How trends in appliances affect domestic CO2 emissions: a review of home and garden appliances. Technical annex

PUBLISHER

Department of Energy and Climate Change (DECC) and Loughborough University

VERSION

AM (Accepted Manuscript)

How Trends in Appliances Affect Domestic CO_2 Emissions: A Review of Home and Garden Appliances

Technical Annex

Prepared for

Department of Energy and Climate Change

Prepared by

Victoria Haines[a], Kevin Lomas[a], Murray Thomson[a], Ian Richardson[a], Tracy Bhamra[a] & Monica Giulietti[b]

Additional contributors

Tang Tang[a], Clare Lawton[a], Liyan Guo[a] & David Allinson[a]

[a] Loughborough University

[b] Nottingham University Business School

May 2010

Executive summary

Defra's Market Transformation Programme currently models the energy consumption for a number of domestic appliances, using market intelligence data, supported by expert assumption where data are not available. Whilst this provides a view of stock and sales, there is currently less information on the real usage of appliances and actual energy consumption in situ. Additionally, not all household appliances are covered and so taking an holistic approach to understanding domestic energy consumption is difficult.

This review, commissioned by the Department of Energy and Climate Change (DECC), set out to review and collate data to provide an evidence base to domestic appliance usage, and to look for evidence of trends affecting future consumption in the home. The potential use of these data in the construction of models that can inform policy was a central consideration. The review covered data in areas currently modelled by MTP, but did not set out to validate or repeat work done as part of MTP which is well established. It attempted to add to this knowledge basis, particularly in areas not already covered, specifically consumer electronics and gardening. The recent expansion in ownership and use in the home of products in these groups means they may be significant users of energy, but not well quantified. Additional information in areas of user behaviour and the whole-house perspective was also sought.

There was an opportunity during the period of the review, through a major research project being led by Loughborough University (4M) to preview recently collected raw data on household appliance ownership and usage. This gave a direct and immediate insight into a particular sample which also provided information on the value that data of this sort can provide. Initial data from this study are presented here to enhance the data reviewed from other public domain sources.

During the review, it became apparent that significant studies of appliance ownership, usage and measured power consumption did not exist, although pockets of data were available, some very specific to a small survey or appliance sub-group; others studies were more general market research data focused on sales. Additionally, the age of some of the studies meant that data comparisons may be flawed, particularly in areas where rapid changes over time have taken place. In many cases, the source data are not published in full. Very few studies took a whole-house perspective, as this has not previously been of such interest, and there was scarce information on trends. Based on the available review data, supported by 'best guess' assumption using the expertise of the project team members, the energy consumption of appliances in an average household was established, although the lack of relevant data meant that some estimates are more reliable than others.

With these caveats in mind, the following (top 16) appliances appear to be the biggest users of energy within households, although in some cases, their more limited market penetration means they may not have the same impact on a national scale:

- Swimming pool equipment
- TV (Plasma)
- Fridge-freezer
- Pond cleaner / filter / vacuum
- Other electric space heater
- TV (LCD)
- Security alarm
- Dishwasher
- Hot tub / Jacuzzi
- Dehumidifier
- Green house heater
- Freezer (various types)
- Electric hob
- Tumble dryer
- CCTV system
- Electric oven

Policies relating to the consumer usage and alternatives to these appliances could be targeted to specific sectors of the population who use them most.

The following (top 16) appliances appear to be large energy consuming products across households, based on average figures across the UK and policies relating to the usage of these appliances might usefully be targeted at the whole population:

- Fridge-freezer
- TV (LCD)
- Washing machine
- Tumble dryer
- Outdoor lighting
- Electric oven
- Refrigerator
- Dishwasher
- TV (CRT)
- Freezer (chest and upright)
- Kettle
- Electric hob
- TV (Plasma)
- Security alarm
- Electric shower
- Desktop computer

A note of caution is appropriate here; whilst an estimate of the priority areas has been attempted within the short time scale of this project, the lack of appropriate information means that much greater understanding is needed before these findings can be verified and effective policies implemented. A better understanding of behaviours is needed in order to develop targeted interventions and policies. There are unknown and complex issues of behaviour to be considered so it is very difficult to give specific intervention strategies at this stage. Detailed and extensive behavioural studies on a national scale and across the range of demographics are needed to better understand how and why people use appliances. The household is a complex system and so understanding the impact of interactions between household members is also needed. This behavioural understanding can then be translated into designs and intervention strategies.

Issues relating to future modelling of appliances have also been uncovered in this review. A significant number of gaps in the data are present, and need filling if a reliable and useful appliance model is included in a future household energy model. Current building stock energy models do not include sophisticated appliance sub-models. BREDEM is at the core of most UK domestic energy endeavours and calculates appliance energy demand based on floor area (or floor area and number of people in the household) alone. Such an approach cannot reproduce the large variations in appliance energy use that are observed in practice. Other more sophisticated models are emerging but they are operationally constrained by the availability of data on appliances and their use, and the relationship of these to occupancy characteristics, particularly with regard to actual appliance use in situ. The review has also discussed issues that should inform the development of a National Household Model, currently being scoped as part of a separate exercise.

In conclusion, this review has examined a wide range and number of sources of information in an attempt to understand current usage of appliances and how ownership, usage and energy consumption might change in the future. In practice, many gaps in the required data have been found, so that reliable conclusions about energy consumption and carbon emissions cannot be drawn yet. This limits the ability to model appliances accurately with the current data, but with targeted data collection, particularly relating to behaviour and use of appliances, will allow this important area to be modelled in the future. The joint Defra, DECC and Energy Saving Trust Product Usage Study recently commissioned will provide some of the required data, but this must be supported by more detailed qualitative investigations of behaviour to provide an understanding of the underlying motivations and barriers to change.

This review, undertaken by a multidisciplinary team from Loughborough University, was commissioned and funded by DECC. The views expressed reflect the review findings and the authors' interpretation; they do not necessarily reflect DECC policy or opinions.

Table of Contents

Appendices

1.0 Introduction

The Climate Change Act (2008) sets a legally binding target of an 80% reduction in national CO_2 emissions by 2050 compared to 1990 levels (TSO, 2008a). In order to achieve these targets, it is important to understand how energy is being used currently, and to take targeted actions that will reduce future energy use and hence carbon emissions. Final energy consumption in the UK by end use for 2008 are shown in the following figure (DECC, 2009).

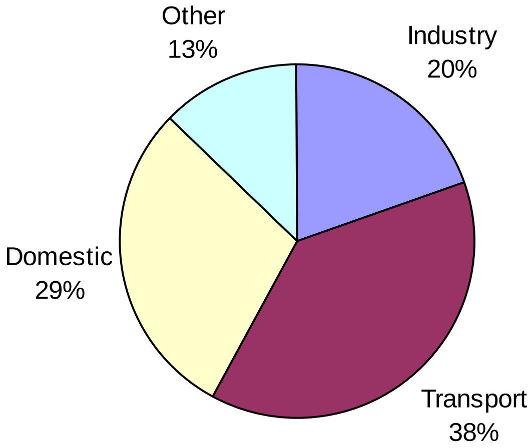


Figure 1. Final energy consumption by end use, 2008

Domestic energy forms 29% of the total UK consumption. This is further broken down in the following figure (2007 data), showing the relative contributions of space and water heating and cooking, lighting and appliances to the total domestic energy use.

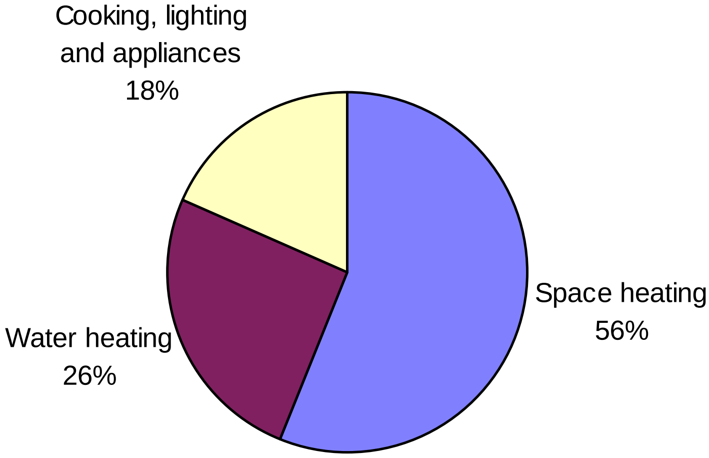


Figure 2. Domestic energy consumption by end use, 2007
Source DECC – secondary analysis of data from Building Research Establishment

More than three quarters of the use of energy in the home is attributed to space and water heating; the rest is as a result of lighting and appliances, including cooking. In the past, domestic CO_2 emissions have been primarily associated with space heating.

Efforts to reduce domestic energy consumption have traditionally focused on improving thermal insulation of buildings and increasing the efficiency of heating equipment.

Building Regulations and related policies focus on improving fabric and energy system efficiency in new dwellings: indeed, the SAP calculation, which underpins the Regulations focuses on ‘the asset’, e.g. the dwelling and its energy systems, with occupancy heat gains being based on a standard usage pattern for all dwellings. The Great British Refurbishment (DECC 2009d) also focuses on fabric and plant in an effort to drive down the carbon emissions of the existing housing stock. However, the marginal Abatement Cost curves published by the Commission for Climate Change, and works by others, show that reduction in appliance energy use by is one of, if not the, most cost effective methods for reducing the carbon emissions of the UK (TSO 2008b). As we move to a future where homes are much more energy efficient, and, perhaps, where electrical energy supplies a much greater proportion of homes energy demands (see section 2 below), understanding and controlling the energy use of domestic appliances will grow in importance.

It is known that there is a very large variation in the electrical energy demands of dwellings (see figure below). Whilst there is a strong lower-bound on electricity demand there is no effective upper bound, thus the upper quartile of electrical energy users consume very much more than the lower quartile. Understanding what drives this high usage is important. One might perhaps focus policy on reducing such high demands? Most current domestic electrical demand models are blind to such variations in usage.

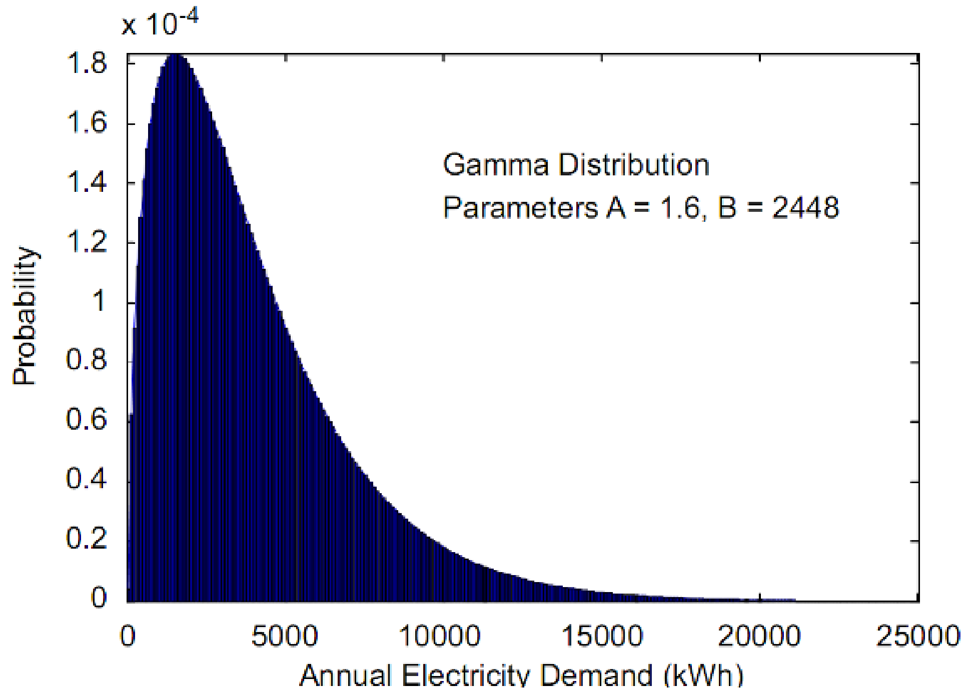
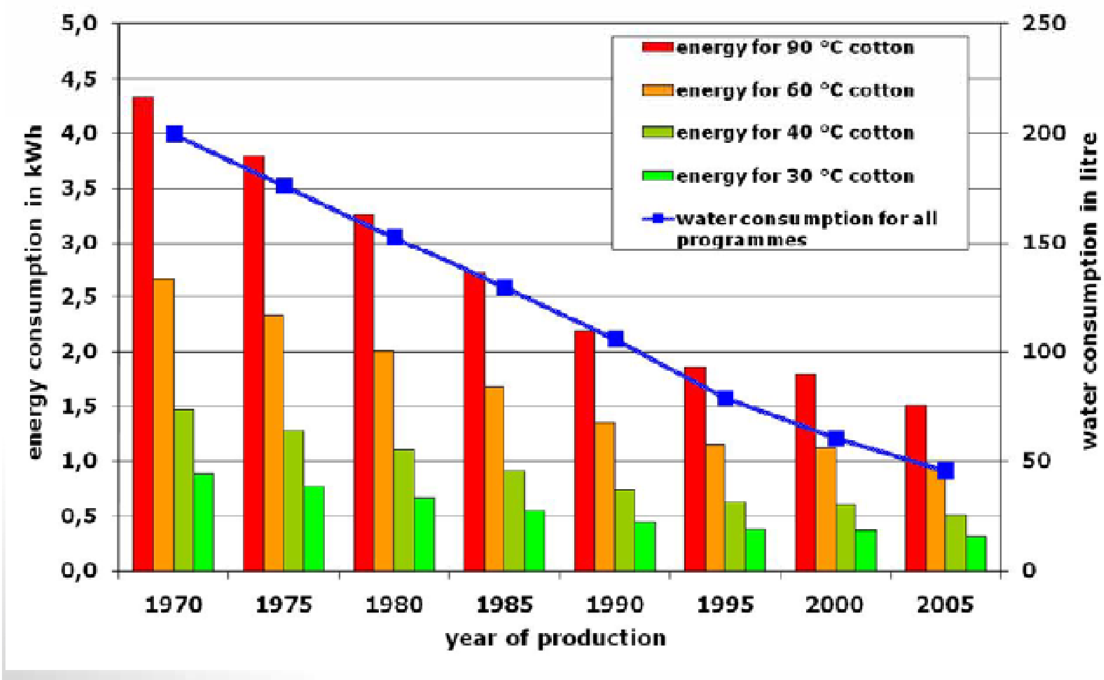


Figure 3. Estimated domestic electrical energy demand for England, after Hawkes and Leach (2008)

There have been achievements as a result of the Ecodesign Directive 2009 which has set a number of measures with minimum standards for lighting, cold appliances, motors, set-top boxes, external power supplies, stand-by, etc. Substantial improvements in technical efficiency of several major appliance types have helped reduce their energy consumption tremendously, for example washing machines, as demonstrated by the following figure (from Gutberlet, 2009)



Source: Prof. Dr. Rainer Stamminger, University of Bonn

Figure 4. Improvements in washing machine energy and water consumption

However, there is still a general rise in electrical consumption in the domestic sector, illustrated in the next figure.

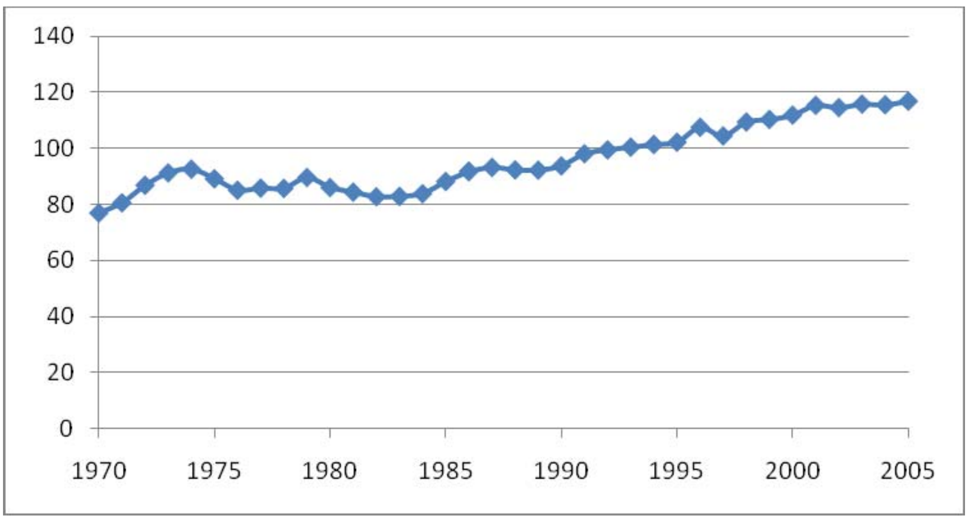


Figure 5. UK Domestic Electricity Consumption (TWh/y)

Source: DUKES, 2009

The overall increase in energy consumption associated with appliances is caused by the two main factors, which have a complex interdependency:

- increased ownership of appliances
- increased use of appliances.

This increase in appliance energy consumption, if unchanged, will have a significant impact on future domestic energy demand, an issue raised by the Energy Saving Trust in 'The Rise of the Machines' in 2006. In order for the Government to make targeted policies in the future, a better understanding of appliance usage is needed. However, this knowledge is limited. Defra's Market Transformation Programme currently models the energy consumption for a number of domestic appliances, using market intelligence data, supported by expert assumption where data are not available. Whilst this provides a view of stock and sales, there is currently less information on the real usage of appliances and actual energy consumption in situ. Simple measurements can provide data on individual appliance power consumption in use. However, understanding of usage of appliances, particularly from a household perspective, is more limited.

As domestic buildings become more energy efficiency, emissions as a result of space heating should reduce. However, if appliance energy continues to rise, the impact of appliances on the domestic sector will increase. This provides an additional imperative to understand the impact of appliances in a domestic context.

The Department for Energy and Climate Change commissioned a team led by Loughborough University to review data on domestic appliances in order to identify where the priority areas for future policy should be. This report details the data collected and highlights issues that a future domestic household model needs to consider when modelling appliances.

This project aimed to draw together information about the energy demands of current domestic appliance use at a household level, and explore trends in future use, in order to predict future demands. This information could then be used to inform future household models that include an element of appliance modelling, building on existing knowledge, and so issues relating to household appliance modelling were also considered to ensure any data were reviewed in context.

This review covered all domestic appliances within the home that could easily be removed (i.e. with a plug), although in some cases it was not easy to isolate only these appliances from data sources. All items that use energy within the garden were also included in the review (e.g. garden power tools, pond filters, security and decorative lighting) to gain a better understanding of this aspect of home energy use.

2.0 Changes on the horizon

2.1 Low-carbon electricity

Plans to reduce overall CO_2 emissions rely heavily on electricity generation from renewables, nuclear and fossil fuels with carbon capture and storage (CCS). The hope is that massive deployment of some or all of these technologies will provide low-carbon electricity. Additionally, this low-carbon electricity will be used to decarbonise transport, particularly through electric vehicles, and could be used to decarbonise heating, particularly by way of heat pumps. All of this is outside the scope of this report, but one very important factor is definitely in-scope and this relates to the carbon intensity of electricity and how it will vary in the future.

At the macro-scale the carbon intensity of UK electricity has decreased significantly over time, although it has risen modestly in recent years, shown below.

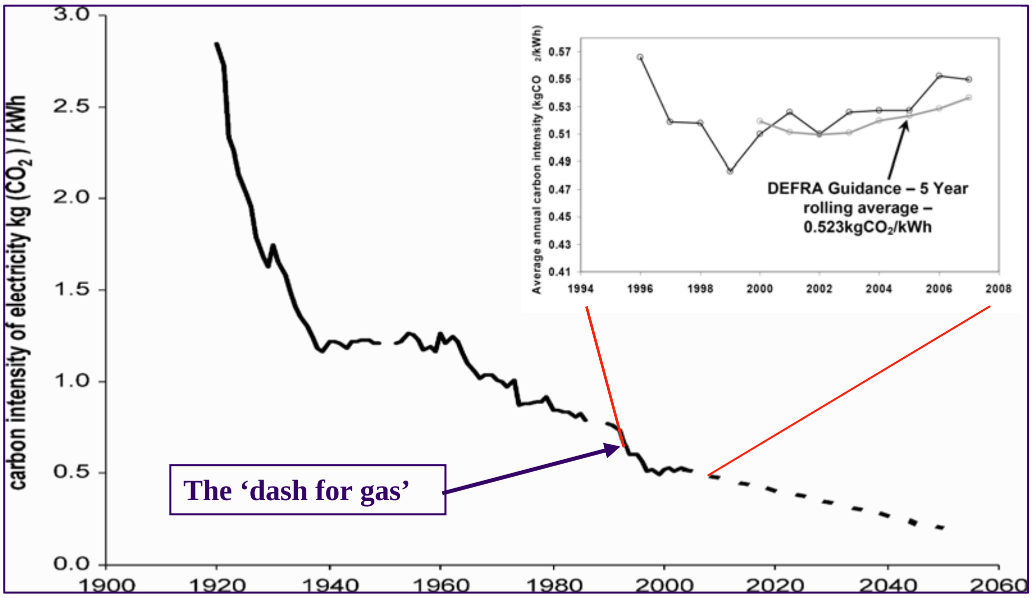


Figure 6. Change in the carbon intensity of UK electricity, with speculative projection indicating trajectory if electricity to have same carbon intensity as gas by 2050[1]
(with thanks to Lowe, UCL, private communication 2009)

At the more detailed, half-hour by half-hour scale, the carbon intensity of electricity is determined by the fuel mix that goes into its generation. In the past and present (2010) in the UK, this mix has been fairly constant with modest swings between gas and coal. Thus, it has been reasonable to estimate an average carbon intensity and to take this as a constant when considering the CO_2 emissions due to appliances (the value used varies with source but is around 0.5kgCO_2/kWh). In other words, there is a simple relationship between saving energy and reducing CO_2 emissions.

[1] Data for electricity generation and fuel inputs are from http://www.dti.gov.uk/files/file18945.xls (accessed 6 Nov 2006). Background Data for Fuel Consumption (http://www.naei.org.uk/reports.php) accessed 6 Nov 2006).

In the future, when the production from renewable sources, such as wind, represents a larger fraction of grid electricity the carbon intensity could vary substantially from one hour to the next. For example, if it is windy in the middle of the night, the carbon intensity could be very low; but if the wind drops when the morning demand pick-up occurs and non-CCS fossil generation has to be deployed, then the carbon intensity would rise sharply. Thus, there will be a much more complex relationship between saving energy and reducing CO_2 emissions.

Furthermore, this issue is not just related to renewables (including wave, tidal and solar as well as wind,) it is also an issue with nuclear and CCS, both of which are likely to be much less flexible than conventional coal and gas plant. Indeed, there is a general view in the electricity supply industry that, no matter which low-carbon technologies are deployed, flexible generation will become increasingly valuable. This has also lead the industry to take a strong and increasing interest in flexible demand.

Flexible demand is also known as demand response and sits alongside demand reduction under the more general heading of demand side management (DSM). All of these are central to the current discussions and developments in smart meters, and it is possible that some form of time-of-use or real-time pricing will come into play in the domestic sector. This price will in some way reflect the carbon intensity.

In conclusion, the time of use of appliances will become a more important factor in determining the consequential CO_2 emissions. It is likely to be more important to know when appliances are being used, to be able to model this, to understand the potential to use them at different times, and how this time-shifting can be achieved.

2.2 Changing number and type of households

There were 25.7m households in the UK in 2006 (Office for National Statistics, 2010a). The latest national statistics on household projections to 2031 for England suggest that the number of households in England is projected to grow to 27.8 million in 2031, an increase of 6.3 million (29 per cent) over the 2006 estimate, or 252,000 households per year (Household Projections to 2031, England, 2009).

Between 1971 and 1991 the average size of household in Great Britain declined, from 2.91 persons to 2.48. It continued to decline, though at a slower rate, throughout the 1990s, falling to 2.32 by 1998, since when it has changed little. In 2008, the average number of persons per household was 2.37 (Office for National Statistics, 2008b). More than two thirds of UK households in 2006 were family households, and 29% were people living alone. A further 3% of households consisted of two or more people who either were not related or were related but did not form a family. In addition, a small proportion of the UK population live in communal establishments (1.8% of the population).

In England, one person households are projected to increase by 163,000 per year, equating to two-thirds of the increase in households. By 2031, 18 per cent of the total population of England is projected to live alone, compared with 13 per cent in 2006.

