.0
Average	**165.1**	**38.3**	**23.3**	**24.8**	**1.9**	**11.5**	**38.6**	**7.7**
Median	**181.3**	**27.4**	**17.7**	**14.1**	**2.0**	**10.5**	**38.3**	**6.3**

[a] H10 used coal and electricity for space heating, and electricity for water heating; [b] H13 based on electricity meter readings; Note: Standby values include electricity consumption from active network appliances (e.g. STBs, modems, routers), when the associated equipment (e.g. television, computers) were not active.