If each household is equipped with a 'set' of appliances, this increase in number of households has a significant bearing on the future domestic carbon emissions. Additionally, although a single occupant is unlikely to use as many appliances in parallel, energy consumption from a single occupant household is not half that of a two person household.

There will also be changes in the demographic:

- The average age of the UK population is expected to increase. These estimates show the biggest increases in people aged 25-34 years and 65+ years. By 2031, 32 per cent of households in will be headed by those aged 65 or over, up from 26 per cent in 2006. This ageing population is reflected in their lifestages where an increased number of people will be retired, spending more time at home.
- The socio-economic group forecast shows an increased number of people in the 'AB' category, based on occupation of the head of the household. AB includes higher managerial, administrative, professional e.g. chief executive, senior civil servant, surgeon and Intermediate managerial, administrative, professional e.g. bank manager, teacher.
- UK household spending has also been increasing steadily and is significantly more than would be accounted for by population increases. This indicates spending per household is increasing and shows no sign of significant change over the next decade. This increased spending means households are able to purchase more appliances and currently can afford to use them without concern for energy costs. More details on this are presented in the next section.

Data tables with further detail of these changes are presented in Appendix A to this report. This changing demographic of the UK is important when understanding appliance use at a household level and predicting how this may change in the future. Only by understanding the users of the future can appliance demand be estimated.

2.3 Changing expenditure on domestic appliances

The recent trends in consumer expenditure on domestic appliances expressed at current prices show a sustained increase in expenditure for telecommunication appliances which does not seem to have been affected by the difficult economic conditions of the last two years. The growth rate in expenditure for all other domestic electrical goods seems to have declined starting from 2004-05. As will be discussed below, however, the trend in current expenditure is partly driven by a persistent decline in price levels which has made some of the items (especially PCs and other computing equipment) much more affordable, relative to average income, in recent years.

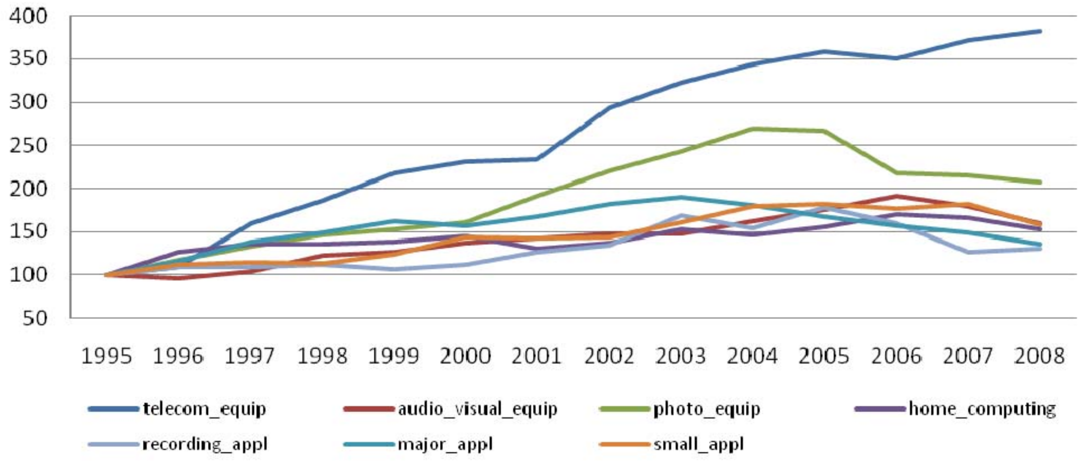


Figure 7. Expenditure at current levels, 1995-2008 (base 1996=100)

The data on expenditure for appliances at 2005 prices give us an indication of the trends in demand for different types of appliances at a relatively low level of aggregation. The figure below reveals a very remarkable increase in demand for home computing equipment. The demand for telecommunication, photographic and audio-visual equipment has displayed a sustained growth, although not as remarkable as for home computing equipment. The demand for audiovisual equipment seems to have declined slightly in the last year, possibly as a result of worsening economic conditions. On the other hand both major and small electrical appliances and recording equipment present a flatter profile over the period of time observed, similar to trend observed in the expenditure at current prices for these items. The growth rates displayed by expenditure at fixed prices reveal a sustained and increasing demand for all items, with the exception of domestic appliances, which is more starkly apparent than from the data on expenditure at current prices, where the measured growth is mitigated by the considerable decline in the relative prices of several of these appliances.

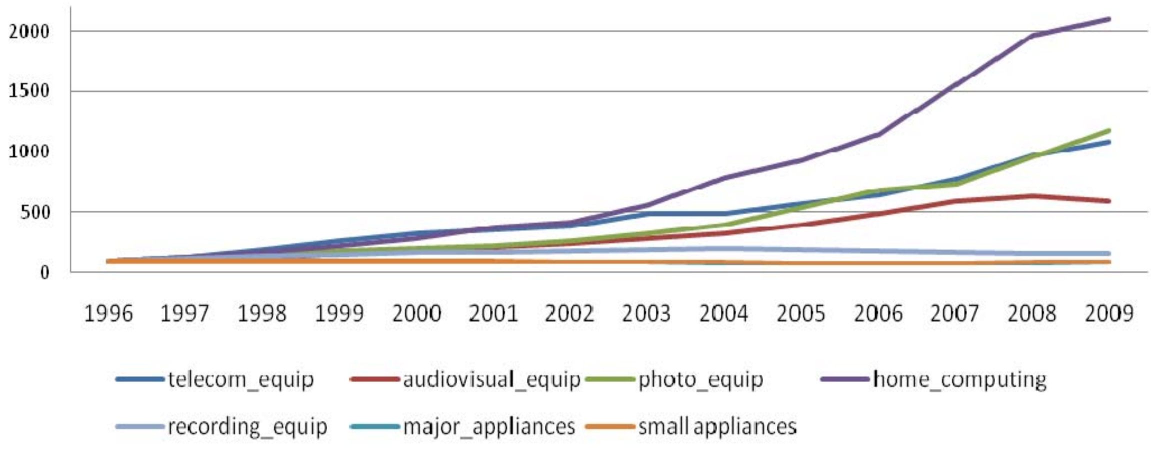


Figure 8. Expenditure on domestic appliances at 2005 prices, 1996-2009 (base 1996=100)

The price indexes for the categories of domestic appliances available from ONS data on consumer prices are less detailed than the information on consumer expenditure. In recent years the price indexes for electrical and electronic equipment have exhibited a declining across all items with more substantial drop in the prices of home computing, audiovisual and photographic equipment, relative to more ‘traditional’ appliances, as illustrated by the figure below.

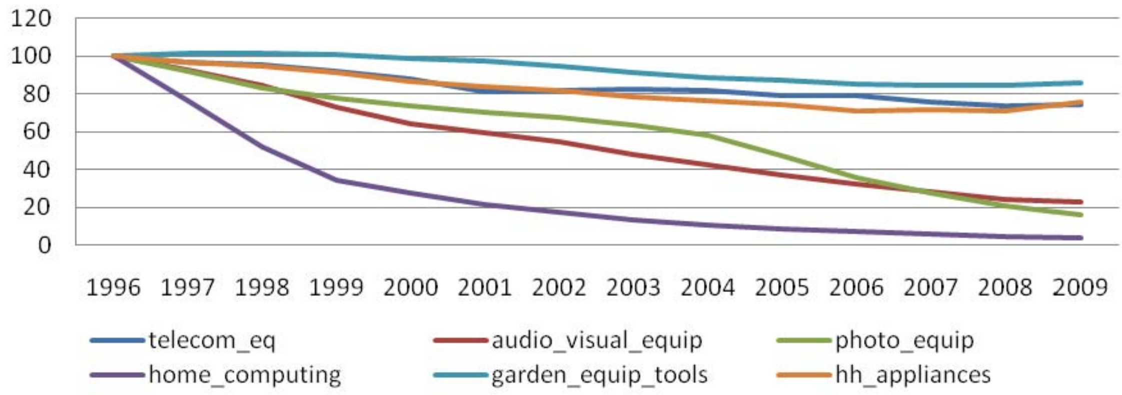


Figure 9. Consumer Price Index, 1996-2009 (base 1996=100)

All the three measures of income chosen to represent the general state of the economy in the period of interest (GDP, households’ disposable income and consumer expenditure) have been characterised by steady growth since 1996, with a recent decline, starting from 2008 as a result of the recent economic recession.

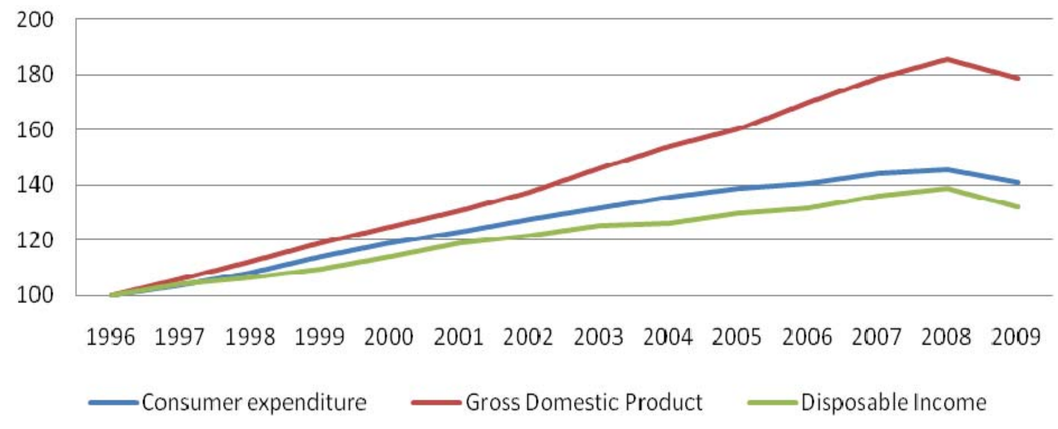


Figure 10. Income and expenditure, 1996-2009 (base 1996=100)

Over the same period of time retail sales in household goods stores have increased on average by 22% with peaks at around 30% in 2004 and 2007 (ONS, 2009). A steady growth was also observed in the number of appliances owned by UK households (DECC, 2008) with the most remarkable increases for home computing equipment and consumer electronics, both with growth rates in excess of 100%, as illustrated overleaf.

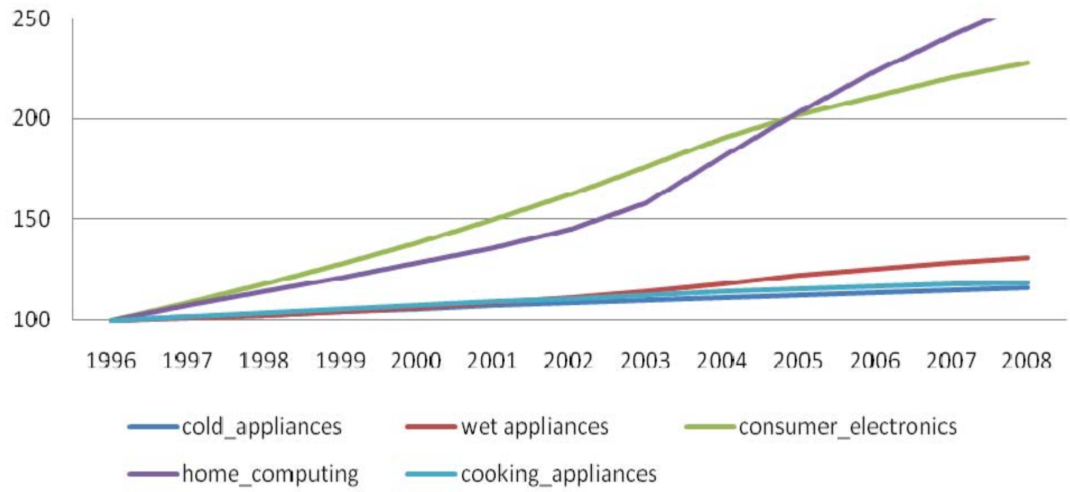


Figure 11. Appliances ownership, 1996-2008 (base=100)

The available evidence, based on quarterly observations from 1996 to 2009, indicates that the consumer demand for the main appliances categories (major appliances, small electrical appliances, home computing and audiovisual equipment) is sensitive to price variations (with a negative elasticity as expected) but not to income variations (the coefficient on real disposable income is not statistically significant in most cases – see table). The main exceptions are telecommunications equipment, with a significant income effect on expenditure for these items, and photographic equipment, which displays a high and significant elasticity (with expected signs) to both own price and income.

These results would therefore lead us predict that future demand for domestic appliances and audiovisual equipment will be driven mostly by trends in prices. The prices for these consumption categories over the last 15 years have been characterised by a sustained decline (as discussed above) as a result of technological change in the production and distribution technology. It is important to remark, however, that the results on demand elasticity do not account in any way either for differences in energy efficiency in the appliances purchased or for levels of emissions associated with different types of appliances.

Table 1. Estimated coefficients of demand elasticity (all variables in natural logarithms)

Product	Telecomms	Audiovisual	Photo	Home computing	Major appliances	Small appliances
price effect	**-2.7262**	**-1.121**	**-0.735**	**-1.198**	**-1.717**	**-1.957**
t-statistic	-3.4396	-5.329	-11.146	-8.610	-6.918	-2.831
income effect	**4.3100**	1.054	**3.799**	-2.112	-0.036	-0.866
t-statistic	5.5204	1.034	10.244	-1.502	-0.124	-1.064

Coefficients in **bold** are significant at 5% level

A more detailed analysis of demand for appliances with different efficiency characteristics (or more generally different quality) might generate different values for both income and price elasticity compared to those discussed here, which are limited by the level of aggregation in the available data.

Furthermore, a more detailed statistical analysis of the drivers of expenditure on these items which also include cross-elasticity with other goods and lagged effects of dependent and explanatory variables should generate more robust results and better defined expenditure patterns, although this is also limited by the level of aggregation and time span of the information about prices.

3.0 Appliance energy modelling

One purpose of this review was to inform the development of appliance energy models that may then be used to inform the development of policies, regulations and other interventions aimed at reducing CO_2 emissions. DECC plan to create a National Housing Model (NHM), to include an appliance sub-model, and have recently commissioned Element Energy to conduct a scoping study. From Element Energy's Functional Specification (2010), they comment that this model will sit at the core of household energy use policy making and evaluation, and is intended to bring a step-change in functionality from any currently available models. The NHM will need to be extremely flexible, modular and offer a wide range of disaggregated results, to enable the evaluation of future policies and interventions.

Clearly, the conclusions from this review will inform and impact on the nature of this model. In order to understand how appliance modelling is undertaken currently, approaches to modelling appliances are summarised in the following sections.

3.1 Purposes of and approaches to modelling

There are several fundamentally different approaches to modelling domestic energy use in relation to appliances that could be considered in pursuit of this general aim. They include "top-down", "bottom-up", statistical and physically based approaches. Each approach has its advantages and disadvantages depending on the intended application and in practice, the most useful models often include a mixture of techniques. Swan (2009) provides a good review of an international selection of domestic energy use models in terms of their underlying modelling techniques.

The key factors regarding the suitability of a specific modelling approach are:

- the intended purpose of the model. – In what respects does it need to be accurate? and,
- the data required to build the model.

These factors are closely related, and an ambition to build a very general purpose model, with the hope of it being universally accurate, is likely to be defeated by lack of data. Successful modelling is characterised by a clear sense of purpose and achievable data requirements.

The potential purposes of enhanced appliance energy models in the UK are multiple. Consider the following example interests:

- The tender for this review mentioned specific interest in communication, entertainment and computing, which suggests a focus on these particular gadgets and equipment, and might lead to a model that can differentiate ***which appliances are being used***, as opposed to merely being owned.

- The tender also mentioned the trend toward larger appliances. However, the relationship between appliance size, power and energy use is not straightforward (a powerful hair drier might complete the task in less time whereas a large television may be viewed for more time). A model to investigate these factors would need to represent ***how appliances are used***.
- The increase in outdoor living and the use of appliances in the garden was also flagged up and this interest would suggest a model that can differentiate ***where in the property*** appliances are being used.
- Local authorities are likely to be interested in localised and regional modelling that represents ***where in the country*** appliances are being used.
- An interest in "different types of houses" concerns factors such as ***floor area, flats, terraced and detached***.
- Changes in household numbers and the ageing population leads to interest in modelling that can represent ***who is using appliances***.
- The prospect of carbon intensity varying significantly from one hour to the next gives interest in modelling that can represent ***when appliances are being used***. Time-of-use is particularly relevant to the electricity supply industry.

The above is just the beginning of what could be a very long list but it already illustrates the breadth of interest in modelling appliance energy use and the potential complexity and data requirements of a general purpose model. It may be better to consider a suit of models with different foci but underpinned by a consistent set of core data.

The above list also points towards physically based bottom-up models. In terms of appliance modelling, this usually means that energy consumption is taken to be the product of:

- power demand of the appliance(s),
- usage, and
- ownership.

With this in mind, much of the data discussed in this review is in this format.

Physically based bottom-up models are well suited to looking at trends in appliances and sudden changes in technologies, ownership and usage. Swan and Ugursal (2009) describe physically based models as "engineering methods" (EM) and confirm: "If the objective is to evaluate the impact of new technologies, the only option is to use bottom-up EM techniques."

Having chosen a physically based bottom-up approach, it is easy to become blinkered, but it is worth remembering that, if the purpose of the model were different, for example to explore the effect of changing domestic energy prices, then a physically based bottom-up model may not be the best approach.

The next sections discuss briefly the status of physically based bottom-up domestic energy models and data sets that are already widely used in the UK. These can be loosely categorised into those focusing on:

- buildings and their thermal behaviour, and
- appliances and their electrical consumption.

Examples of each often include simplified aspects of the other. Building stock models are discussed first, and then appliance-focused modelling.

3.2 Building stock models

Building stock models are often based on physical models of individual buildings or building archetypes. The outputs of these calculations are then summed in order to represent the building stock as a whole, be it at a neighbourhood, local authority or national level. In this way, they are bottom-up models, well suited to assessing the impact of individual technological interventions.

Their use in the domestic sector has historically focused on thermal modelling, because heating energy has been the dominant component in domestic energy consumption. Such models usually have an appliance energy sub-model but this is often relatively crude, in many cases being based simply on floor area.

Appendix B to this report summarises thirteen such models and identifies that most of them rely on floor-area methods BREDEM and SAP for their representation of appliance energy. In some cases, more sophisticated or better calibrated appliance modelling is employed, but the general picture is that there is considerable room for improvement, given the broad range of interest in enhanced modelling outlined above.

3.3 Individual appliance models

A little separate from the building thermal modelling described in the previous section, there has also been much work completed in modelling energy use for individual appliances or classes of appliances. Much of this is currently managed by Defra's Market Transformation Programme and includes models for a selection of domestic and commercial appliances. These can be accessed via Defra's What-If Tool and are supported by various Policy Briefs and Briefing Notes.

Domestic appliances included in the What-If Tool include:

- Cold: Chest freezers, fridge-freezers, refrigerators, upright freezers.
- Cooking: Electric hobs, electric ovens, gas hobs, gas ovens, kettles, microwaves.
- Domestic lighting
- Domestic ICT: computers, monitors, non-thermal printers and thermal printers
- Electronics: power supplies, set top boxes, televisions, video recorders.
- Wet: dishwashers, tumble dryers, washer-dryers, washing machines.

For each appliance type within the tool, the annual national energy consumption is calculated as the product of:

- power demand per appliance while in use,
- hours of use, and
- national ownership (total number in UK stock).

An allowance is made for standby power and some appliances are worked out on a per-cycle basis rather than hours-of-use.

The tool provides predictions out to 2020 and is widely used with regard to the appliances it covers. It does however have various limitations:

- It does not cover all appliances.
- It has no concept of a house or household.
- It provides only national averages and totals.
- It provides only annual figures.

3.4 Household and all-appliance models

One might hope that modelling all the appliances in the domestic sector would simply be a matter of adding the individual appliance models mentioned in the previous section, supplemented by similar models of the remaining appliances. In practice however, this approach is fraught with problems. The first of which is getting the parts to add up to the whole.

In the absence of any single comprehensive data set, the modeller is obliged to take data from disparate sources and to make adjustments in order to achieve numeric consistency within the model. Given the level of inconsistencies and gaps within the available data, these adjustments are likely to be gross and lacking justification. The resulting models may be significantly misleading.

As an example, the following figure shows national electricity demand data for 1998, at a domestic appliance level, from four different data publications / updates (Fawcett et al, 2000; Defra's What-If? Tool, (consulted 26th February 2010); DECC, Energy Consumption in the United Kingdom, 2009 Update, Table 3.10; DECC, Energy Consumption in the United Kingdom, 2008 Update, Table 3.10). Each of the sources shown lists a number of domestic appliances (or appliance groups), which are represented by the different colours.

It is immediately apparent that summing all the individual appliance demands for each source gives very different total energy demand figures. This can be partially explained by the exclusion of electric space and water heating in some cases, but even taking this into account does not lead to a consistent picture.

Also apparent is that the sets of appliances are not the same in each case, either because there is a different appliance categorisation, or the granularity of the data is different. However, even where the appliance types are the same, the individual energy demands do frequently differ, in some cases considerably.

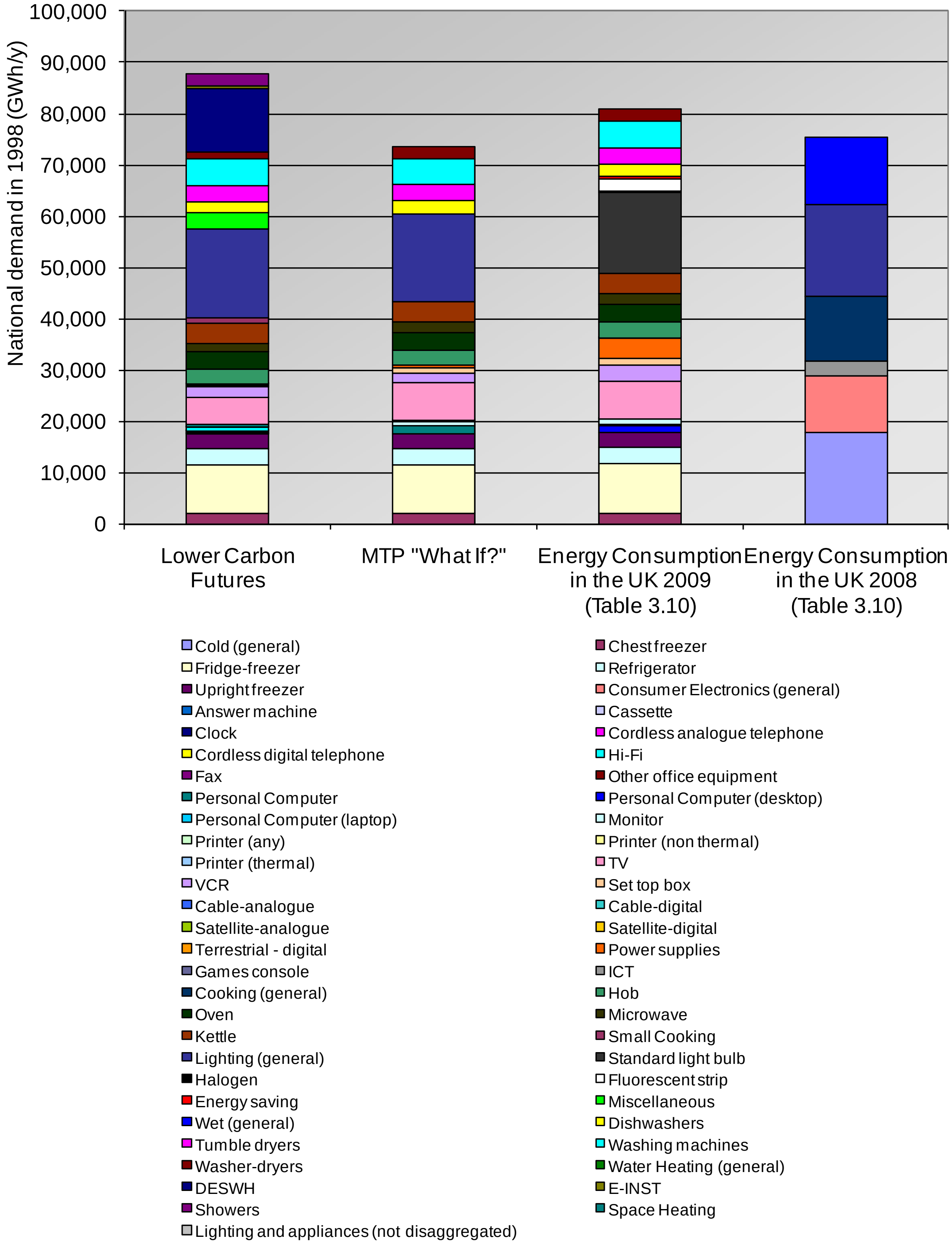


Figure 12. National domestic electricity demand in 1998 from four different sources

The second problem in bringing together individual appliance data into a household model is the lack of statistical confidence. As an example, three of the four publications discussed previously provide three different annual demand levels for a microwave appliance. At a 95% statistical confidence level, taking these three values into account, it can only be said that the national annual demand from this appliance type is in the range 1425 GWh/y to 2239 GWh/y. In this example, a notional 100 GWh/y demand reduction target would be lost in this considerable statistical uncertainty.

Compounding this concern is the observation that, when data do appear to be consistent between publications, it is often so close as to infer that it is derived from the same source. To have confidence in models, it is necessary to understand the basis and assumptions of the input data. Published appliance data rarely has this.

3.5 Enhanced appliance modelling

The discussion on the purposes of appliance modelling, at the beginning of this Section, included a short but ambitious list of specific interests that would require models with specific functionality. This pointed to the need for physically based bottom-up models and mentioned their significant data requirements. These data requirements are related directly to the specific purpose of the model in hand. For example, a model to look at the effect or the ageing population would require data disaggregated in this respect.

The intervening discussion, however, has presented a rather weak starting point for any such ambitious modelling. Significant inconsistencies and uncertainties in the aggregated national annual figures have been illustrated and this provides a poor basis on which to build detailed disaggregated models. The next Section will take a closer look at the data required to address this.

4.0 Data requirements and availability

In order to understand domestic appliance energy demand, three key categories of information are important:

- **Ownership of appliances by households.** Often referred to as market penetration of appliances, the key factor is presence in the home, rather than the legal ownership, although the term 'owned' will be used in this report for ease. This is informed by numbers of sales of new products, but also requires an understanding how long people keep old appliances and what they do with old ones when they buy new. Sales figures alone do not provide information on the spread of appliances between households; for example one product per household does not determine whether every household has one or whether only 50% of households have two, so understanding multiple ownership is important. Understanding about how products are disposed of and their end of life use is also relevant to this issue.
- **Usage of the appliance in the household.** Some appliances are in constant use, for example cold appliances, so it is reasonable to assume that the majority of fridges in households are in use 24 hours a day. Other products are used regularly, but not constantly, for example TVs, kettles and cookers, which are likely to be used each day but only for a part of the day. Other products are used less frequently, for example power tools and certain kitchen appliances. These may be used seasonally (e.g. garden appliances) or weekly (e.g. cleaning appliances). Households also contain products that are rarely or never used; an old fan heater in the garage is still owned but no longer used. Where multiples of appliances are owned, it is possible that the primary appliance is used more than the secondary or tertiary (e.g. televisions). However, multiple cold appliances are all likely to be in use 24 hours a day. Behaviour and interaction with an appliance is also of relevance – products are not always used as per the manufacturer's instructions and so this may affect the energy demand.
- **Power consumption of the appliance.** The power consumption of individual appliances depends heavily on the appliance in question: the magnitude and variation of power demand are both an issue. Clearly some appliances have much greater power demands than others, differences may be of 2 or 3 orders of magnitude: a recharging phone a few watts, and a kettle, 2 kW. Variations though, are more complex, microwaves, cleaners, ovens, and many other appliances, have different average power demands during their period of active use depending on the 'setting' chosen (see also washing machines above). Also, many appliances consume power, and different amounts of power, when in the 'off' mode as well as in stand-by mode. Thus, the 'average power demand' of many electrical items has much more to do with the way they are used than their nominal power rating.

There are significant efforts to model individual appliance energy demands through the Market Transformation Programme, but this does not provide a household perspective. There are few studies that have tried to itemise household appliance ownership and even fewer that have explored usage of these appliances. This isn't so surprising given the complexity of the problem. Since all three of the above factors are at play in any one household, and because the rate of change of appliance ownership can be relatively rapid, there are marked variations in appliance energy demand between households and even households that live in nominally very similar homes can have very different appliance energy demands.

For example, one investigation Firth et al (2008)[2] found a six-fold variation in the measured annual electricity consumption of the 72 studied dwellings over a two year period. Even dwellings on the same site and with similar built form had notably different annual electricity consumptions. Clearly, the number of occupants, number and type of appliances, and occupancy patterns are in this case, more influential than built form.

There are reasons why data on appliance use is limited:

- The UK's Load Research Group was wound down in 2003 and since then data collection activities have typically been piecemeal and piggy-backed on other research.
- Data collected or sponsored by commercial organisations is usually not widely available.
- Even universities are now reluctant to share data since they are credited for publications but not for the data per se.
- Dramatic improvements in data-logging technology have not yet been fully exploited. Even the "smart meters" currently being trialled in the UK will not provide data at the required resolution.

However, the rapid developments in wireless sensor technology are revolutionising the monitoring, and even the control, of electrical appliance. We may be on the cusp of a monitoring revolution, which could significantly enhance our understanding.

Data about appliances are presented in a number of places and these have been consulted in this review:

- Published reports from market research organisations and trade associations, usually focusing on the value of the market and speculation on future trends in sales. These are usually based on large samples, with detailed information about demographics of the market but rarely include details of product usage or energy consumption.
- Research reports of studies into aspects of energy consumption or supply, often where measurements from specific appliances are reported, but few behavioural aspects are included.

[2] A monitoring study of the electricity consumption of a sample of UK domestic buildings. Five-minutely average whole house power consumption was recorded for 72 dwellings at five sites over a 2-year monitoring period.

- Research reports of studies into behaviour or lifestyle with an energy consumption focus, but usually without detailed monitoring of appliances.
- Academic papers, often reporting small scale studies or more extensive surveys of specific product types.
- Other sources, including websites, news articles, etc.

Raw data are seldom published and so aggregated information only is available. There are also limitations in terms of how appliances are described and classified into groups. For some appliance groups like 'Cold appliances' there are reasonably consistent terms used (Fridge-freezer, refrigerator etc). However, for other groups, the categorisation is less consistent, e.g. the categories 'Information technology', 'Information and consumer electronics' and 'Entertainment' include overlapping areas and total values are given, rather than detailed breakdowns. The so-called convergence of technologies (machines for TV watching, photo viewing, internet browsing, messaging, and Skyping, for example) also complicates categorisation.

There are also issues relating to the depth of data published. Studies may collect detailed demographic data or information about other influencing factors (such as whether a house has a garden), but these are often not included in published outputs if they do not form part of the argument being made.

4.1 Opportunities to access more detailed data

Running concurrently with this project, and yielding relevant information, was an EPSRC funded project called, for short, 4M[3]. Led by Loughborough University and funded by the Engineering and Physical Sciences Research Council, the project is attempting to model the direct carbon footprint of the city of Leicester by:

- **Measuring** the carbon released by traffic, by the burning of fossil fuels in homes and places of work, and the rate at which green plants and trees capture carbon and lock it in the soil;
- **Modelling** the effects on carbon budgets of: road layouts, traffic volumes and traffic speeds, the way we use energy in our homes and places of work, and the way we look after green spaces;
- **Mapping** the sources and sinks of carbon for the whole city and comparing this with the social and economic well-being of its 270,000 inhabitants; and
- **Management** studies which will investigate how to shrink the city's carbon footprint through: changing the road network and/or the provision of better public transport; alterations to the maintenance of green spaces and the treatment of waste; and the use of renewable and low energy systems and energy efficiency measures to reduce the carbon emissions for the provision of power and light.

[3] Measurement, modelling, mapping and management: a methodology for shrinking the urban carbon footprint (EPSRC, SUE2 programme).

As part of this research project, a face-to-face interview had undertaken with c500 households to understand, amongst other things, the socio-economic status of the household and the fabric construction and energy systems. This was supplemented, during the course of this DECC project with a postal appliance questionnaire from which there were c250 responses. The aim was to gain a better understanding of the appliances owned, the size of the major appliances and their energy demands. The DECC project team had early sight of the raw data. Further details of the 4M survey are presented in Appendix C to this report.

5.0 Review of appliances

Literature relating to domestic appliances was reviewed, to determine data about the key issues of ownership, usage and energy consumption. Additional data were noted where they appeared relevant to understanding the landscape of household domestic appliances.

A wide range of sources in the public domain were reviewed to support the data from the Market Transformation Programme used in current appliance modelling; these included large scale Mintel market survey reports, formal reports of comprehensive research studies and academic papers reporting small scale detailed surveys of specific appliances. Pertinent data from each of these were collated and compared with information from other sources, to identify any commonalities or trends and these are discussed in the following sections. During the review, it became apparent that significant studies of appliance ownership, usage and measured power consumption did not exist, although pockets of data were available. In some cases these applied to only one product type, or one consumer group. As a result, a 'patchwork' of information was built up, rich and robust in some cases, threadbare in others. Where little information was found, assumptions based on the expertise of the project team were used. Therefore, a level of confidence about the reliability of the data was created, as follows:

High Confidence - Where a study of a significant or representative number of people or households has been conducted, such as a recent Mintel survey or where there are several smaller studies of reasonable reliability are all saying the same thing, and where the product in question is clearly identified.

Moderate Confidence - Where there is some guidance, perhaps from a reliable survey but not relating to a specific product (e.g. kitchen mixers / blenders / food processors etc); or where there is a smaller or older study that is indicative but not necessarily robust; or where there are several studies all saying quite different things, but a mean, median or mode could be taken.

Low Confidence - Where there was no information found, where assumptions based on expertise was necessary or where significant interpretation of the data was required.

Data are categorised as follows, in an attempt to follow other categorisation systems where found:

- Domestic cold appliances
- Domestic wet appliances
- Domestic cooking appliances
- Domestic information, communication and entertainment appliances
- Domestic garden and DIY appliances
- Domestic standalone environmental control
- Other domestic appliances.

5.1 Domestic cold appliances

Domestic cold appliances include refrigerators, fridge-freezers, chest and upright freezers. Data about their ownership and use is reasonably consistent and reliable, with several market research studies covering these appliances being completed in the last few years.

There is an almost 100% penetration level for cold appliances in all EU countries including the UK (Bertoldi and Atanasiu, 2009) and this is not expected to fall in future (Mintel 2007a).

5.1.1 Refrigerators, fridge-freezers and freezers

Fridge-freezers form the majority of the UK market, with approximately 65% penetration (63.7% in 2008 (Mintel 2009h); 65.1% in 2010 (4M, 2010)), which is in line with DECC's figures of 65.1% in 2006 (DECC, 2008). Mintel (2009h) also report that fridge-freezer ownership has increased at the expense of refrigerators and freezers. Yao and Steemers (2005)[4] and Mansouri et al (1996) [5] report 58% ownership of fridge-freezers from their studies.

Mintel (2009h) report 2008 ownership of refrigerators at 53.3% of households, a figure approximately in line with other sources (53% Yao and Steemers, 2005; 58% Mansouri et al, 1996). There is evidence that more men than women are buying new refrigerators, perhaps as a result of single men setting up home for themselves (Mintel, 2007a). Although the market for refrigerators is declining (Mintel, 2009h), sales of larger US style larder fridges is growing. However this is limited by the size of UK kitchens so may be a capped market. Small drinks chillers and fridges are also becoming more popular (Energy Saving Trust, 2006), although minimal data were available about their market penetration. A total of 3% of households in the 4M appliance survey reported small drinks coolers in addition to their main cold appliances; however this is from a very small sample who volunteered additional information about these appliances rather than a formal survey of this type of cold appliance.

Ownership of freezers is around 46% (Mintel, 2009h). DECC's 2008 figures of 29.1% upright and 16.3% chest are roughly supported by recent 4M data (26.0% upright, 19.6% chest). Mansouri et al recorded upright freezers in 35% of their sample from 1994 and chest freezers in 20%. The market for freezers is reported to be stagnating, with fridge-freezers having become more popular. Although overall sales of freezers are expected to stabilise, there is also an increasing trend towards upright freezers from chest freezers (Mintel, 2007a).

---

[4] Based on a review of previous studies, end use electrical appliance energy consumption for an average size household was calculated.

[5] A questionnaire survey of energy within households of 661 adults (aged 18 +) mainly in the South-east of England taken between May and November 1994

Whilst there have been improvements in the efficiency of new cold appliances, this has been coupled with an increase in the number of appliances in each home often located away from the kitchen, with figures of 1.4 (Boardman, 1997) and 1.77 (Mansouri et al 1996) cold appliances per home. Data from a large survey in Sweden[6] (Swedish Energy Agency, 2008) found 1.89 cold appliances in houses, although only 1.33 for households living in apartments. AEA (2009) report a recent phenomenon of households owning more than one refrigerator - one for food, one for drinks, negating any energy efficiency gains. Mansouri et al also found that 46% of their households owned two cold appliances, and over 10% reporting to own three. Data from 4M's appliance survey[7] found 48.1% of households with one cold appliance, 37% with two and a further 14.4% of the sample with three or more cold appliances in their homes.

Table 2. Total number of cold appliances in 4M households

Number of cold appliances	Number of houses	Percentage
1	113	48.1%
2	87	37.0%
3	28	11.9%
4	5	2.1%
5 or more	1	0.4%
none	1	0.4%

4M's appliance survey found 29 households with both a fridge-freezer and refrigerator. Almost half of these (14) also had a third cold appliance (upright freezer 5, chest freezer 6, second refrigerator 3). Reported combinations of cold appliances from this sample are shown below.

Table 3. Combination of cold appliances:

1st cold appliance	2nd cold appliances	Number of houses	Percentage
Fridge-freezer (153 houses)	None	96	62.7%
	Refrigerator	29	19.0%
	Upright freezer	14	9.2%
	Chest freezer	25	16.3%
Refrigerator (109 houses)	None	17	15.6%
	Fridge-freezer	29	26.6%
	Upright freezer	51	46.8%
	Chest freezer	26	23.9%

Data on combinations of cold appliance are presented in the table below, comparing Mansouri et al's data with 4M data.

[6] Measurements of the domestic use of electricity in 200 houses and 200 apartments in Sweden between 2005 and 2007

[7] Early analysis of data collected in Jan-March 2010 from 4M appliance survey of 253 Leicester homes. Not yet published.

Table 4. Comparison of combinations of cold appliances owned by the surveyed households

Combination	4M (2010) (n=235)	Mansouri et al (1996) (n=656)
Refrigerator	7.2%	8.2%
Fridge-freezer	40.9%	32.0%
Refrigerator + upright freezer	13.2%	19.4%
Refrigerator + chest freezer	6.4%	9.9%
Refrigerator + fridge-freezer	6.4%	7.0%
Fridge-freezer + upright freezer	3.4%	4.9%
Fridge-freezer + chest freezer	6.8%	3.5%
Upright freezer + chest freezer	0.4%	Not listed, assume 0%
2 fridge-freezers	0.4%	Not listed, assume 0%
Refrigerator, fridge-freezer + upright freezer	2.1%	4.9%
Refrigerator, upright freezer + chest freezer	0.4%	2.7%
Refrigerator, fridge-freezer + chest freezer	2.6%	1.5%
Other combinations [a]	9.4%	6.0%

[a] Including households owning more than one of the same type of appliance and those with more than three refrigeration appliances.

From the 4M data there was a small proportion of households with four appliances, combinations of which included:

- 2 fridge-freezers and 2 refrigerators (n=1, 0.4%)
- 2 fridge-freezers, an upright freezer and a chest freezer (n=1, 0.4%)
- 2 refrigerators and 2 fridge-freezers (n=2, 0.8%)
- 2 refrigerators, and upright freezer and a chest freezer (n=2, 0.8%)

The age distributions of cold appliances in the 4M survey are shown in the following figures.

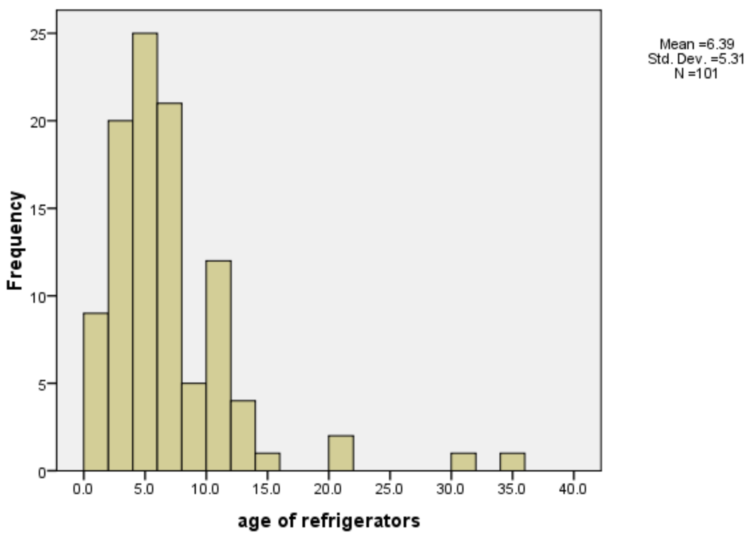


Figure 13. Age distribution of refrigerators in 4M sample

The average reported age of refrigerators in this sample was 6.39 years, ranging from new to approximately 35 years. Although there were only five refrigerators 15 years old or over, this does demonstrate that some very old cold appliances are still in use.

The distribution of reported age for fridge-freezers is shown below.

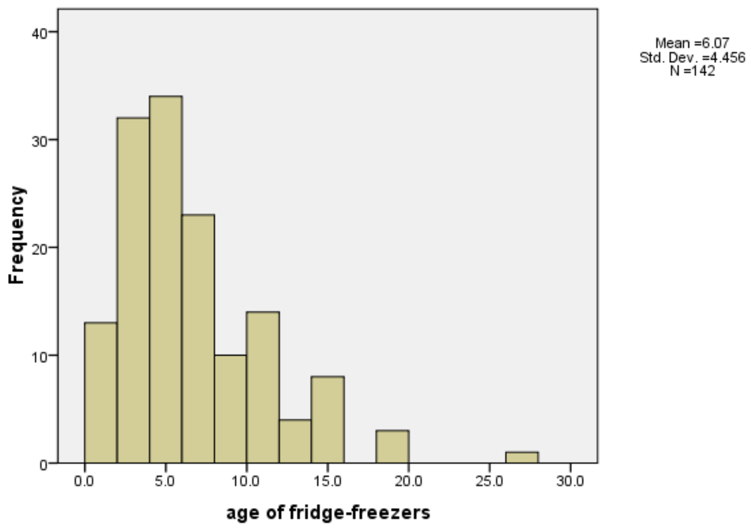


Figure 14. Age distribution of fridge-freezers in 4M sample

The average reported age of fridge-freezers in the sample was 6.07 years, with 11 appliances over approximately 15 years old.

The distributions of reported age for upright and chest freezers are shown in the following figures.

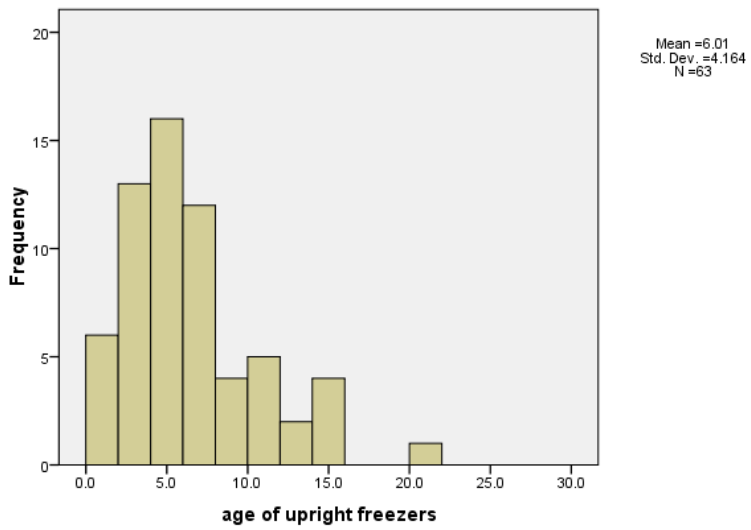


Figure 15. Age distribution of upright freezers in 4M sample

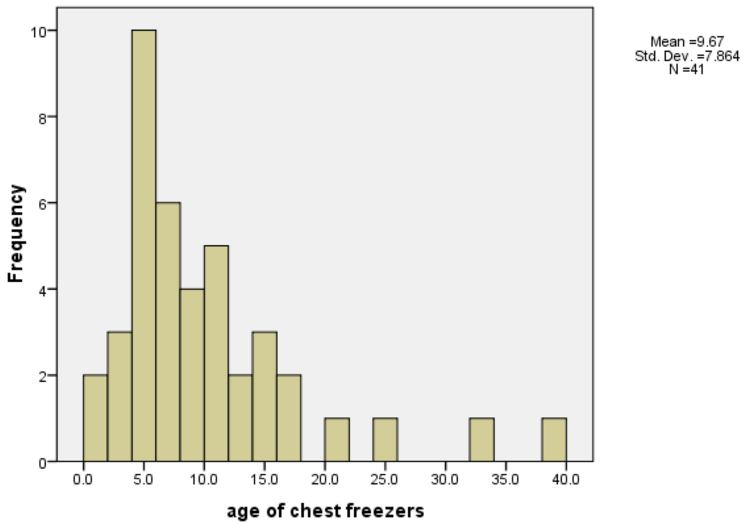


Figure 16. Age distribution of chest freezers in 4M sample

The mean age for freezers in the 4M survey was 6.01 years (upright) and 9.67 years (chest). There were two chest freezers over 30 years old still in use, perhaps a reflection of the more robust design of chest freezers. There is little to ‘go wrong’ compared with the more vulnerable parts of an upright freezer or fridge-freezer (plastic drawers, shelves, doors).

These data indicate that there are still some very old cold appliances in use. To investigate whether households who owned several cold appliances had kept old products even after purchasing a new one, an analysis of patterns of appliance age per household was undertaken. These are complex because of the different combinations of cold appliances. In total, there were 121 houses with more than one cold appliance in the sample, with 70 dataset for households with two cold appliances. The average age of the newer appliances was 5.1 years (range 0-20 years), and the average age of the older appliances was 9.1 years (range 1-38 years). There were 27 households (38.6%) where the two cold appliances were the same age.

The age patterns of households with three cold appliances were also analysed. The mean age of the newest cold appliance was 3.0 years (range 0.1-9 years); the mean age of the second oldest cold appliance was 5.1 years (range 2-10 years) and the mean age of the oldest cold appliance was 8.5 years (range 2-32 years). There were two households who reported that their three cold appliances were the same age, suggesting they had been purchased at the same time, and a further 6 households who had three cold appliances of similar ages (within 2 years of each other).

There are clearly households who have requirements to purchase new cold appliances in multiples, and others who appear to buy a new appliance and retain the old. One 4M household had the following set of cold appliances:

- Upright freezer – 7 years old
- Refrigerator 1 – 11 years old
- Chest freezer – 15 years old
- Refrigerator 2 – 35 years old.

Another 4M household had the following set:

- Chest freezer 1 – 9 years old
- Refrigerator – 10 years old
- Chest freezer 2 – 32 years old.

Full details of the ages of cold appliances in combination within a household (3 cold appliances or more) from 4M are shown in Appendix D to this report.

Mintel (2007a) reported that householders aged 25-34 were most likely to have bought a new fridge or combination fridge-freezer in the previous 12 months, as part of setting up their first home and so would be buying a wide range of household appliances. By contrast those most likely to be purchasing a freezer are aged 35-44 and this is most likely to be a spare freezer stored in another room in the house. Households of five or more people are also more likely to have a second freezer (Mintel, 2009h). Details of recent cold appliance purchase by householder age are shown below.

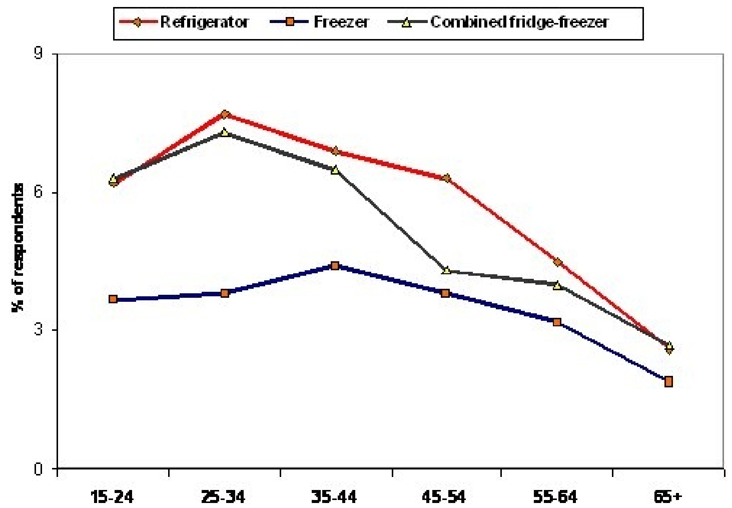


Figure 17. Purchase of cold appliances in the last 12 months, by age, 2006 (Mintel 2007a)

There is clear evidence that old cold appliances are passed on to others creating a second hand market. E-SCOPE study conducted by Cooper and Kieren (2000) investigated the ownership, purchase, use and disposal of household appliances in the UK. The research methods used included face-to-face interviews and focus groups. In total, 802 households were interviewed in over 180 locations across the UK and five focus groups were held involving a total of 50 participants. Cooper and Kieren found that 15.1% of cold appliances discarded were donated for free to family or friends, 0.8% were donated to charity and a further 6% were sold on (second hand shops, dealers). This study also reported the lifespan of refrigerators and freezers to be 11 years.

Cold appliances are usually in use 24 hours a day, every day of the year. There was no information found on whether households had cold appliances that were not in use, so it is reasonable to presume that the ownership data refers to products in use.

Householders are buying cold appliances with increased capacity to extend the life of fresh food (Mintel, 2007a) and to allow storage of greater quantities of frozen food, taking advantage of BOGOF offers in supermarkets (Mintel 2009h). Consumers with less time to shop and an increased focus on cooking at home may also result in a trend for increased capacity to store food.

Mintel (2007a) report a tenth of consumers upgrading to a more energy efficient model, with 56% looking for energy efficiency at time of purchase. However, the limited numbers of A+ and A++ models available may have limited people's purchasing decisions at that time; for fridge-freezers, around 80% of sales are for A-rated but only around 2% are A+ rated (Environmental Change Institute, 2005). The UK market favours frost free products, but the limited availability of A+ and A++ frost free cold appliances further compounds the problem of moving householders to more efficient models.

The figure below illustrates the UK sales of cold appliances between 1995 and 2000 which met the minimum energy performance standard (from Schiellerup, 2002). The sharp rise in the graph coincides with when minimum standards came into force at the end of 1999, indicating the effect policy changes can have on consumer purchases.

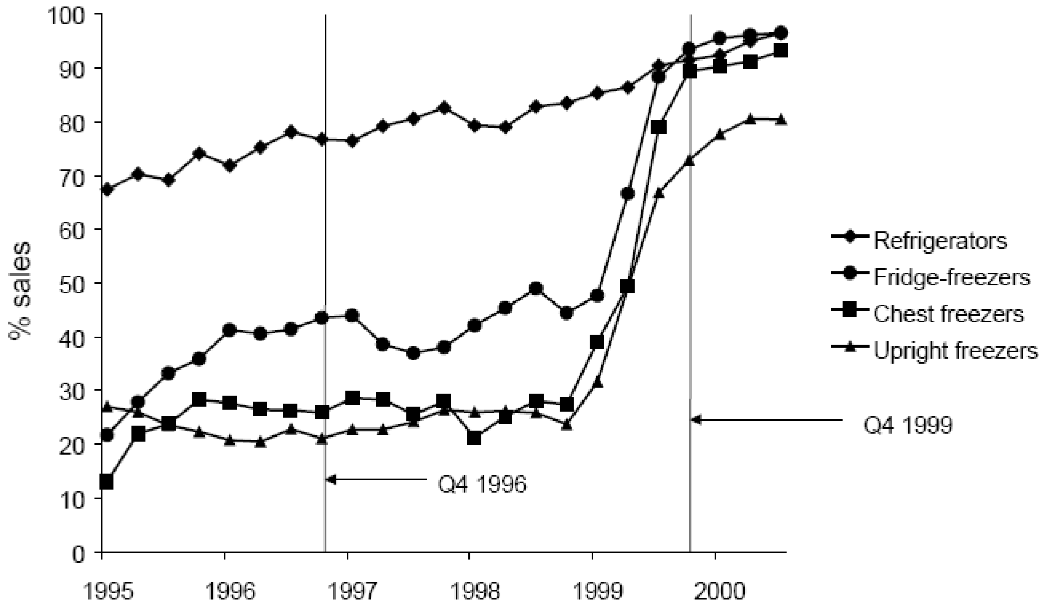


Figure 18. Proportion of cold appliance sales meeting minimum standards, UK, 1995–2000 (Schiellerup, 2002)

The average size of cold appliances on the market was increased by 15% between 1995 and 2001 (Environmental Change Institute, 2005), although the appliances are more efficient. This means that manufacturers are not selling appliances with lower overall energy consumption (Lockwood and Murray, 2005). On the demand side, it is reported that every household at least own one cold appliance often with two or more (Environmental Change Institute, 2005). Mintel (2007a) shows that in 2007, the sales in this sector grew by 8% compared with 2005.

Recently, consumers are enthusing about larger and more energy hungry appliances, such as, American style fridge freezers containing integrated LCDs or ice producers. Over its lifetime, an American style fridge and freezer consumes 1800 KWh more than the typical average sized A-rated appliance. Furthermore, using small drink chillers and coolers in the bedroom, living room and car is becoming popular. The Energy Saving Trust report (Energy Saving Trust, 2006) states that "a small drinks chiller can use 50% more electricity than an under-the-counter A-rated fridge"

Increasing consumer expectation for comfort, convenience, speed and security as well as the social and psychological contexts within which cold appliance consumption behaviours exist are challenging the energy gains of technological improvements of reducing the impact of product use.

Consumer behaviour can significantly influence the energy efficiency of cold appliances, for example through door opening practices. The current energy label test is criticised by consumer bodies and experts for not reflecting actual energy consumption of home use (Tang and Bhamra, 2008). For example, during the test doors are not opened, the test load is unrealistic and also temperature recovery from insertion of warmer food and response to ingress of humid air is not examined (Van Holsteijn en Kemna, 2005; MTP, 2007b). In research of the real-life usage, the consumer surveys on actual energy consumption have given the different results (see Table below).

Table 5. Difference in electricity consumption of fridge and/or freezer between actual and the label provided by research from different countries (from Mennink et al. 1998; Van Holsteijn en Kemna, 2005; Tsurusaki et al, 2006; MTP, 2007a, 2007b)

Energy Consumption Research community	Effects of actual energy consumption
Food Refrigeration and Process Engineering Research Centre (FRPERC) report	The effect of door opening is 1-2% The influence of warm food is 4-10%
Mennink et al. (1998) tested a 200 litre refrigerator	The effect of door opening is 8% (2.2W) The influence of Adding food at room temperature is 11% (3.1W)
Refrigerators and Freezers, product case 5, Methodology Study Eco-design of Energy-using Products (MEEUP) for European Commission	Ice-up of the evaporator deteriorate the efficiency by 10-20% 1°C difference in temperature causes a 4% difference in energy consumption.
ECUEL project SAVE (1999) in France used metered appliances in around 98 households for one month between January and July 1998 to monitor	Keeping a cold appliance in a non-heated storeroom rather than a kitchen gives an average energy saving of 36%. On average, freezers were operating at 3.1°C colder than the recommended temperature (-18°C), leading to 17.6% more energy use.
In Japan, the surveys on Actual Energy Consumption of Top-Runner Refrigerators of Jyukankyo Research Institute (2006) monitored over 100 refrigerators in household for one year	Average annual actual electricity consumption was 65% larger than the JIS test value (Japan Industrial Standards test in 1999)

James et al (2008) reviewed operating temperatures of domestic refrigerators and summarising many key findings of research into refrigerator thermostat operation and energy use. They cite 21 studies into refrigerator operating temperatures where a combined total of at least 3424 domestic refrigerators were tested.

The results showed the most common storage temperature was between 6 - 6.9°C with the majority of results lying between 3 - 8.9°C. This variation in storage temperature can have a considerable effect on energy use. Stamminger et al (2007) cite two studies that have investigated the impact of inserting and storing hot or cold items in the refrigerator: the first is Böhmer et al (1998) which states that the insertion of food into the fridge is responsible for 10% of its yearly energy consumption and cooling food with a temperature of 50°C uses three times more energy than cooling food with a temperature of 20°C; the second study by Lepthien (2000) found that thawing frozen food in the refrigerator can reduce energy consumption up to 26%.

Door opening practices also affect energy consumption of cold appliances. ELIMA (2005) report a typical range of opening times for fridge doors of between 8 - 19 seconds. Tang (2008) reported on a video study which included the observation of behaviour of a young family using the refrigerator at breakfast. In this case study the fridge was opened a total of 21 times and on three occasions the fridge was left open for a total of 191 seconds. Elias (2009) gives the most frequent opening time of 3 seconds and an average opening time of 7.5 seconds, although the door can be left open for significantly longer periods if food is being searched for or stored after a shopping trip.

The EuP report (Stamminger et al. 2007) two studies:

- Lepthien (2000) who states that 20 door openings a day would generate an increase in electricity consumption of between 1 - 6%.
- Böhmer et al (1998) state that losses due to air change in the refrigerator, as a result of door openings, made up 3% of the total electricity consumption. Unfortunately it is unclear what this percentage is in actual energy terms as the total energy use of the refrigerator is not mentioned.

A study by Alissi (1987, cited in Saidur, 2002) showed that consumption increased by 6.4% for 20 door openings a day, with a 12 second opening time. A second study cited in the same source by Gimes et al (1977) showed that energy consumption would increase by 6 - 8% for 24 door openings a day, also with a 12 second opening time. Mennink et al’s 1998 study, with similar opening frequency but reduced opening time of 5 seconds would give a similar result of 8% from door openings, in this case 20 kWh. Saidur (2002) estimate an energy impact of 9Wh - 12.4Wh per 12 second door opening and this is by supported by Parker and Stedman (1993) who estimated an impact of 9Wh per opening. A further study by Peart (cited in Stamminger et al, 2007) says that 40 door openings per day can add between 50 - 120 kWh per year to the total energy consumption; a not insignificant amount, entirely dependent on the user’s behaviour.

Elias (2009) concludes that it is essential to be able to quantify the impacts users are having on energy consumption before any changes can be made. To do this an energy value is needed which corresponds to an amount of time the door is open.

It is clear that there have been several studies into calculating an energy value for a door opening, unfortunately from the published work on these studies, the methods for obtaining the results are often unclear and some important facts, such as open time per door opening are not disclosed. As a result only the two studies where enough information is given to establish any degree of accuracy are those of (Mennink et al 1998 and Saidur et al 2002); and these give an average of 0.68Wh per second the door is open.

5.2 Domestic wet appliances

Domestic wet appliances include washing machines, dryers, washer-dryers and dishwashers. Electric showers have also been included in this section of the review. Although only a small product group, a wide variety of options are available for these appliances:

- Washing machines – including automatic front-loaders, top-loaders, washer-dryers and twin-tubs.
- Dryers – separate tumble dryers (gas or electric), vented or condenser machines; and standalone spin dryers (electric only).
- Dishwashers – full-size, slimline or tabletop models.

5.2.1 Washing machines, washer-dryers and tumble dryers

Most households own some sort of clothes washing facility. Washing machine ownership rates varied in the literature reviewed, for example:

- 95% in 2003 (The Business Book, 2003)
- 82.8% in 2007 (Mintel, 2008d)
- 93.2% in 1994 (Mansouri et al, 1996)
- 88% (Yao and Steemers, 2005)
- 80% (Waterwise, 2008)
- 87.2% (4M, 2010)

There is little growth in this market which is largely a replacement market as almost every house has access to a washing machine or washer-dryer (Mintel 2008d). There is a market for second hand washing machines, with Cooper and Kieren (2000) reporting that 8% are donated to friends or family, with another 3% sold on.

Washing machine age was requested as part of the 4M survey, results are shown below. The mean age of products in use was 5.25 years. Older appliances will almost certainly have been subject to repair; a factor perhaps more important to this category of appliance than most others.

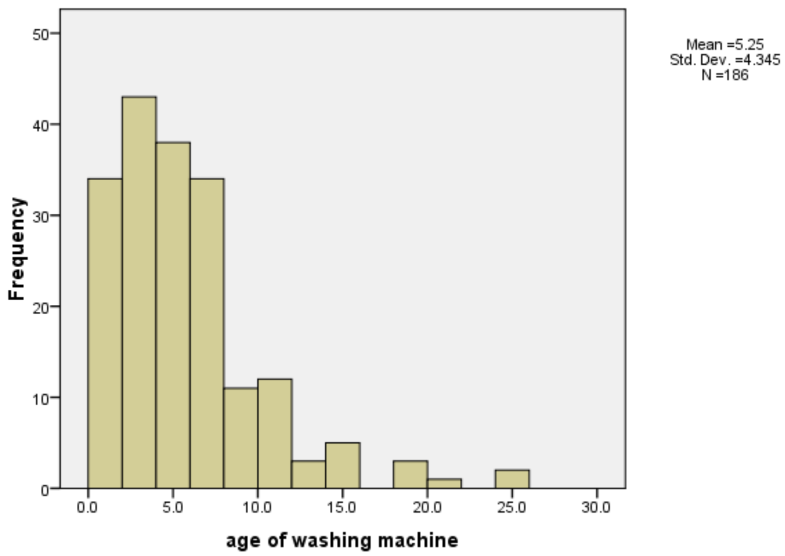


Figure 19. Age of washing machine from 4M appliance survey (2010)

DECADE's figures for tumble dryers (Fawcett et al, 2000) predict 43.2% in 2008 rising to 45.3% in 2020. Other sources were similar with Mintel (2008d) stating 44.6%, 49% from Yao and Steemers (2005) and 53.6% from Mansouri et al (1996). The Office for National Statistics state 56% including washer-dryers for 2002-03. There are few statistics for washer-dryer ownership; Mintel report 12.2% of households, in line with the recent 4M survey where 12.8% of households had a washer-dryer. The 4M survey found only 33.6% of households owning a tumble dryer, lower than other data, but this population had a lower average household income than the UK norm, so this may have affected ownership rates.

There is potential for the washer-dryer market to increase for both younger and older householders, particularly where the household is small and for people in the AB social group (Mintel 2008d).

Sales and use of tumble dryers are reported to be weather dependent, with increased sales following the rainy summer of 2007(Mintel 2008d). A very gradual increase in this market is expected over the next decade, however, growth has recently levelled out, perhaps a reflection of consumer attitudes and weather conditions. Future tumble dryers with heat pump technology which may be more energy efficient are likely to be very expensive and out of the price range of most UK customers (Mintel 2008d).

Five households in the 4M sample (2.1%) had both a washing machine and a washer-dryer; one of them, with a single occupant, also had a tumble dryer. Age distribution of washer-dryers and tumble dryers from 4M are shown below. The mean age of products in use was 4.65 years.

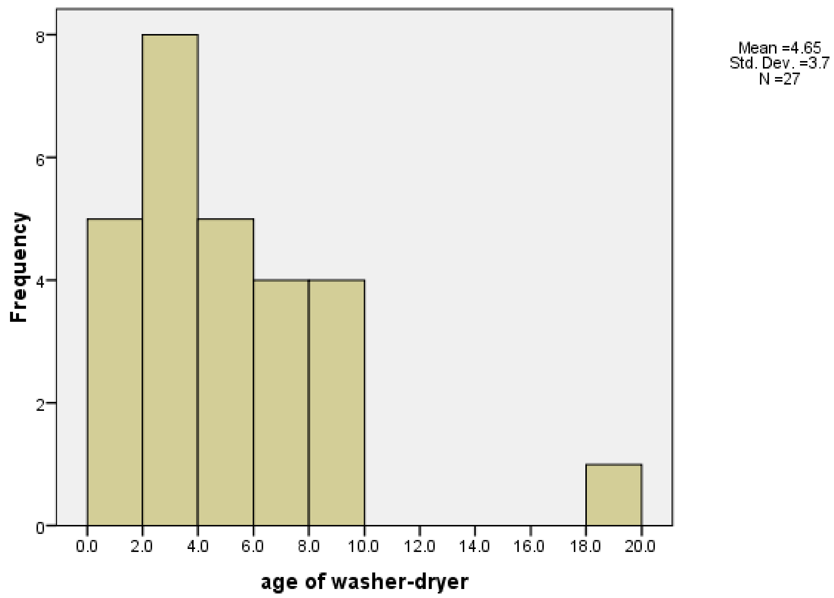


Figure 20. Age of washer-dryer from 4M appliance survey (2010)

The distribution of age of tumble dryers is shown below; mean age of products in use was 7.12 years.

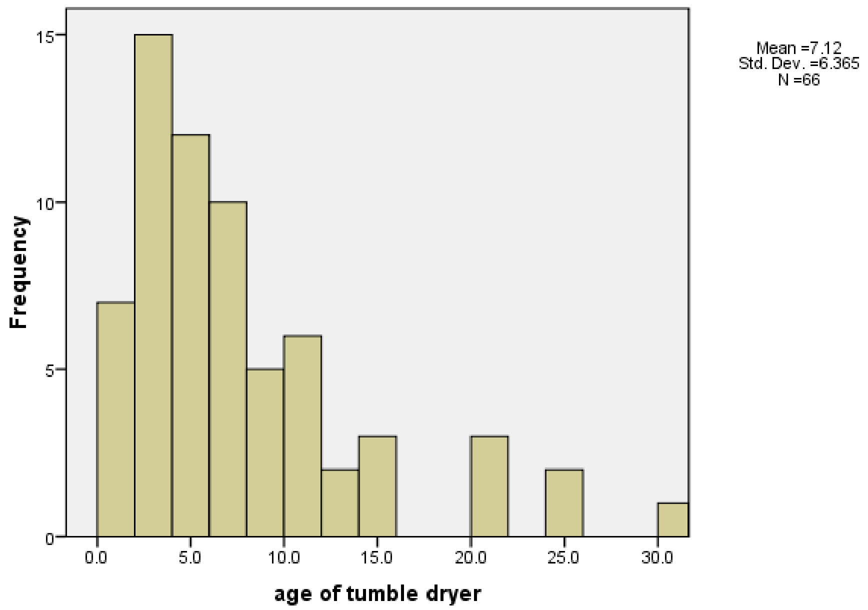


Figure 21. Age of tumble dryer from 4M appliance survey (2010)

It can be seen that a number of tumble dryers were over 20 years old in this sample. It was also found that in houses with both a washing machine and a tumble dryer, the age of the tumble dryer is mostly higher than that of the washing machine, if their ages are not same of similar (as shown in the figure below). The average age of tumble dryers is 2.5 years old than the washing machines. This may indicate that the lifespan of the tumble dryer is longer than that of the washing machine. Perhaps tumble dryers are used occasionally, especially when weather conditions preclude outside drying (as noted above) or when cleaned garments are needed immediately.

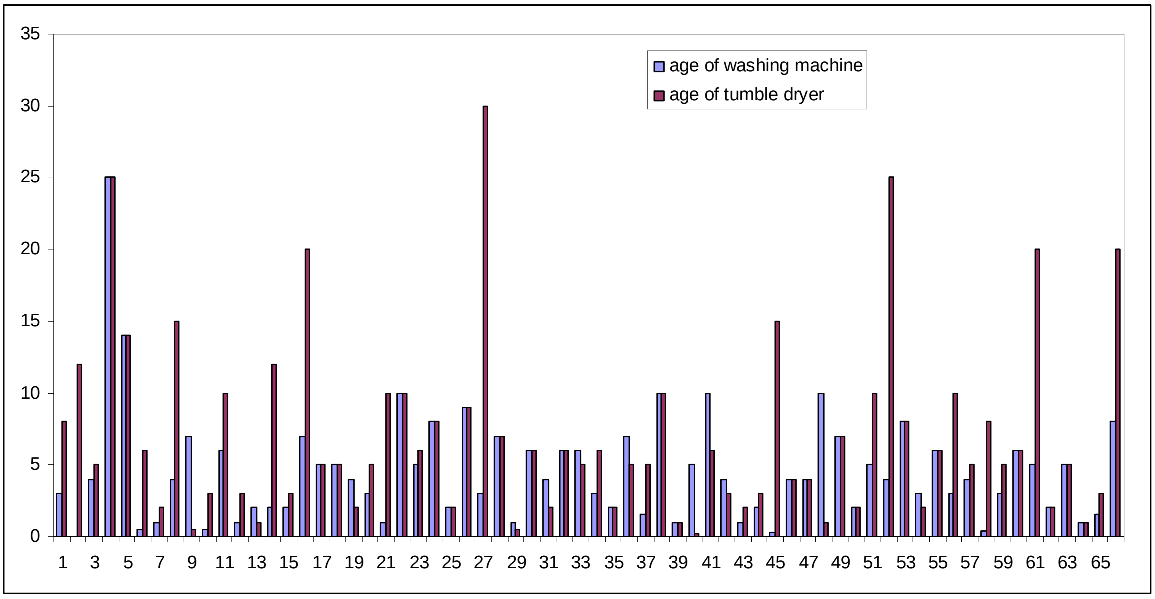


Figure 22. Comparison of ages of washing machine and tumble dryer within households owning both (4M, 2010)

Washing machine usage is reported to be very varied between households. Mansouri et al (1996) found a range of 1 to 30 washes per week in their survey. More details are shown in the following table.

Table 6. Reported washing machine use (Mansouri et al 1996)

Range	% of households in sample
1-6 cycles/week	64%
7-12 cycles/week	30%
13-30 cycles/week	7%

The average number of washes per person per week ranged from 1.3 to 2.6, with frequency of washing machine use depending on household occupancy. However, the authors noted that enormous variation, caused by lifestyle and behaviour variations were present. For example, the most extreme number of wash cycles per week (30) was indicated by a household of two adults and three children (of 12-18 years); 8 wash cycles per week would have been predicted for the number of people in this household. The temperature of washing programme was also recorded, with 47% of washes being described as ‘cold’, 48% ‘hot’ and 5% ‘boil’ washes. Lower temperature washes provide an opportunity to reduce energy use from washing clothes, however lower temperature washing may result in build up of bacteria and fungi in machines, especially if higher temperature servicing of the appliance is not established. Poor bleaching may also affect washing performance at less than 30°C (Bain et al, 2009).

The Swedish Energy Agency work found households who lived in houses used their washing machine 250 times a year, those that lived in apartments, 150 times a year.

The distribution of washing / drying frequency reported in the 4M survey is shown below.

Table 7. Average use of washing/drying appliances per household per week

<table>
<tr><th colspan="2" rowspan="2"></th><th rowspan="2">Average cycles/ week</th><th colspan="2">Distribution of usage frequency</th></tr>
<tr><th colspan="2">% of households in sample</th></tr>
<tr><td colspan="2" rowspan="4">Clothes washing (n=229)</td><td rowspan="4">3.6</td><td>1-3 loads/week</td><td>61.1%</td></tr>
<tr><td>4-6 loads/week</td><td>26.2%</td></tr>
<tr><td>7-12 loads/week</td><td>10.0%</td></tr>
<tr><td>>12 loads/week</td><td>2.7%</td></tr>
<tr><td rowspan="8">Clothes dryer (n=97)</td><td rowspan="4">Summer</td><td rowspan="4">1.0</td><td>None of washings</td><td>62.1%</td></tr>
<tr><td>0 to half of washings</td><td>23.2%</td></tr>
<tr><td>Half to every washing</td><td>6.3%</td></tr>
<tr><td>Every washing</td><td>8.4%</td></tr>
<tr><td rowspan="4">Winter</td><td rowspan="4">3.2</td><td>None of washings</td><td>12.9%</td></tr>
<tr><td>0 to half of washings</td><td>28.0%</td></tr>
<tr><td>Half to every washing</td><td>24.7%</td></tr>
<tr><td>Every washing</td><td>34.4%</td></tr>
</table>

Mintel (2008d) reported that consumers want washing machines with shorter wash cycles and the capacity to take larger loads. Washing machines with larger capacity are increasingly available, with machines capable of taking a 9kg load being offered, increasing from a typical 6kg capacity for current machines. Consumers also want to do smaller loads for convenience and want higher spin speeds to reduce the amount of drying required. Advertising of low temperature washing powder and an awareness of energy efficiency has also fuelled a demand for machines that wash well at lower temperatures.

Tumble dryer usage is presented in some detail in Mansouri et al (1996). The tumble dryer was used regularly by only half of the owners; 25% used if for every load in autumn and winter and a further 9% used it for every load throughout the year. Use was, on average, 1.8 to 3.4 cycles per week, with a weighted average 'regular' use per household of 2.11 cycles per week, rising to 2.5 cycles per week if occasional uses were included. This gives a yearly figure of 130 cycles per household, less than the 148 times/year in the current MTP model (BNW06). Perhaps unsurprisingly, tumble dryers are more likely to be used in households with children (Mintel, 2008d).

Condensing tumble dryers are the increasing trend, negating the need for an external vent. An increased capacity (from typically 5kg to 7kg) is also desired (Mintel, 2008d), which may increase the energy demands. The introduction of sensor technology minimises any excess use.

Clothes drying behaviour from the 4M survey was compared with access to a garden. As can be seen from the following table, only 34.8% of households without a garden had a dryer (washer-dryer or tumble dryer), compared with 51,2% of households with a garden.

Table 8. Comparison between households with/without private front and back garden (4M, 2010)

House group	N (percentage)	Ownership of Dryer	
		frequency	Total Percentage
Without garden	69 (29.4%)	Washer dryer (8)	34.8%
		Tumble dryer (16)	
With garden	166 (70.6%)	Washer dryer (22)	51.2%
		Tumble dryer (63)	

That households without a garden actually showed lower ownership of a dryer, compared with houses with a private front and back garden is perhaps surprising It probably indicates that the ownership of a dryer not only relies on the accessibility of outdoor drying spaces, but is more likely influenced by other socio-demographic characteristics of the households. For example, a dwelling without a private garden may be of smaller size and owned by relatively lower income households, which might limit the household's ability to buy a tumble dryer or washer-dryer. When a similar analysis of the 4M data was applied to people living in flats and houses, it was found that only 1/3 of households living in flats owned a dryer (either a washer-dryer or a tumble dryer), compared to 48.1% of households living in houses.

5.2.2 Dishwashers

The reviewed literature is very variable in the level of dishwashers ownership quoted:

- 34.7% of households (Mintel 2008d)
- 41.9% (Mansouri et al 1996)
- 28% (Waterwise, 2008)
- 16% (Yao and Steemers, 2005)
- 22.1% (4M, 2010)

Ownership was reported to drop off from social group A to E, and increase with household size (Mintel 2008d). Ownership is no longer considered a luxury, but there are still consumer attitudes (relating to performance and cost) that limit the market. Two thirds of households do not own a dishwasher, offering potential for further market penetration. Although sales doubled between 1987 and 1997, the market is now reaching saturation, limited by lack of space in UK kitchens (Defra 2009). Slimline or compact dishwashers may increase in numbers, especially in smaller households, although currently 80% of the market is full size dishwashers (Defra 2009)

Dishwasher age from the 4M survey is shown below; mean age was 5.36 years.

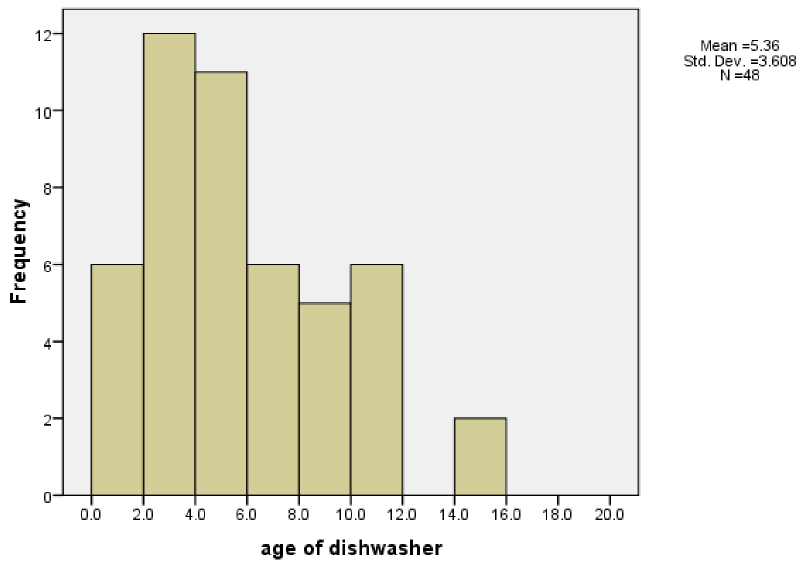


Figure 23. Age of tumble dryer from 4M appliance survey (2010)

Usage of dishwashers was reported in Mansouri et al (1996), with a weighted average of 0.78 cycles per day (258 cycles per year). Further details are shown in the following table.

Table 9. Reported dishwasher use (Mansouri et al 1996)

Range	% of households in sample
More than once a day	4.6%
Once a day	50.2%
Every 2 days	34.7%
Other patterns	10.5%

The Swedish Energy Agency study (2008) recorded 200 cycles a year for dishwasher use and the EU Energy label assumes 220 cycles per year. DECADE's figures of 110 washes at 55° and 135 washes at 65° are in line. 4M data suggest that the dishwasher is used 3.5 times per week on average (182 times per year), again in line with other estimates.

Table 10. Average use of dishwasher per household per week (4M, 2010))

	Average cycles/ week	Distribution of usage frequency	
		% of households in sample	
Dishwashing (n=51)	3.5	More than once a day	0
		Once a day	23.5%
		Every 2 days to once a day	19.6%
		Less than every 2 days	41.2%
		Not in use	15.7%

5.2.3 Electric showers

Energy Saving Trust report 35% of households having an electric shower (Energy Saving Trust 2006), Mintel (2010) report 54% and recent 4M data showed 54.9% of the sample households having and electric shower. A dated study by Herring (1995)[8] suggested electric showers were owned by only 21% in 1987.

Information on electric shower usage was limited. A number of studies discussing bathing habits are published, but few give specific details on how many showers are taken per person or household, and none related this to solely electric showers. Mintel (2008g) report that 40% of adult internet users usually took a shower in the morning, 15% usually took a shower in the evenings, and only 1% usually showed in both mornings and evenings. Herring (1995) estimated 23 hours a year was spent showering in the show (nearly 3.8 minutes each day). An on-line survey by Treehuggers found 53% of respondents saying they showered or bathed once a day, 24% every other day, 6% once a week or less and 15% 'whenever needed'. 4M data suggest that the electric shower is used 9.9 times per week on average. Given the average number of people per household in this survey, this equates to 4.1 showers per person, per week.

Table 11. Average use of electric shower per household per week (4M, 2010)

	Average cycles/week	Distribution of usage frequency	
		% of households in sample	
Electric shower (n=130)	9.9	0	7.0%
		1-7	49.6%
		8-14	27.9%
		15-21	4.7%
		21-28	5.4%
		28-35	5.4%

[8] Data are from an unpublished CEGB estimate of minor appliance ownership and consumption for 1987, drawing on work from the then Electricity Council. Figures for ownership come from market research surveys not listed in the paper.

Data from Waterwise (2009)[9] give a mean shower time of 10 minutes 40 secs for women and 10 minutes 1 second for men. Other key information from the survey included:

- Time spent in the shower decreases with increasing age. On average, people aged 55 or over (mean shower time: 8 mins, 41 secs) is 5 minutes shorter than people aged 18 to 24 (mean shower time: 13 mins 26 secs).
- Well over a third (39%) of people aged 55 or over shower in five minutes or less.
- More than half (53%) of 18-24 year olds took 10 minutes or less in the shower.

[9] Research figures based on 2000 people interviewed online by ICM Research over the weekend of August 15/16 2009

5.3 Domestic cooking appliances

Domestic cooking appliances include major items such as cookers, ovens, hobs and microwaves as well as small kitchen appliances. There is a wide range of small kitchen appliances on the market and they include widespread items such as kettles, toasters, mixers and blenders, as well as bread makers, ice cream makers, slow cookers, popcorn makers, steamers, grills, deep fat fryers and so on. Whilst there are some data sources to show the number and usage of the main kitchen appliances, reliable information about the minor appliances is scarce. Mintel (2007c) report an increased focus on cooking in households, and so more being spent on appliances. This trend is likely to increase the number and usage of kitchen appliances, but no data were found to evidence the scale of this.

5.3.1 Oven and hobs

Mansouri et al (1996) identified 56.1% of households with an electric oven, supported by Yao and Steemers (2005) – 56% and the 4M (2010) appliance survey (52.3%). Mansouri et al reports a 39.0% ownership of gas ovens, although no other data were found to support this.

Gas hobs are more widespread than electric, with Mansouri et al finding 58.6% gas hobs to 36.5% electric. Yao and Steemers give 37% of households as having an electric hob, with the 4M survey lower at 25.5%.

No data were found on combinations of oven, hob and cooker ownership within a household. It is not unreasonable for a household to have a cooker and additional hob, especially where ranges such as Aga are present. Multiple fitted ovens are also possible and the data presented here do not separate these out. In a household that cooks regularly, two ovens and the hob may be used in combination, so ownership modelling may need to account for this.

Ovens are reported to be used 36 minutes a day (Bennett, 1998, cited in Yao and Steemers 2005)) and 30 minutes a day (Yao and Steemers, 2005). Mansouri et al (1996) report more detail, shown in the following table.

Table 12. Oven use (all types) (Mansouri et al (1996)

Oven use (all types)	Percentage of households in survey
<45 minutes a week	7.8%
45-60 minutes a week	7.7%
1-2 hours a week	14.7%
2-3 hours a week	17.1%
3-4 hours a week	16.7%
4-5 hours a week	12.6%
More than 5 hours a week	23.4%

Mansouri et al also give figures of 15-30 minutes a day use of a hob (all types). Yao and Steemers (2005) cite 60 minutes per day supported by Bennett (1998) at 58 minutes a day.

Cooper and Kieren (2000) report a 7 year lifespan for microwave ovens and a 12 year lifespan for cookers. They also report that 13.2% of cookers are donated to friends and family at the end of use in a household, and another 10% are sold on.

5.3.2 Microwave ovens

Reports of microwave oven ownership are mixed:

- 35% in 1987 (Herring, 1995)
- 73.8% in 1994 (Mansouri et al, 1996)
- 86.5% in 2008 (Mintel, 2009h)
- 63.9% (inc 11.1% combination ovens) in 2010 (4M)

28% of microwaves are donated to friends and family and another 6% sold on (Cooper and Kieren, 2000). This demonstrates a reasonable second hand market for these appliances.

Microwave oven use is 10 minutes a day (Mansouri et al), although Herring gives a figure of 150 hours a year (approximately 24 minutes a day) which is significantly more and may be unreliable. E.ON have recently produced a customer information sheet with details of how much various household activities cost (to raise awareness), and they use 10 minutes a day of microwave use as their reference point, suggesting this is their anticipated typical use.

5.3.3 Other kitchen appliances

Ownership data of other kitchen appliances are presented in the following table, from three sources: Mintel (2009h), Herring (1995) and 4M (2010). Whilst the Mintel data provides a recent, large sample response, Herring's data are not likely to be representative of the current market, and 4M's data are from a particular household sample.

Table 13. Small kitchen appliance ownership

Appliance	Mintel (2009h)	Herring (1995)	4M (2010)
Toaster	74.3%	50%	82.1%
Kettle	87.8%		97.9%
Mixer / processor	24% / 26.5%	70%	34.9%
Blender	25.6%		61.7% (blender / mixer)
Sandwich toaster		40%	45.1%
Rice/slow cooker		17%	26.8%
Deep fat fryer		25%	16.2%
Bread maker			9.8%
Juicer	13.0%		15.7%
Grill		7.0%	17.9%
Coffee maker	21.1% (inc espresso maker)	38%	6.8% (hot drink maker)
Ice cream maker			2.6%
Steamer			15.7%

Issues of categorisation are highlighted here – mixers and blenders formed a group in one survey, mixers and processors were recorded separately in another. For comparable data analysis, consistent categorisation is needed.

The range of powered kitchen gadgets has expanded significantly over the past 20 years. However, usage of these items may be intermittent.

Kettle use has been a topic of interest in raising awareness of energy waste in the kitchen. Boiling excessive quantities of water and re-boiling water repeatedly are behaviours that have been highlighted as wasteful. No data were found on the frequency and nature of these behaviours on a household level in order to quantify the real usage more accurately.

Herring gives additional figures for use of the small appliances in his paper; however, these appear to be general estimates without any referenced substantiation and so are not reported here.

5.3.4 Cooker hoods

Data for ownership of cooker hoods were also presented by Herring (16%) and 4M (48.1%). No data on length of time for which cooker hoods are used were found in the review.

5.4 *Domestic information, communication and entertainment appliances*

Domestic information, communication and entertainment appliances describes a large category of household appliances that include consumer electronics and information and communication technology (ICT), for example:

- Computers, monitors, printers, etc
- Phones, routers, modems etc
- TVs, set top boxes, video recorders, home cinema
- Games consoles and electronic toys
- Audio players, video players

The following figure, taken from Coleman et al (2009), shows the rapid increase in domestic electricity consumption for consumer electronics and ICT, which comprise this group. These areas are increasing in energy demand at a much faster rate than any other recorded group in the home and so warrant close attention.

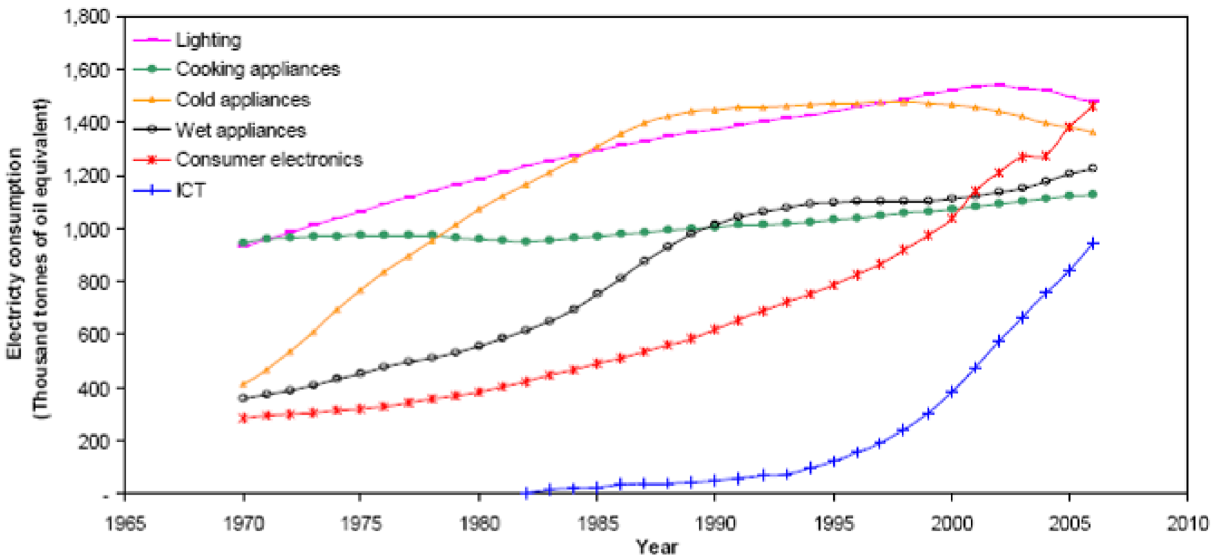


Figure 24. UK domestic electricity consumption by appliance type (from Coleman et al, 2009, based on DECC 2008)

Defra's Market Transformation Programme currently cover televisions, external power supply units, set top boxes, video recorders and games consoles, with possible future consideration of video projectors, home theatre/audio systems and internet routers.

5.4.1 Desktop and laptop computers and monitors

In Rise of the Machines, Energy Saving Trust (2006) reported market penetration of computers in 2002 at 45%; this has risen in recent years and Mintel report figures of 76.6% for 2008. Desktop computers are in slight decline at 52.8% and laptops, increasing by 23% since 2004 to 30.1% in 2008 (Mintel, 2009d). 49.8% of the 4M sample had a least one desktop computer, and 50.6% had at least one laptop.

It is common for households to own more than computer, Mintel give this figure as 30.5% of households; 4M found a similar number, 32.9% of their sample owing more than one computer. 4M data revealed 6.7% households owning 3 computers and 2.4% owning at least four[10].

Mintel also report multiple household ownership of computers, with 47% owning one personal computer, 17% owning two, and 10% owning three (Mintel, 2008e). It is likely that computers are passed on from one family member to another (not necessarily in the same household) following the purchase of a new product. This increases the lifetime of the product.

Market penetration of monitors is likely to match desktop computer ownership, since the two products are more or less dependent on each other. Docking stations, with additional monitors and keyboards, are less common in the home environment. Energy Saving Trust (2006) match monitor ownership to computer ownership in 2002 at 45%. Laptops, with their built in monitors, do not form part of this statistic. No data on types of monitors owned were found in the review.

Time Use Survey data (Lader et al, 2006) report 10 minutes a day spent on computing. If the average household has 2.3 people, this equates to 23 minutes a day per household. However, there is clearly a wide variation in this, with some households spending little or no time on a computer and others spending hours each day.

Data for computers in use does not account for computers left idle or in standby. Firth et al's data (2008) on power consumption in active and standby modes measured 100W typically in use and 7.1W in standby from home computers. The Swedish Energy Agency study measured energy consumption for computer suites at home at 390 kWh/year for families compared with 207 kWh/year for a single person and 194 kWh/year for couples with no children at home. Coleman et al (2008) also found that across all areas investigated video, audio, computing and telephony) standby accounted for nearly 34% of total electricity consumption (approximately 44kWh).

A study undertaken by BRE for the Energy Saving Trust and MTP (2006b)[11] found 96.3% of its households had a printer (all households had a computer) and 48.8% had a scanner. Computers were in active use for just over 6 hours a day (where the computer was running at full power, even though the householder was not actively using the computer). Computers were in reduced power mode for an average of 12 minutes a day (using power management features) and computers were switched off on average 18 hours a day, primarily with the computer switched off but the mains power switched on.

[10] The survey only asked about first and second desktop computers and first and second laptop computers. It is feasible that some households had more than four computers.
[11] A data-logging study of computer use in 80 households in England.

A total of 92.5% of these households reported that the mains power is not switched off if the computer is inactive for up to 2 hours and 81.3% reported that the main power is not switched off if the computer is inactive for a longer time such as overnight. This was supported from the findings from the data loggers which showed that 72.5% of computers were rarely or never switched off during the two week monitoring period.

Purpose of use was also recorded in this study, summarised in the following table.

Table 14. Use of home computers (MTP, 2006b)

Purpose of computer use	**Questionnaire respondents**	**Other household members**
Work related activities	60% of respondents 37.6% up to 1 hour daily	61% other householders 20% up to ½ hour daily 11% 1-2 hours daily
Non-work related activities	80% of respondents 27.5% up to ½ hour daily 23.8% ½ to 1 hour daily	77.5% other householders 23.8% up to ½ hour daily 13.8% 2-3 hours daily

This relates to data on working from home, a trend likely to increase with changes in costs to travel or improved technology allowing flexibility of working.

5.4.2 Network and communications devices

Mobile phones have a high market penetration: 89% (Ofcom, 2009), 94% (Mintel 2007d) 92.3% (4M, 2010) and the increased functionality in recent years of mobile devices such as the Blackberry and i-Phone has increased usage (8% of men and 3% of women own a smartphone (Mintel 2007d); 20% of adults in England have accessed the internet on their mobiles and 17% claimed to listen to audio content on a mobile (Ofcom, 2009). Energy Saving Trust (2006) commented on the habit of charging mobile phones overnight despite a maximum charge being achieved within 2 hours, leaving the rest of the night (and likely sometimes the day depending on behaviour) with the charger in a no load charging state. Although this is a minimal power consumption per phone, the repeated behaviour and multiple homes per household may make this consumption significant. Coleman et al (2008) measured telephony as accounting for 1.2% of household electricity use (1.5kWh).

As with computers, it is not uncommon for mobile phones to be passed on to other family members, usually from children to parents when they upgrade to a newer model. This leaves the phone still in use, although possibly at a reduced level, and extends its lifespan, giving it a second (and sometimes third) lifetime.

Routers provide connection of home computers and other media devices to the internet, sometimes also providing a wireless network within a home, to allow multiple access in a household. As Mintel (2009f) report, the internet has made the home more central to people's lives, enabling it to be a hub for everything from work to social networking and shopping. 4M has found 60.4% of their households had routers. Firth et al (2008) measured the modem's in use power of 4W on continuously. Coleman et al found electricity use from routers was greater than that from computers and accounted for 54% of the total electricity consumed from computing appliances. In one particular household the router's continuous active state meant that this appliance accounted for 87% of total computing electricity consumption for the household (3.8kWh total). The Swedish Energy Agency's work (2008) attributed broadband to using 38kWh annually and the modem 80kWh.

Over one third of households have used the internet to watch TV and video content, watching catch-up TV, user generated content and music videos. Ofcom (2009) also report that 13% of adults in England said some on their household had made voice calls over the internet (VOIP), demonstrating the use of the internet for extended services.

These network service appliances are likely to be always on and active, and although only likely to be one per household, will be used by multiple users and automated systems meaning it may be active for a significant proportion of the day. Loveday et al (2008) comment on the '24/7' or 'always on' culture that continues to grow, and the increased use of social networking sites and streamed/downloaded music means that routers are active for an extended periods each day, with householders accessing the internet from early morning to late at night.

5.4.3 Televisions

TV sales data are well established, this review attempted to understand how these relate to household ownership. Data from Mintel (2008c) and 4M (2010) on household TV ownership is shown in the following table.

Table 15. Comparison of household multiple TV ownership

	Mintel (2008c)	4M (2010)
No television	2.2%	5.1%
One television	20.6%	37.9%
Two televisions	32.6%	31.9%
Three or more televisions	44.6%	30.2%

4M recorded data for numbers of households with four and five TVs; 8.5% and 5.1% respectively. The proportion of multiple TV ownership per household from 4M is shown below.

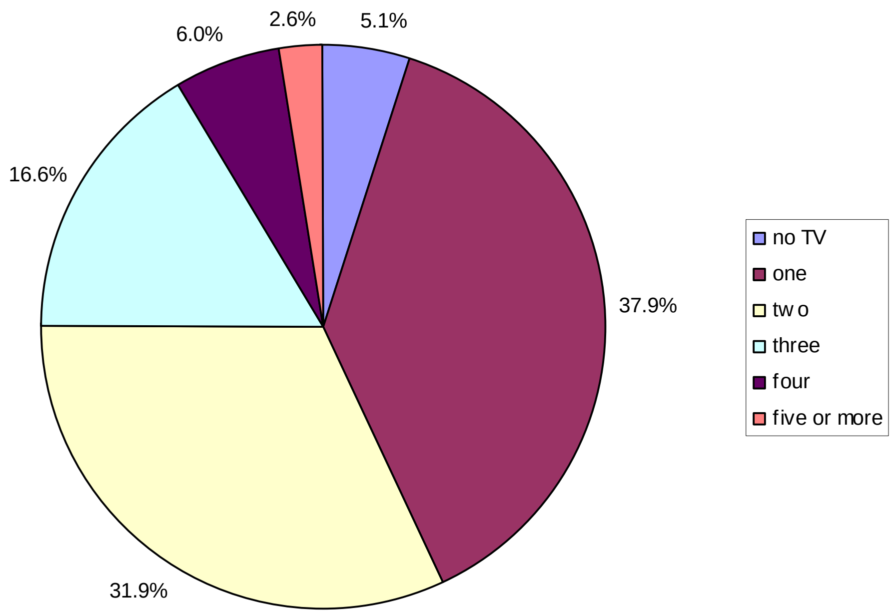


Figure 25. Number of TVs owned in 4M households

On average 4M found 1.9 televisions per household, Mansouri et al found (1996) 1.89. Televisions in children's bedrooms are commonplace; Childwise (2008 cited in Crosbie, 2008) reports that 80% of British children aged 5-16 years have a TV in their bedroom. A study by Biddle et al (2005)[12] on the sedentary behaviour of Scottish children found 26.6% watched TV for at least 2 hours a day on average, 22.7% watched for about 3 hours a day, 14.2% watched for about 4 hours and 14.2% watched for about 5 hours a day.

Ofcom (2009) give a figure of 3.8 hours viewing a day per person (228 minutes). The Time Use Survey (Lader et al, 2006) reported 152 minutes per day on average (watching TV, DVD, video, audio and music), with men watching 170 minutes and women watching 145 minutes a day on average. Peacock and Newborough (2004) reported usage of a TV screen (for TV, DVD, video and games) per household for 2001 at 38.1 hours a week (equivalent to 327 minutes a day). If the mean size of households is 2.3, this gives 142 minutes a day per person. The Time Use Survey identifies older age groups spending an increased time watching TV and listening to the radio. As the population ages, this could increase the total energy consumption of this activity.

Mintel (2009g) report a 23% increase in sales of Plasma televisions between 2007 and 2009, to 900,000 in the UK, compared with a 23% increase in LCD TVs to 7.9million in the same period. Meanwhile, CRT TVs have decreased by 160% to 50,000. The increased availability of LCD and Plasma TVs, especially those with large screens, has increased the energy consumption of these appliances. Details of types of TVs owned in the 4M households are shown below.

[12] A self-report diary of "free time" behaviours that school students completed outside of school hours, completed over 4 days (three weekdays and one weekend day); sample=1056.

Table 16. Ownership on different types of TVs in 4M

	CRT	LCD	Plasma	Total TV
One	39.6%	33.6%	11.9%	37.9%
Two	18.3%	12.8%	0.9%	31.9%
Three	4.7%	3.8%	0.4%	16.6%
Four or more	1.3%	1.7%	0.0%	8.5%
None	36.2%	48.1%	86.8%	5.1%
Ownership	63.8%	51.9%	13.2%	94.9%

In total, there are 444 TVs in the 235 households, of which 51% were CRT TVs, 41% were LCD TVs and 8% were plasma TVs. No obvious correlations were found between number of TVs and household size, or between number of TVs and number of bedrooms, as shown in the figures.

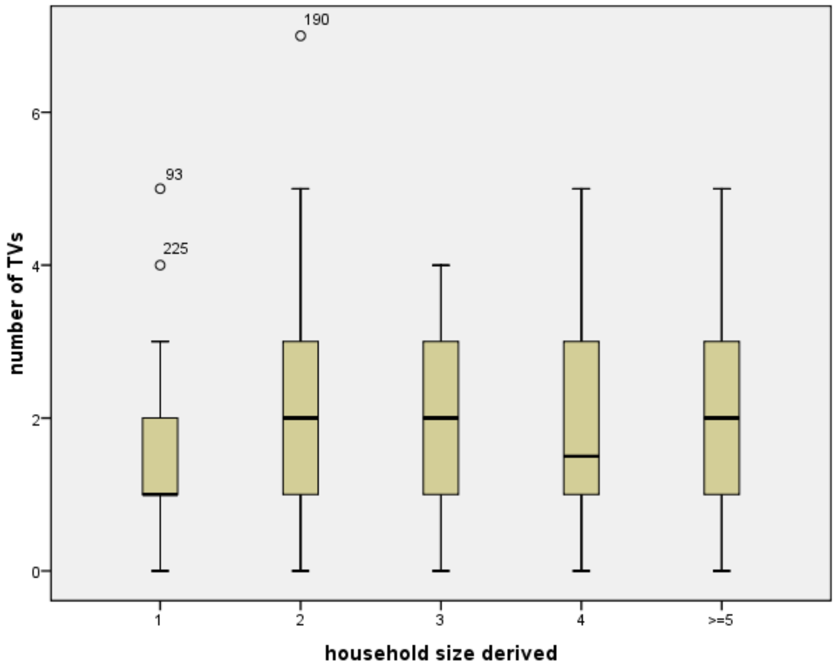


Figure 26. Comparison of number of TVs per household and household size (4M, 2010)

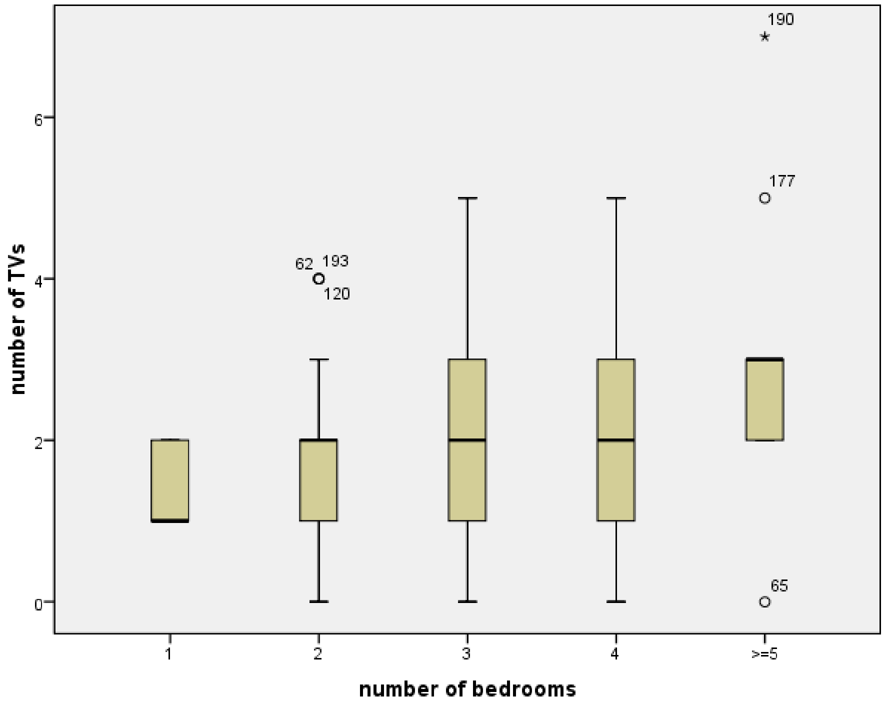


Figure 27. Comparison of number of TVs and number of bedrooms per household (4M, 2010)

The distribution of working hours for each television in the 4M study are shown in the tables below.

Table 17. Working hours of all TVs in 4M households

	TV working hours per day		
	Weekday	**Weekend**	**Average hours/day**
First TV	6.4	7.7	6.8
Second TV	2.5	3.2	2.7
Third TV	1.8	2.4	2.0
Fourth TV	1.7	2.9	2.0

This indicates the primary TV is watched significantly more than the others, with the second, third and fourth televisions being watch a similar length of time on average.

Type of television showed little difference in the hours watched – slightly more time was spent by those households with a Plasma TV during weekdays and weekends. There was a consistent pattern of more TV watching at weekends for all television types.

Table 18. Working hours of the primary TV in 4M households

Type of primary TV	Number of houses	Percentage	Working hours per day - weekdays	Working hours per day - weekends
CRT	93	39.6%	6.0	7.7
LCD	97	41.3%	6.5	7.6
Plasma	28	11.9%	7.4	8.2
Don't know	5	2.1%		
no TV	12	5.1%		

Mintel (2009g) report that people in social groups A and B are more likely than those in other social groups to buy plasma screen TVs.

Sizes and ages of TVs in the 4M households were ascertained and details are shown below.

Table 19. Distribution of TV size in 4M households

Size (inch)	Percentage (%)
<14	2.7
14-19	25.1
20-22	11.5
23-25	4.5
26-28	17.6
29-33	21.4
34-37	6.1
38-43	10.2
>44	0.8

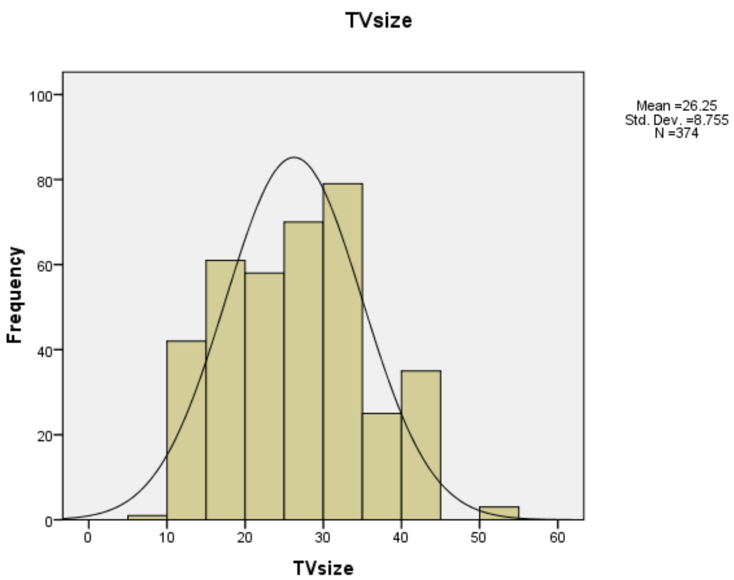


Figure 28. Distribution of TV size in 4M households

Televisions are another product that are passed on to other household members, e.g. an older CRT TV is retained when a new LCD or plasma set is purchased. Although the majority of TV sets in 4M households were reported to be 5 years old or under (65.6%), there were 7.2% of sets over 10 years old, and one set approximately 30 years old still in use.

Table 20. Distribution of Age of TV in 4M households

Age (years)	Percentage (%)
<=1	22.7
1-5	42.9
5-10	27.3
10-15	4.1
15-20	2.6
>20	0.5

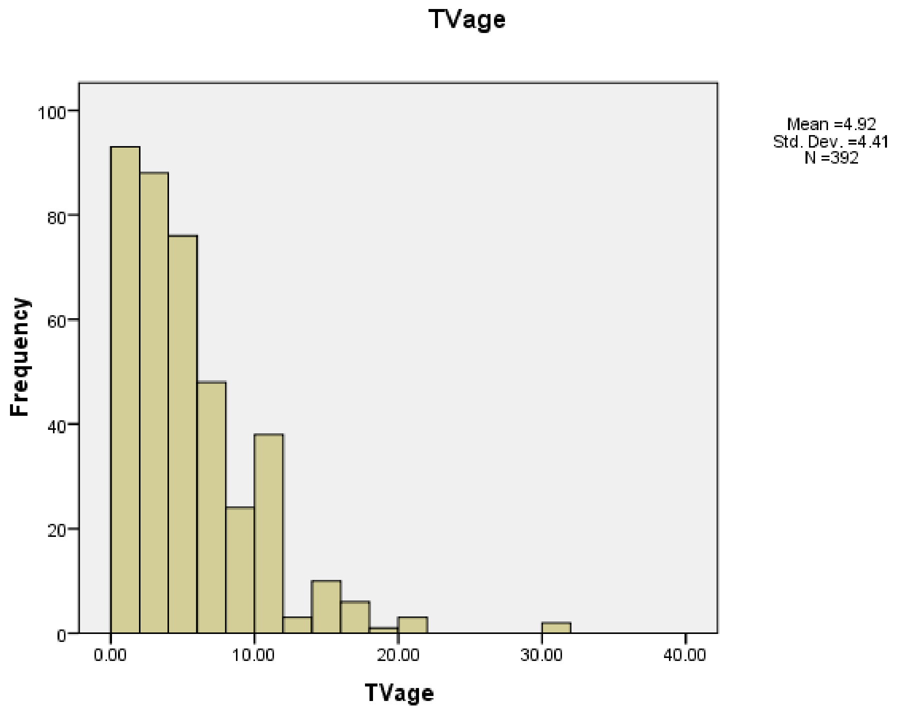


Figure 29. Distribution of TV age in 4M households

There is also some practice of leaving the television on as a background picture with the sound turned down (Crosbie, 2008[13]), when not in use for watching TV. There are other examples of the TV being used as a focal point of the room like a fireplace even if the TV is not being watched (Coleman et al, 2008). Rodriguez and Boks (2005) reported that 90% of their participants[14] said they had the TV on at some point only to hear the sound, ranging from 5 minutes to over and hour a day.

[13] Using in-depth interview data collected from 20 UK households in 2006
[14] Observations through shadowing of five participants during the evening at home, noting appliance use (active and standby)

The introduction of new technologies may result in increased market penetration, for example OLED offers opportunities to hang a TV in bedrooms previously unsuitable for a CRT, LCD or plasma screen because of its thin, flexible design. OLED screens are more energy efficient, but an increase in number could just add to the number of TVs in homes, rather than replace existing products. However the emergence of LED array backlight technology has extended the lifespan of LCD technology and further developments could improve LCD picture quality further, narrowing the gap with OLED each time and so OLED may not take off in the market despite its potential benefits (Smith, 2010). 3D TV is also likely to change technology, with recent increases in films made in 3D; double from 2009 to 2010 (Shiels, 2010), but no further information on the energy implications of this were found.

Home cinema ownership is also increasing. Figures of 11.5% and 18% of households (4M, 2010; and Mintel, 2009d) are reported, with the Swedish Energy Agency reporting 124kWh energy consumption annually for home cinema systems. Home cinema is popular for gaming because of the immersing experience it gives, and is used for extended periods significantly longer than a typical film.

5.4.4 Multi-functional devices

Convergent products, with broader functionality (e.g. games, computing, household information and communications) are increasing (Mintel 2009g). Crosbie (2008) describes televisions as becoming ‘one stop service providers’ which have the potential to reduce domestic energy consumption by slowing the proliferation of consumer electronics in the home, which otherwise might be used simultaneously. However, in some cases this approach uses more energy, for example use of a set top box and television to listen to the radio, increasing the number and energy consumption of appliances in use. Crosbie found that almost half of the households in her study listened to digital radio via the television on a regular basis and a third of radio listeners in England claimed to be using digital TV to listen to radio channels (Ofcom 2009). Crosbie also found that 16 of the 20 households reported that they left sopme of the TVs or other consumer electronic devices on standby because if was necessary for one of the functions of those appliances that they used on a regular basis. Many consumer electronics and services are designed with the assumption that standby is used (e.g. timing devices, personal settings, overnight updates). However, some devices such as IDTV (Integrated Digital TV) can receive signals without separate set top boxes and do not lose their settings if switched off.

There is also evidence of increasing demand by householders to carry out parallel activities at the same time, e.g. using a laptop whilst watching TV, listening to the radio whilst playing a computer game. This may be by one individual, or by different members of the household wanting to share the same social space but carry out individual activities. 80% of users in Rodriguez and Bok’s study have a combination of the following appliances turned on at the same time, at least one hour a day: computer and TV; computer, stereo and TV; stereo and TV.

Crosbie (2008) found that in all households with more than one person, different members of the family watched different programmes in different rooms of their homes, with each TV needing a set top box.

5.4.5 Games consoles

A total of 51% of the population over 16 years are reported to take part in electronic gaming (15.1m on a home computer, 12 m on games consoles, 9.5m on mobile phones and 4.7m via the web), with 21% of 16 year olds playing everyday (BRMB, 2010). Ofcom (2009) suggests 15% of the population own an Xbox, 9% Playstation, 20% Nintendo Wii. 31.1% of households had some sort of games console in the 4M survey. Games consoles are another multifunctional device and can be used for watching audio-visual content on demand – including streaming and downloading films; watching high-definition content using the Blu-ray and HD-DVD drives on the Playstation 3 and the Xbox 360; downloading new content (such as audio-visual content or games) and extras to the console; playing networked games and communicating and chatting with other players; and watching live streamed television from Sky on the Xbox 360 (Ofcom 2009). The Swedish Energy Agency measured the following energy consumptions for games consoles:

- Game Cube – 29kWh annual
- Playstation – 30 kWh annual
- Xbox – 84 kWh annual.

No robust information on use and recharging practices of handheld electronic games and toys in the household was found in the review.

5.4.6 Portable devices

There are a variety of small portable devices, including:

- Personal audio and video players, including MP3, MP4, CD and DVD players
- Portable DAB radios
- Portable games consoles
- Cameras and digital frames
- Satellite navigation devices

In 2006, Mintel estimated that retail sales in the sector were worth just over £3 billion, up 13% in the previous year and up 78% since 2001 (Mintel 2007d) They report that one in ten consumers are ‘completely gadget-mad’, owning six or more mobile technology devices. The spread of Wi-Fi technology means the portable device market is expanding.

There is a variety of audio devices in use, many used as personal audio players (e.g. MP3 formats) which dock to a PC or other device (e.g. radio alarm clock). Mintel (2007d portable technology) report 45% of men and 39% of women owning a MP3 player, and 10% of men and 6% of women owning a MP4 player. Portable video players are popular for children (used by 22% of adults and 38% of children (Mintel 2009c; d).

Mintel also report that 26% of children have a digital / personal video recorder. Portable DVD players allow mobile TV and video services to be viewed in a convenient way.

14% of adults in 2006 owned a portable DAB radio and 42% of adults owned a portable CD player (Mintel 2007d), with 21% of adults owning a DAB radio at home (Mintel 2008a).

Mintel (2009i) report that 38% of adults own some sort of portable satellite navigation system and 22% of adults owned a portable games console.

Coleman et al found 2.0% of the total household electricity consumption used on audio equipment (2.6kWh). Individually, these devices use small amounts of electricity in use and in standby, but the abundance and range of portable devices could be significant.

5.5 Domestic garden and DIY appliances

Garden and Do-It-Yourself (DIY) products are currently not modelled by the Market Transformation Programme and so understanding of their energy consumption is unknown. However, 86% of homes in the UK have a garden (HTA 2009) and they are increasingly used as an outdoor living space, requiring maintenance and equipping with lights, cooking facilities and decorative features. According to social trends 2008, published by national statistics, 49% of adults undertake gardening (Mintel, 2009e)

Mintel (2007b) report the following garden type access for UK adults:

- 70% of adults have a garden that is mostly grass and flowerbeds (with a higher proportion of over 35 year olds and social groups A and B)
- 18% have a garden that is mostly paved
- 4% have access to a communal garden
- 5% have a window box or balcony
- 6% have no garden or yard at all, with a higher proportion of under 24 year olds and social groups D and E in this category.

Data show that 90% of gardens are maintained to some extent (HTA, 2006). Just over half the gardens in the UK are under 2000 ft^2, with only 8% over 4,000 ft^2 (Mintel 2008i).

Table 21. Proportion of population with a garden (HTA 2009)

	Sex		Age				Social grade		
Total	M	F	15-34	35-54	55-64	65+	AB	C1C2	DE
86%	86%	87%	80%	88%	91%	90%	93%	86%	79%

Energy using equipment for gardens include:

- Maintenance equipment, e.g. lawnmowers, strimmers, hedge trimmers, shredders, chain saws etc
- Pond / water feature equipment, e.g. pond pumps, filters, cleaners
- Greenhouse equipment, e.g. lighting and heating, propagators
- Garden living equipment, e.g. decorative lighting, garden heaters, barbecues, chimeneas, fire pits etc
- Security lighting
- Swimming pools, spa pools

This area is not well researched in terms of appliance energy demand; however there are some potentially high demand products (such as greenhouse heaters and patio heaters). If these are only used infrequently in the domestic sector, the overall energy use and carbon emissions may be small.

The potential to embrace the environmentally friendly message within gardening is huge. Retailers, such as Wyevale, are pursuing a strategy of green initiatives, encouraging their customers to think about things like recycling and water conservation, as well as looking to source products from ethical sources.

In March 2008, Wyevale launched the Easy Gardener collection, an Eco Range including products that fall into one or more of the following categories: 1) those made from a renewable natural resource; 2) those made from recycled materials; 3) those made from long-lasting materials, thereby reducing wastage (Mintel 2008i).

HTA (The Horticultural Trades Association) have carried out a number of market research surveys about gardening[15]. Summary information is presented here, but more detailed breakdowns are available to inform any future modelling, once the eventual modelling approach is determined. BMRB's Target Group Index also provides data on some garden appliances[16] reported by Mintel.

The total UK consumer market for gardening products was estimated in 2005 £4,950 million. In three years from 2003 to 2005 it is estimated that the market grew by 9%. Since 1991 the UK garden products markets has more than doubled (UK Ecology, 2010).

The UK garden market for gardening equipment was estimated to have been worth £860 million, at retail prices of 2005, a 2.4% increase on the previous year. (Garden equipment in this case includes lawn mowers, power tools, hand tools, water management and gardening aids such as plant ties, mesh, trellises and gloves). It is anticipated that growth in garden equipments will be at a modest rate, with total value increasing by 1.7% between 2005 and 2006. However the sectors of power tools and equipment and of water management equipment are forecast to see the best growth rates (UK Ecology, 2010).

There is an increase in sales between March and June, equivalent to double the rest of the year (UK Ecology, 2010).

Mintel forecasts the UK market for gardening will grow by an estimated 3% to reach a value of £5.37 billion at current prices over the period 2008-13[17]. In real terms, with inflation for household goods taken into consideration, this represents an increase at a rate of 1% over the forecast period. The current economic climate is, however, of concern for the more expensive items, especially for the premium-end ranges. Lawnmowers, garden furniture, barbecues and garden power tools are all areas that may see purchases being delayed or reduced as domestic spending becomes more considered. (Mintel 2008i).

[15] Data are available from 1999-2007 from a household panel. Data were collected on a self-completion paper diary on a monthly basis using a representative sample of around 6000 households weighted to represent the population of GB. Data can be analysed by a wide range of socio demographic variables.

[16] A consumer survey of adults based on a rolling sample of 2000 15+ adults a month with analysis undertaking on a rolling 12 months sample of around 24000 adults.

[17] Mintel used the SPSS time series package to forecast the market to 2013. SPSS correlates historical market size data with key economic and demographic determinants (independent variables), identifying those factors having most influence on the market. Using forward projections of these factors, a market size forecast is produced.

According to social trends 2008, published by National Statistics, 49% of adults undertake gardening (Mintel 2009e). The main market for garden equipment is the over 50s (UK Ecology, 2010). Use of garden appliances is related to seasons, with increased use of products in spring and summer. Domestic DIY appliance use will also have peaks, in line with weekend and holiday periods.

From the Time Use Survey (Lader et al 2006), repairs and gardening occupied 17 minutes a day, with the 65 years and over category recording the greatest proportion, at 26 minutes a day. Clearly, not all this time will be spent using energy using products. Almost twice as much time (24 minutes compared with 14 minutes) is spent on these activities at the weekend.

The number of people with gardens is growing because of new house builds and land being divided up amongst more owners because of decrease in garden size (HTA, 2006).

5.5.1 Garden maintenance equipment

Garden equipment which covers lawnmowers, other powered tools and equipment, hand tools and water management equipment for use in domestic gardens was worth £851 million in 2008, having increased by 13% since 2004. However the rate of expansion has slowed, reflecting the changing economic climate. This change was most evident in more expensive products, such as lawnmowers and power tools (Mintel 2009e).

The UK Ecology website gives figures of £660million (Retail Selling Prices - RSP) for lawnmowers and garden power tools, just under 13% of the total gardening market (2006 estimate), with water management and pond equipment at just over 2%. The following table shows the further breakdown for specific product groups.

Table 22. The UK market for selected garden equipment (UK Ecology 2010)

£ million RSP*	**2004**	**2005**
Lawn Mowers	340	348
Power Tools	297	302
Hand Tools	76	77
Gardening Aids and Sundries	27	28
Water Systems (Irrigation)	83	86
Water Gardening Equipment	17	19
Total	840	860

Ownership of specific appliances for 2006 is reported by Mintel (2007b). This include 60.4% owning lawnmowers (no identification of whether powered or not), 50.2% owning garden tools (again, no identification of whether powered or not) and 26.1% owning electric hedge trimmers. The majority of the market for lawnmowers is powered (83% share by value at RSP), with ride on / tractor mowers at 9% and hand driven movers at 8%.

Lawnmowers are still a strong market benefiting from the good growing conditions in the cool wet summer of 2007, following reduced sales in 2006 after a hot dry summer. The necessity of this equipment for every lawn owner stimulates a level of needs-driven replacement sales and the lawnmower is one of the major garden tool purchased even by reluctant gardeners (Mintel 2008i).

The power tools market includes (UK Ecology, 2010)

- Tidy and Clean (blowers and vacs, shredders and mulchers etc..) - 9% Share by Value (RSP)
- Cutting and edging (Trimmers, strimmers, loppers and saws) - 86% Share by Value (RSP)
- Lawn care (Electric lawn rakes, scarifiers, cultivators, aerators) - 5% Share by Value (RSP)

Ownership of tools has declined because of the trend for many small gardens to be low maintenance and often focused on pots and containers, which do not need many tools. With fewer hedges and large plants, the demand for hedge trimmers and shears, for example, will fall (Mintel 2008i).

Lawnmower and other power tools ownership is broken down by age and social group in the following tables. Herring (1995) reported 60% of households owning a lawnmower and 48.1% of 4M households had one.

Table 23. Breakdown of domestic lawnmower purchases by age (HTA 2010

	<16	16-24	25-34	35-44	45-54	55-64	65+
Total	0	0	247	369	341	392	617
%	0%	0%	12%	18%	17%	20%	31%

Table 24. Breakdown of domestic lawnmower purchases by social group of the 'head of household' (HTA 2010)

	A	B	C1	C2	D	E
Total	73	310	588	453	296	284
%	4%	15%	29%	23%	15%	14%

Table 25. Percentage of households purchasing lawnmowers during the year (HTA, 2010)

	Total	16-34 ABC1	16-34 C2DE	35-54 ABC1	35-54 C2DE	55+ ABC1	55+ C2DE
2006	2.4%	0.0%	1.6%	1.7%	2.3%	4.3%	2.9%
2007	3.3%	1.6%	1.1%	3.9%	3.2%	5.4%	3.6%
Combined	3.0%	1.2%	1.3%	3.0%	2.8%	4.9%	3.3%

Table 26. Percentage of households purchasing other power tools during the year (HTA, 2010

	Total	16-34 ABC1	16-34 C2DE	35-54 ABC1	35-54 C2DE	55+ ABC1	55+ C2DE
2006	2.5%	0.0%	3.1%	1.4%	2.3%	3.2%	3.3%
2007	2.8%	0.8%	1.8%	2.4%	2.7%	5.9%	2.5%
Combined	2.7%	0.6%	2.3%	2.0%	2.6%	4.8%	2.8%

The lawnmower market has seen some innovation with smaller, more compact and manoeuvrable products coming onto the market. In addition, technological advances in battery technology have enabled manufacturers to introduce mowers with smaller, lighter batteries that give more power and recharge more quickly, while one manufacturer has introduced a hybrid battery/electric cable machine, (Mintel 2007b).

5.5.2 Barbecues

Barbecue ownership stands at 50% of households with a garden. Barbecues are either fuelled by charcoal (62%) gas (37%), with 1% using electric griddles. Further breakdown of the market is shown in the table below.

Table 27. Barbecue penetration and fuel type (HTA 2009)

	Gender		Age				Social grade		
Total	M	F	15-34	35-54	55-64	65+	AB	C1C2	DE
Market Penetration									
50%	49%	50%	50%	61%	55%	24%	57%	53%	33%
Charcoal									
32%	33%	32%	34%	40%	30%	17%	36%	34%	24%
Gas									
19%	18%	20%	16%	25%	25%	9%	24%	22%	8%

Barbecue sales and sales of fuel are seasonal and weather dependent. Poor weather during the main barbecue season damaged sales in 2007, but there is a continued trend towards trading up with gas being popular. Design improvements of portable barbecues have reduced the sales of disposable barbecues, with these being purchased by just 10% of the people with access to a garden. With better weather the market is expected to move forward, as barbecues become more part of everyday eating in the summer rather than only social occasions (Mintel 2008i). Barbecues are, on average, 3.6 years old (HTA 2009).

There is a clear peak amongst 25-44-year-olds in terms of using the garden to entertain family and friends, e.g. for a barbecue. Older age groups may not see the appeal of eating outside (this is preferred by younger age groups wanting to eat outside as much as possible) or find the idea of a barbecue simply too much work, (Mintel 2007b). No information was reviewed on how trends will change in future as the current population becomes older and attitudes to outdoor living change.

Use of the garden for a range of social activities is presented in the following table. As before, the data shown are based on respondents with access to a garden. Although a proportion of respondents said they never use their garden for these social activities, gardens are most often used for social activities when the weather allows.

Table 28. Use of garden for social activities as proportion of those with access to a garden (HTA 2009)

	Household meals	BBQs for family / friends	More formal dinner parties	Parties for family / friends	Children's parties	Casual entertaining with friends or family
Never	33%	34%	67%	40%	63%	29%
Very rarely	16%	14%	15%	18%	14%	16%
Occasionally, when the weather allows	29%	32%	10%	29%	14%	32%
Regularly, when the weather allows	13%	10%	2%	6%	3%	11%
Often, when the weather allows	4%	4%	1%	2%	1%	5%
Lots, it has to be wet or very cold to stop me	0%	1%	0%	0%	1%	1%
Don't know	5%	5%	4%	5%	5%	4%
Ever (net)	62%	62%	28%	56%	33%	66%

5.5.3 Garden heaters

Garden heaters are available in a range of designs, with a variety of fuel sources. A total of 10% of those with a garden own some type of garden heater (HTA 2010). Only 2.1% of the 4M sample owned a garden heater (although 70% of the sample had a garden). HTA (2009) give a breakdown of types of garden heater owned.

Table 29. Type of garden heater owned as proportion of those with access to a garden (HTA 2010)

		Gender		Age				Social grade		
	Total	**M**	**F**	**15-34**	**35-54**	**55-64**	**65+**	**AB**	**C1C2**	**DE**
Gas	5%	4%	6%	6%	6%	8%	1%	7%	5%	4%
Chimera - clay	1%	1%	1%	2%	0%	1%	0%	1%	1%	2%
Chimera - metal	2%	2%	1%	1%	3%	1%	1%	2%	2%	0%
Brazier	0%	1%	0%	1%	0%	0%	0%	0%	1%	0%
Open hearth	0%	0%	0%	0%	1%	0%	0%	0%	1%	0%
Electric	2%	3%	1%	3%	1%	2%	2%	3%	2%	1%
Don't know	3%	2%	4%	3%	3%	1%	3%	3%	3%	2%
Any (net)	10%	10%	10%	12%	11%	12%	4%	13%	10%	6%

Patio heaters, fuelled by gas cylinders enjoyed a period of short-lived popularity, but its lack of environmental status has damaged sales with more eco-friendly options benefiting such as chimeras or chimeneas and fire pits Wyevale, a major garden retailer has chosen to sell off remaining stock and not restock them (Mintel 2008i).

The following table shows estimated consumption/emissions for patio heaters per year (Fawcett et al, 2000).

Table 30. Patio heater estimated consumption and emissions

	Value	Unit
Average power of patio heater, (S)	8.90	kW
Days per year in (D)	30	Days
Hours per day in use (H)	4	Hours
Energy used per year (E=S x D x H)	1,068	kWh
CO_2 emissions per year (=E*0.214)	229	Kg CO_2

5.5.4 Greenhouse heaters

Greenhouse heaters are powered by paraffin, propane, gas or electricity, are available in a range of power outputs, typically 2 - 3kW but are available up to around 12kW. Almost all electric greenhouse heaters are fitted with a thermostat, an essential feature. Heat mats and propagators are also used by gardeners, but no information on the extent of the market or usage was available.

5.5.5 Garden lighting

Respondents to HTA's survey who had access to a garden were asked about their garden lighting. 30% of these reported they had mains electric lighting in their garden. A further 24% had solar lamps and less than one percent had gas/oil lamps. Further details are presented in the following table.

Table 31. Type of garden lighting owned as proportion of those with access to a garden (HTA 2010)

		Gender		Age				Social grade		
	Total	M	F	15-34	35-54	55-64	65+	AB	C1C2	DE
Mains electric lighting	30%	29%	30%	24%	34%	37%	25%	36%	28%	27%
Solar lights	24%	23%	25%	20%	25%	29%	24%	26%	26%	18%
Gas/oil lamps	0%	1%	0%	0%	1%	1%	0%	1%	0%	0%
No answer	51%	53%	49%	58%	49%	42%	54%	46%	51%	59%

Mintel (2009b) also report the proportion of people with outdoor lighting/heating. Data from 2009 are shown in the figure below.

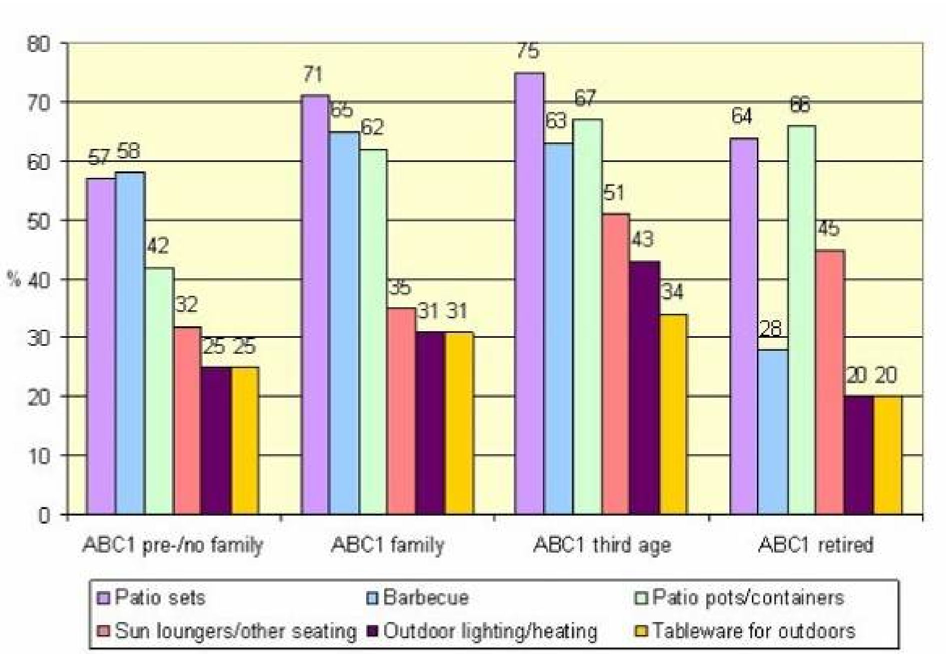


Figure 30. Ownership of outdoor living items, as a proportion of those with a garden – ABC1 families only (Mintel 2009b)

5.5.6 Water gardening

Water gardening has become more popular and the water equipment market is split into two broad sectors, pond pumps and cleaning products (such as filters, silt removers and pond vacs etc.) 60% of the market share by value (RSP) is pond pumps, 40% filters and cleaning equipment.

The overall water garden market, which comprises ponds and water features such as fountains, was estimated at approximately £90 million in 2005, whilst the water gardening equipment sub-sector is valued at an estimated £19 million. (UK Ecology, 2010).

AMA (2009) estimated that 7-8% of UK homes currently have some form of water feature. Data specifically relating to powered pond pump and filtration system usage was not found in the review. Pond ownership is expected to increase in the longer term, although has declined slightly in recent years.

5.5.7 Swimming pools and spa pools

Swimming pool heating and pumping systems are likely to be big users of energy when in use; however these are likely to be used seasonally and are present in a small proportion of UK houses. No data on the penetration of swimming pools and spa pools were found during this review.

5.6 Domestic standalone environmental control

Only freestanding environmental control appliances (those that plug in or stand alone) were considered here – heating, lighting and air treatment that forms part of the fabric of the house were not reviewed. The ownership, usage and energy demands of heating and lighting are often reported as combined so difficult to separate out. They also form an area that has been well researched, so this review focused on other appliances.

5.6.1 Air treatment appliances

Domestic air treatment forms a very small percentage of the total market, where commercial air treatment is much more widespread. The total UK market for domestic air treatment products, appliances and equipment was estimated to be worth £39.2 million in 2000, with dehumidifiers forming the largest market in 2001. In real terms, the market has declined by 28% between 1995 and 2000, chiefly due to a fall in average unit prices. In volume terms, sales have risen by some 16% over the same period, (Mintel 2001). Sales of dehumidifiers in 2000 were assisted by falling prices, which encouraged new consumers to enter the market. However, people tended to trade up from single use products to those with additional features, driving market value rather than household penetration.

Mintel (2001) report ionisers losing both value and volume share, with a change towards air cleaners/filters which incorporate ionisers and offer other benefits. Sales of air filters/cleaners therefore grew more rapidly. There is a tendency for consumers who own ionisers to trade up to an air cleaner with an ioniser, rather than purchase a replacement ioniser.

Portable air conditioners have very low penetration in British homes, the vast majority of sales being into small commercial premises such as shops and offices. However, Mintel suggest that an increase in 'home offices' may have assisted demand. A key driver has been the falling unit prices of portable air conditioners, which has made smaller units more affordable.

Table 32. Volume sales of air treatment products, by sector, 1996-2000 (Mintel, 2001)

	1996		**1998**		**2000 (est)**		**% change**
	000 units	%	000 units	%	000 units	%	1996-2000
Dehumidifiers	103	30.0	110	30.1	135	34.6	+31.1
Ionisers	130	38.0	121	33.2	100	25.6	-23.1
Air filters/ cleaners	80	23.0	105	28.8	120	30.8	+50.0
Portable air conditioners	31	9.0	29	7.9	35	9.0	+12.9
Total	**344**	**100.0**	**365**	**100.0**	**390**	**100.0**	**+13.4**

Ionisers are the least expensive items in the air treatment market, with an average price of £20 in 2000. They are believed to be of use for those with asthma and other allergic conditions as they remove dust from the air, by emitting a stream of negatively charged ions.

Sales of air cleaners/filters were worth an estimated £6 million in 2000. These products benefit from a relatively low price, a wide range of sizes and formats, from small table-top devices to floor-standing 'whole house' appliances, and a scientific basis for their operation. Improved quality filters, such as the HEPA filters, have given added credibility to air filtration. Furthermore, it is easy for consumers to understand the benefits of cleaner, dust-, pollen- and odour-free air.

Estimates of the number of domestic air conditioners sold vary considerably as it is difficult to separate those which are purchased purely for domestic use from purchases for small shops or business premises. Mintel (2001) estimates that portable domestic air conditioner sales were in the region of 35,000 units in 2000, equating to £12.3 million. Lower unit prices and price promotions by DIY stores have assisted volume sales. Demand is generally influenced by the weather, being much higher during long hot summers. However, sales of air conditioners for the home remain a niche sector, with far greater numbers going through specialist retail channels into small shops and offices.

According to Mintel (2001) demand for dehumidifiers is driven by problems of excess humidity in the home leading to condensation, which may damage window frames, cause wallpaper to peel, and allow mould to grow on furnishings and in unventilated cupboards. The greater use of washing machines, tumble-driers, dishwashers and showers add to the excess moisture that becomes trapped in poorly ventilated rooms. Ironically, both double-glazing, which decreases ventilation, and central heating, which allows the air to take up additional moisture, increase the chances of condensation.

The very low level of sales of humidifiers, by contrast, is likely to fall further. Humidifiers are smaller and much cheaper units than dehumidifiers and are useful for certain medical conditions, such as asthma and allergic rhinitis, which can be exacerbated by dry air. However, apart from occasional hot dry summers, the British weather tends to be too damp rather than too dry, hence humidifiers have a relatively small share of the market.

The demand for air-conditioning in the home is twofold (Mintel, 2001):

- The increase in 'home offices' and working from home. A fully equipped home office could include a computer, printer, scanner, photocopier, phones etc, all of which generate heat and attract dust. An air-conditioning unit would be a relatively small additional cost, but could help to make the working environment more comfortable.
- The range of features which newer air conditioners offer. Whereas a basic unit may simply cool the air, and therefore may only be used during a (rare) hot spell of weather, new models offer dehumidifiers, air

filtration, and even heating, making them more worthwhile for year-round use, and hence a better investment.

5.6.2 Portable heaters

A total of 20.9% of houses in the 4M survey reported regularly using a portable electric heater in their house.

Portable heaters for conservatories were considered in more detail, as they may contribute to a significant part of the household energy use where present. However, little information was found relating to the numbers and usage of conservatory heaters in households, although 4.7% of the 4M survey said they regularly used a portable electric heater in their conservatory. The design of conservatories (glazing in particular) can affect the extent to which heating and cooling are needed in a conservatory. Future options to use heat pump technology could reduce the energy consumption of heating and cooling conservatories; these are likely to be built into the fabric of the home rather than appliances. Portable all-in-one units are an option but are less efficient and more intrusive, as they are invariably floor-standing units and so are likely to be less appealing to the householder (Mintel, 2004a).

5.7 *Other domestic appliances*

5.7.1 Cleaning

Powered cleaning products covered by this section include vacuum cleaners, irons and floor polishers. Mintel (2009j) report that in 2008 18.5% of adults spend 'a lot' of time cleaning, 45.7% 'a fair amount' and 26.5% 'a little'. An estimated 10 million people only do the cleaning at the weekends. This is heavily influenced by working patterns, with those in employment reporting to only tidy up as they go along throughout the week and opting to 'blitz-clean' at the weekend. Older people are reported to be typically more house proud than younger demographics. This is influenced by the presence of small children in younger households and the fact that retired people may have more time on their hands to spend cleaning.

Mintel (2008h) reported that 96.2% of households owned a vacuum cleaner in 2007. 55.1% were upright cleaners, 33.5% were cylinder cleaners and 7.6% owned a wet and dry cleaner. Mansouri et al (1996) reported one vacuum cleaner per household, and they were present in 96.2% of 4M households. The market for vacuum cleanings is largely a replacement one, with product life spans extending as reliability of appliances has improved.

90% of respondents in the Mintel survey (2008h) reported that they vacuumed their home at least once a week; once a week vacuuming is increasingly prevalent, whilst once a day/once every 2-3 days has declined. Further details of vacuuming frequency are shown in the following figure.

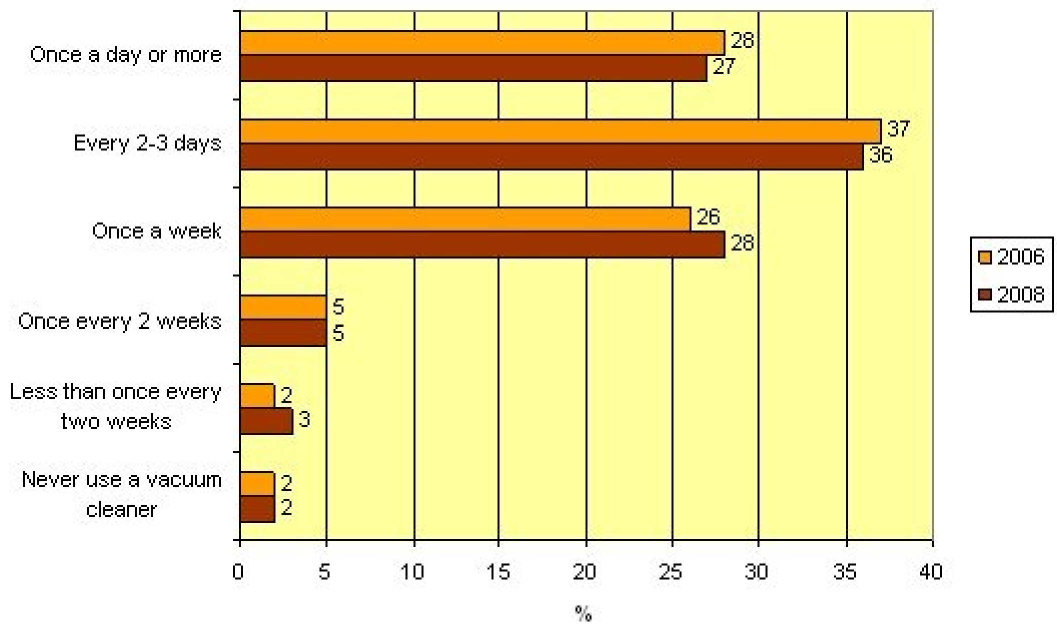


Figure 31. Frequency of vacuuming house, 2006 and 2008 (Mintel 2008h)

Irons also have a high market penetration: 76.1% in 2008 (Mintel, 2009h), 98% in Herring (1995) and 96.2% in the 4M households. There was little information on how long people spend vacuuming, ironing or using other household cleaning appliances.

5.7.2 Beauty, health and hygiene

Hair care products are used by 94% (Energy Saving Trust 2006) and these include energy using appliances such as hair dryers, straighteners and curlers. A total of 61.7% of households in the 4M survey (2010) reported owning electrical hair styling equipment and Herring (1995) found 75% of his sample using this type of appliance. Herring estimated that people spend 20 hours a year using hair dryers and 25 hours a year using hair curlers. A typical duration of using a hair dryer is given as 20 minutes in E.ON's factsheet (2010). In 2004, 31% of adults owned an electric toothbrush (Mintel 2004b).

Other powered products in the home include toothbrushes, shavers, hair removers, massagers, steamers and home spas. No robust information on usage was found in the review.

5.7.3 Medical aids

Aids, adaptations and alarms often enhance the functional independence of those wishing to remain in their homes, notably elderly and physically disabled people. Whilst most of these items are not powered, there may be aspects of the market that should be considered further in household energy modelling. Mintel (2009a) report that expenditure on aids, adaptations and alarms is expected to increase as a result of increased expenditure on home care services. The development of telemedicine is likely to accelerate the trend of caring for people at home, by enabling current home-based procedures to be monitored more closely by specialists. This involves the development of medical implements which can communicate directly with a hospital to monitor and adjust treatment regimes and allowing the closer monitoring of patients by fewer nurses. However, the implementation of telemedicine remains limited due to the lack of evidence for its clinical and cost effectiveness. Nevertheless, increased demand for call centres and online health information has identified public demand for these services. Indeed, NHS Direct uses call centres, its website and more recently NHS Direct digital TV, a digital television channel to try to triage patients.

Powered stair lifts, bed hoists, bath hoists, reclining beds and chairs also should be considered in this category, as well as mobility scooters if they are kept by the householder.

5.7.4 Hobbies and leisure

A number of hobbies and leisure activities not already covered also use energy in the home. These include:

- Exercise and fitness equipment (e.g. treadmill)
- Sunbeds and solaria
- Fish tanks and vivariums
- Musical instruments (keyboards, electric guitars etc)
- Sewing machines

as well as Christmas decorations.

Little data on the ownership and usage of these products were found in the review. Whilst many of these products may only be used occasionally, or by a small proportion of the population, the individual energy use may be significant (heated and filtered fish tanks, for example). Fish tanks were reported in 2.1% of the 4M households and vivariums with heaters in 1.7%. The Swedish Energy Agency (2008) measured aquariums using 230kWh/year. This study also reported energy usage of 6 kWh/year for hot tubs/Jacuzzi (present in 0.3%, n=13). There was a hot tub in 0.9% of 4M households.

5.7.5 Others

There are a range of other devices that may be found in the domestic environment that use energy. Whilst it is anticipated that these are either low penetration items, or low energy usage items, they are listed here for reference:

- Security devices – security, carbon monoxide and smoke alarms, CCTV
- Baby equipment – bottle warmers, sterilisers, baby monitors (audio and video)
- Children’s toys – various, fuel using ride on vehicles (FURVs), plus batteries for all.

5.8 *Appliance ownership – a household perspective*

Data from 4M were further analysed on a household level to explore whether there were any patterns or trends in appliance ownership in two types of households: a lone person over 70 years and a household with a married couple and children. In the 4M appliance survey data, there were 23 households in the former category and 22 in the latter. The aggregated data for these two household types are shown in the table below.

Table 33. Comparison of two household types from 4M

		Single person (over 70) households	Households with married couple and children
Number of households		23	22
Number of cold appliances	1	43.5%	54.5%
		fridge-freezer (7) refrigerator (3)	fridge-freezer (11) refrigerator (1)
	2	52.2%	22.7%
		refrigerator + upright/chest freezer (8) fridge-freezer + up/chest freezer (1/2) fridge-freezer + refrigerator (1)	refrigerator + upright/chest freezer (2) fridge-freezer + chest freezer (2) fridge-freezer + refrigerator (1)
	3	4.3%	18.2%
		refrigerator + upright freezer + chest freezer (1)	fridge-freezer + refrigerator + upright/chest freezer (4)
	4	0	4.5%
			2 refrigerators + 2 upright freezers (1)
Wet	Washer*	91.3%	100%
	Dryer**	30.4%	63.6%
	Dishwasher	13.0%	40.9%
	Electric shower	47.8%	50%
TVs	0	4.3%	0
	1	56.5%	54.5%
	2	30.4%	22.7%
	3 or more	8.7%	18.2%
PCs	Desk-top	26%	86.4%
	Laptop	4.3%	59.1% (5 houses have 2 or more laptops)
	Overall	26%	100%

* either a washing machine or a washer-dryer
** either a washer-dryer or a tumble dryer

Key observations from these two types of household:
- Every family household had some sort of computer, compared with only 26% of older lone householders.
- More family households had a dish washer (40.9%) compared with only 13% of older lone households.
- Perhaps surprisingly for a person living alone, 39.1% of older lone householders had two or more televisions, compared with 40.9% of family households. However, it is highly likely that some of the family TVs are watched simultaneously, whereas it might be presumed that the lone householder only watches one TV at a time.
- A total of 63.6% of family households had a dryer of some sort (tumble dryer or washer-dryer), compared with only 30.4% of older single-person households.
- Although there were similar numbers of households with just one cold appliance, there were significantly more single person households with two appliances (52.2% compared with 22.7% for family households), primarily with a fridge and upright or chest freezer. There were more family households with three of more cold appliances (22.7%of households) which usually comprised a fridge-freezer, refrigerator and a freezer.

In order to understand more about individual households, two households in each of these categories were selected at random to observe their particular circumstances and appliance inventory. These are not meant to display 'typical' households as each household has its own particular characteristics, but provide a snapshot of households and their appliances. Summaries of these households are shown below. All information including usage is reported, so no confirmation of data presented was obtained to validate responses.

Table 34. Snapshots of two older single-person households (4M)

Typical households	**Single person (over 70) households**	
	Household 1	Household 2
Socio-demographic background	Female, age 88, widowed, NS-SEC 2, income unknown, lives in (and owner of) semi-detached 2-storey 3-bedroom house, total floor area 98 m^2.	Male, age 72, divorced, NS-SEC 5, income in band £5200 -£10399, lives in rented flat.
Fridge and freezers	1 refrigerator and 1 upright freezer, both bought 5 years ago	1 fridge-freezer bought 13 years ago
Clothes washing and drying	1 washing machine bought 2 years ago, clothes wash: 3 loads a week at 40 °C.	No washing machines and dryers, possibly use shared/communal laundry equipment; clothes wash: 1 load per week at 60 °C.
Dishwashing	No dishwasher.	No dishwasher.
TVs	Has one 32" flat panel LCD TV, bought 2 years ago. The TV is normally switched on for 10 hours per day for both weekdays and weekends.	One 32" flat panel LCD TV bought 6 years ago; TV is normally switched on for 10 hours per day for both weekdays and weekends.
Other consumer electronics	Has one VCR and one DVD, but doesn't use much.	1 VCR, 1 set-top box for TV, 1 DVD and 1 hi-fi system; uses DVD 2 hours per day.
Cooking	Electric oven and electric hob (with cooker hood) as main cooker (no cooking hours indicated), also uses electric kettle, pop-up toaster; no other small kitchen appliances.	Electric oven and electric hob (no cooker hood) as main cooker, oven is on for about 4 hours/day on weekdays and 2 hours/day on weekends; hob is on for about 6 hours per day on weekdays and 2 hours/day at weekends; also has microwave, slow cooker, kettle and pop-up toaster.
ICT	None	1 mobile phone.
Electric shower	No electric shower.	Has electric shower (3 showers per week).
Gardening	Has front and back garden (private); 1 electric lawn mower; lawn is mown 3 times a year, about 20 minutes each time.	Has shared/communal front and back garden; has garden strimmer, hedge trimmer, shredder, chainsaw and electric lawn mower (but not in use)
Other electric appliances	1 hair styling equipment; 1 iron; 1 vacuum cleaner.	1 iron, 1 vacuum cleaner, 4 power tools, 1 dehumidifier and 1 portable fan.
In total	15 listed electric appliances.	27 listed electric appliances.

The snapshots of two family households are shown below.

Table 35. Snapshots of two family households (4M)

Typical households	Households with a married couple and children	
	Household 3	Household 4
Socio-demographic background	Household size 4 (2 adults, 2 children), HRP age 31, male, NS-SEC 5, household income in band £5200-£10399, live in rented mid-terrace, 2-storey house, total floor area 78 m^2, no garage.	Household size 4 (2 adults, 2 children), HRP age 43, female, NS-SEC 1, household income in band £41600-£46799, live in (and owner of) semi-detached, 3-storey, 5-bedroom house, total floor area 218 m^2, has a garage.
Fridge and freezers	One fridge-freezer bought 9 years ago.	One refrigerator (10 years), 1 upright freezer (7 years) and 1 fridge-freezer (3 years).
Clothes washing and drying	One washing machine bought 6 months ago; clothes wash: 1 load a week at 80 °C; no tumble dryer.	1 washing machine and 1 tumble dryer (age not specified), clothes wash: 2 loads a week at 40 °C, tumble dryer works 1 load/week in winter, and normally is not used in summer.
Dishwashing	No dishwasher.	Full size dishwasher bought for 1 year. Average 3 loads dishwashing per week at 60°C.
TVs	One 28” CRT TV 9 years old; TV is normally switched on for 3 hours/day for weekdays and 5 hours/day on weekends.	Three plat panel LCD TVs, only two are in regular use; first one 37” (3 years old), watched 4 hours/day for weekdays and 9 hours/day for weekends; second TV 40” (6 months old), watched 2 hours/day for weekdays and 4 hours/day for weekends.
Other consumer electronics	1 VCR, 1 DVD (used 2 hours/day), 1 hi-fi system and 1 game console.	One set-top box for TVs, 2 VCRs (only used 2 hours/day on weekends), 2 DVDs (only used 2 hours/day on weekends), 1 DTR (digital TV recorder), 3 digital radios, 1 hi-fi system, 1 record player and 1 game console.
Cooking	Gas oven and gas hob (with cooker hood) as main cooker; gas oven is rarely used, gas hob is used 6 hours/day for weekdays and 3 hours/day for weekends; no microwave; other kitchen appliances	Electric oven and electric hob (with cooker hood) as main cooker; oven is not normally used on weekdays but is used 2 hours/day on weekends; hob is on for about 1.5 hours/day on weekdays and 2 hours/day

	include 1 electric kettle, 1 pop-up toaster, 1 sandwich toaster and 1 food processor.	on weekends; also has microwave, slow cooker, 2 electric kettles, 1 pop-up toaster, 1 sandwich toaster, 1 electric juicer, 1 food processor and 1 electric blender/mixer.
ICT	One desk-top computer (CRT monitor, used 0.5 hour/day on weekdays and 4 hours/day on weekends); 1 telephone/answering machine, 1 mobile phone and 1 broadband modem/router.	1 desk-top computer (no usage specified); 2 laptop computers (1st laptop on for 14 hours per day for weekdays and 10 hours at weekends, 2nd laptop on for 2 hours per day, same for weekdays and weekends). 1 multi-function printer, 1 telephone/answering machine, 2 mobile phones, 1 broadband modem/router.
Electric shower	No electric shower.	Has electric shower (5 showers per week).
Gardening	Has private back garden but no lawn; no gardening tools.	Has private front and back garden; no gardening tools (presumably hire someone else for garden management); lawn is mown 4 times a year, about 30 minutes each time.
Other electric appliances	1 hair styling equipment, 1 iron, 1 vacuum cleaner.	1 hair styling equipment; 1 iron; 1 vacuum cleaner; 1 extractor fan; 2 power tools; 1 home security system.
In total	19 listed electric appliances.	49 listed electric appliances.

The ‘snap-shot’ family households reported to have more electrical appliances per household than the older single-person households (a total of 19 and 49 appliances in family households, 15 and 27 in the older single-person households). It is not easy to calculate this number for all the houses, as some people reported “10 power tools” whereas others left a box blank, not thinking to mention some appliances. The appliance survey was not intended to record a complete inventory of all appliances in the home (which would require a much more complex approach, outside the scope of the current 4M data collection), just an indication of the number of specific items chosen by the researchers.

Work by Gruber and Schlomann (2006)[18] at the Fraunhofer Institute showed how electrical consumption increased as the number of appliances in the household increased and the following figure is reproduced from their paper.

[18] A written survey in 20,235 households in Germany in December 2002.

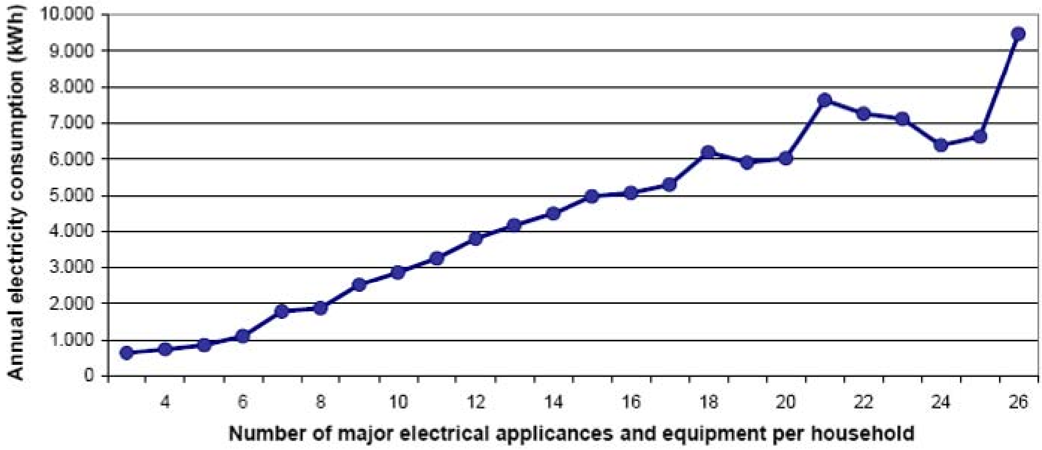


Figure 32. Influence of the number of appliances on electricity consumption (from Gruber and Schlomann, 2006)

Rodriguez and Boks (2005) presented their small study data through tabulation to indicate parallel use of appliances in active and standby modes. An extract from their paper is reproduced below, to show how combinations of appliances and lights were used simultaneously, indicating the complexity of understanding behaviour.

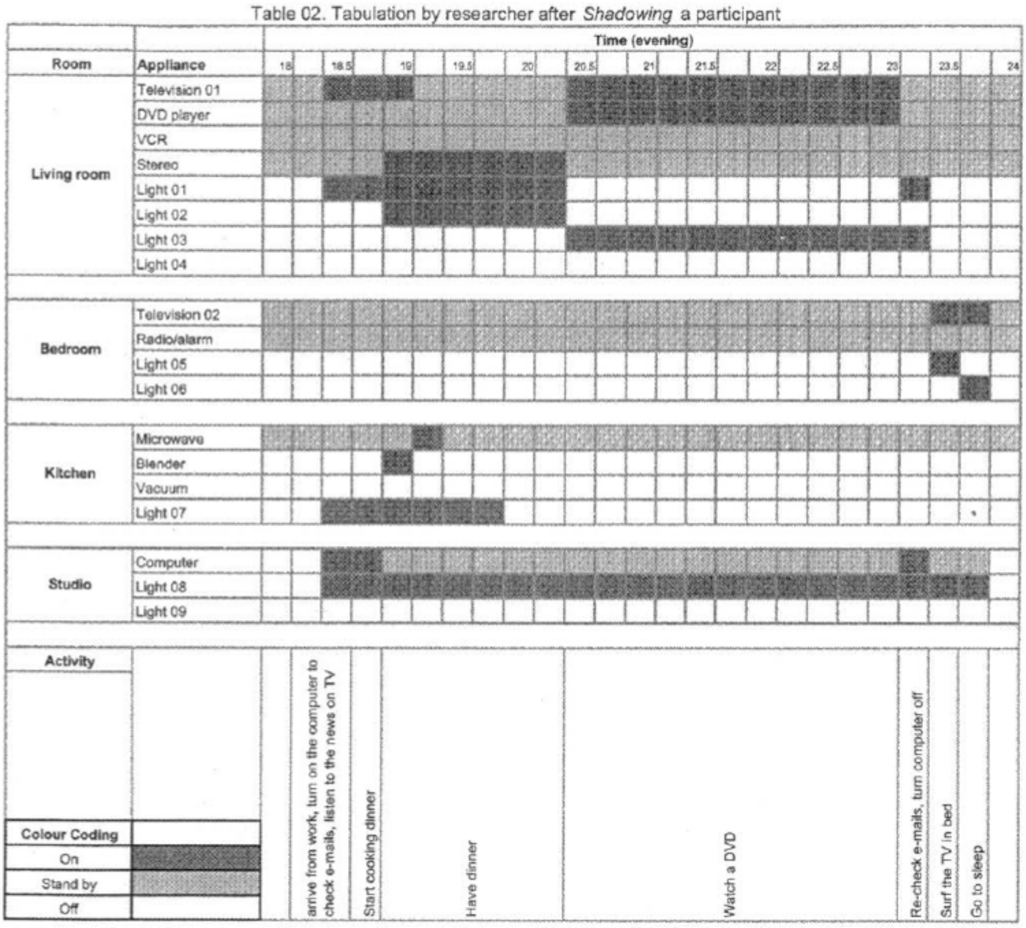


Figure 33. Parallel use of appliances and lights (Rodriguez and Boks, 2005)

6.0 Energy consumption of appliances

Energy consumption for each appliance, based on the information gathered in the review, was estimated and details are presented in this Section. For each, estimates of three primary factors that determine energy demand are given. These factors are:

- **Usage**. Usage is represented by either the number of hours per year that the appliance is switched-on, or the number of cycles per year that the appliance is used for, depending on power demand figure used above. The time spent in standby is also estimated.

- **Ownership**. Ownership in this case represents the mean number appliances owned and in active use by each household. Active use means that the appliance is not just stored (such as an old television stored in a garage), but is part of the set of appliances frequently used by household occupants. This number may be greater than one, for example, for CRT televisions where it is common to own and use more than one.

- **Appliance power demand**. In each case, one of two columns is used to indicate the power demand. The first is the mean power demand when in-use, which is more relevant to long running appliances or where the length of used varies considerably. The second is the energy demand per cycle, which is more suitable for describing appliances that are switched-on and subsequently operate over a cycle, such as a washing machine. An estimate of the power demand of the appliance when in a standby state is also given.

Results from these calculations are presented by appliance group in the following sections of this report. Electricity demand is presented in two ways in the tables: firstly without ownership being taken into account, and then with taking ownership into account. The average electricity demand of the respective appliance is given in the first case. The overall contribution to the mean domestic demand level constitutes the second. In-use, standby and total demands are shown for each appliance in the tables.

As an example, for cold appliances, the mean in-use demand for a refrigerator is 23 W in the table. This represents the average level of demand when switched-on at the socket over a long period of time. (This is different from the peak demand seen as the fridge cooling compressor cycles on and off). Fridges are usually left switched-on all the time. A figure of 8760 hours per year is therefore given as the usage pattern. Multiplying these two figures gives an annual energy demand of approximately 200 kWh per appliance. To take ownership into account, the mean number of appliances owned by each household is in this case given as 0.53. Multiplying the previous result by this ownership level gives the annual demand per household for this appliance type. In this case, this represents a mean electricity demand of 107 kWh per household.

Some of the figures are based on MTP and other established sources. Some are estimates. In light of the range of different sources of data, a colour coding scheme is used to indicate the level of confidence that is held for each power, usage and ownership data value given in the table. Confidence is banded into high, moderate and low levels. The interpretation of each band, already discussed in Section 5, is explained in the following table.

Colour code	Confidence	Interpretation of the uncertainty in the values given
Green	High	The mean value is likely to be within 10%.
Yellow	Moderate	The mean value is likely to be within a factor of 2 difference.
Red	Low	The mean value may be outside a factor of 2 difference.

Table 36. Levels of confidence in the data – colour coding

6.1 Whole house results

Statistics indicate that the average domestic annual electricity consumption in 2006 was 4457 kWh (UK Department for Business Innovation and Skills, 2007)[19]. Calculations using our best estimates of how this breaks down into the comprehensive appliance categories are presented. This is done firstly by whole-house, using a list of 120 different appliances categorised into major end-use categories; secondly each appliance category is presented and discussed in more detail.

Note that the sum of the electricity demand for all the appliances in the table gives a total of 4847 kWh when household ownership is taken into account. (Heating and heating related electrical energy use is included in the calculations to give a whole-house figure). Clearly, there is considerable uncertainty in the figures used to calculate this value total, but the fact that is does not add up illustrates the points made earlier. Nevertheless, the result is within 10% of the national average figure referenced earlier. Given the uncertainty, this is considered a close result.

Whilst there is some use of gas for appliances in the home (cooking in particular), these have not been included in these calculations.

[19] The calculated figure of 4,847 kWh/y includes a proportion of houses with electric heating, as shown in Table 49 in Section 6.2.12 in this report. For comparison, the MLSOA data (2006) indicates: Ordinary domestic - 4,013 kWh/y; Economy7 domestic - 6,167 kWh/y; Total Domestic - 4,457 kWh/y. The value of 6,167 kWh/y for Economy7 domestic is considerably higher than Ordinary domestic as a result of electric heating (particularly storage heaters, being run at night on this tariff.) Table 49 includes estimates for electric space heating devices - these have high power demands, but relatively low ownership levels. Houses with electric heating (such as storage heaters) will have considerably higher electricity demands than those that do not, and therefore electric heating is considered a major factor in the range of electricity demand.

Table 37. Domestic electricity demand by appliance – whole-house

	Appliance type	Mean in-use power demand (W)	Energy demand per cycle (kWh)	Standby demand (W)	Hours in-use per year (h/y)	Cycles per year (1/y)	Hours spent in standby per year (h/y)	Annual in-use demand per appliance (kWh)	Annual demand in standby per appliance (kWh)	Total annual energy demand per appliance (kWh)	Ownership	Annual in-use demand per household (kWh)	Annual demand in standby per household (kWh)	Total annual energy demand per household (kWh)
Cold														**616**
1	Fridge	23			8760			200		200	0.53	107		107
2	Fridge-freezer	57			8760			500		500	0.65	325		325
3	Freezer (various types)	46			8760			400		400	0.46	184		184
Wet														**529**
4	Washing machine		1			200		200		200	0.85	170		170
5	Tumble dryer		2.5			130		325		325	0.45	146		146
6	Washer dryer		1.75			130		228		228	0.13	30		30
7	Dishwasher		1.05			250		263		263	0.35	91		91
8	Electric shower	10000			23			230		230	0.40	92		92
Cooking														**516**
9	Electric Oven	1100		5	183		8000	201	40	241	0.56	112	22	135
10	Electric Hob	1000		2	365		8000	365	16	381	0.37	135	6	141
11	Microwave	800		5	3		8000	2	40	42	0.87	2	35	36
12	Toaster		0.07			365		26		26	0.74	19		19
13	Kettle		0.1			1825		183		183	0.88	161		161
14	Breadmaker		0.34	1		25	50	9	0	9	0.10	1	0	1
15	Juicer	100			1			0		0	0.13	0		0
16	Food mixer / processor	300			5			2		2	0.26	0		0
17	Blender	100			6			1		1	0.26	0		0
18	Grill	1000			25			25		25	0.10	3		3
19	Coffee maker	600			25			15		15	0.16	2		2
20	Coffee grinder	140			0			0		0	0.20	0		0
21	Sandwich toaster	750			8			6		6	0.45	3		3
22	Deep fat fryer	1250			10			13		13	0.20	3		3
23	Rice / slow cooker	100			100			10		10	0.20	2		2
24	Cooker hood	150			100			15		15	0.48	7		7
25	Hot plate	500			50			25		25	0.08	2		2
26	Ice cream maker	500			10			5		5	0.03	0		0
27	Steamer		0.2			50		10		10	0.16	2		2
Information, communication and entertainment														**1002**
28	Desktop computer	100		6	1460		1460	146	9	155	0.53	77	5	82
29	Laptop	30		6	1460		3650	44	22	66	0.30	13	7	20
30	Monitor	26		0.5	1460		1460	38	1	39	0.53	20	0	20
31	Printer / copier			12			4380	0	53	53	0.34	0	18	18
32	Fax machine			5			8760	0	44	44	0.03	0	1	1
33	Broadband modem / router	10			8000			80		80	0.60	48		48
34	Mobile phone	4		0	730		2000	3	0	3	0.89	3	0	3
35	Landline phone (line and cordless)			2			8760	0	18	18	0.64	0	11	11
36	PDA / personal organiser	4		0	730		2000	3	0	3	0.05	0	0	0
37	Clock			2			8760	0	18	18	0.45	0	8	8
38	Energy monitor			2			8760	0	18	18	0.01	0	0	0
39	Office shredder		0.0001	0.5		1000	4380	0	2	2	0.20	0	0	0
40	TV (CRT)	84		3.5	2373		2920	199	10	210	1.21	242	12	254
41	TV (LCD)	130		1	2555		2920	332	3	335	0.65	216	2	218
42	TV (Plasma)	350		1	2847		2920	996	3	999	0.14	136	0	136
43	DVD	25		3	730		4015	18	12	30	0.83	15	10	25
44	BlueRay DVD	25		3	730		4015	18	12	30	0.14	3	2	4
45	Video / VCR	25		6	730		4015	18	24	42	0.87	16	21	37
46	DTR (Digital TV recorder)	25		3.5	730		4015	18	14	32	0.19	3	3	6
47	STB / Sky Digibox	25		8	730		4015	18	32	50	1.00	18	32	50
48	Games console	14		1.5	2190		2190	31	3	34	0.44	13	1	15
49	Hi-fi music system	50		1	365		1000	18	1	19	0.94	17	1	18
50	Radio (digital and analogue)	5		5	1168		4380	6	22	28	0.95	6	21	26
51	Personal audio players	2			300			1		1	0.56	0		0
Garden and DIY														**160**
52	Lawnmower (electric)	1000			10			10		10	0.60	6		6
53	Garden strimmer	320			5			2		2	0.35	1		1
54	Hedge trimmer	500			4			2		2	0.27	1		1
55	Shredder	2000			2			4		4	0.08	0		0
56	Chainsaw	1000			1			1		1	0.03	0		0
57	Garden vacuum / blower	1000			1			1		1	0.01	0		0
58	Water feature / pond pump	23			4380			101		101	0.01	1		1
59	Pond cleaner / filter /	100			4380			438		438	0.01	2		2
60	Green house heater	2500			200			500		500	0.01	5		5
61	Outdoor lighting	60			2920			175		175	0.80	140		140
62	Electric patio heater	2000			120			240		240	0.02	5		5
63	Power drill	500			1			1		1	0.50	0		0
64	Sander	500			1			1		1	0.20	0		0
65	Wallpaper stripper	2000			1			2		2	0.10	0		0
66	Power saw	500			1			1		1	0.10	0		0
67	Angle grinder	500			1			1		1	0.05	0		0

… Continued overleaf.

	Appliance type	Mean in-use power demand (W)	Energy demand per cycle (kWh)	Standby demand (W)	Hours in-use per year (h/y)	Cycles per year (1/y)	Hours spent in standby per year (h/y)	Annual in-use demand per appliance (kWh)	Annual demand in standby per appliance (kWh)	Total annual energy demand per appliance (kWh)	Ownership	Annual in-use demand per household (kWh)	Annual demand in standby per household (kWh)	Total annual energy demand per household (kWh)
Environmental control														**619**
73	Indoor lighting											575		575
74	Air conditioning unit	2000			100			200		200	0.01	2		2
75	Kitchen ventilation	30			183			5		5	0.50	3		3
76	Fan	30			365			11		11	1.00	11		11
77	Air humidifier							0		0		0		0
78	Dehumidifier	300			2190			657		657	0.04	28		28
Cleaning														**36**
79	Vacuum cleaner	1200			25			30		30	0.95	29		29
80	Iron	200			25			5		5	0.96	5		5
81	Steam cleaner							0		0		0		0
82	Floor polisher							0		0		0		0
83	Water pump / jet wash	2000			6			12		12	0.20	2		2
Beauty / hygiene / personal care														**45**
84	Hair dryer	1000			20			20		20	0.94	19		19
85	Hair curler / rollers	400			25			10		10	0.20	2		2
86	Shavers	1			8760			9		9	0.35	3		3
87	Toothbrush	1			8760			9		9	0.50	4		4
88	Massager	1			8760			9		9	0.50	4		4
89	Sun bed	2400			9			21		21	0.00	0		0
90	Towel heater / rail	150			250			38		38	0.06	2		2
91	Electric blanket	100			250			25		25	0.40	10		10
Medical / assistive														**1**
92	Stair lift	1000			26			26		26	0.00	0		0
93	Personal health monitoring	3			8760			26		26	0.00	0		0
94	Mobility scooter	200			500			100		100	0.01	1		1
95	Electric wheelchair							0		0		0		0
Hobbies and Leisure														**31**
96	Christmas decoration	50			120			6		6	1.00	6		6
98	Swimming pool heater / filter / pump	7500			1200			9000		9000	0.00	9		9
99	Hot tub / jacuzzi	500			4380			2190		2190	0.00	2		2
100	Pet related / fish tank	20			8760			175		175	0.02	4		4
101	Camera	20		2	208		1000	4	2	6	1.00	4	2	6
102	Video camera	20		2	208		1000	4	2	6	0.20	1	0	1
103	Digital photo frame	10			4380			44		44	0.05	2		2
104	Musical instrument	100			52			5		5	0.10	1		1
105	Sewing machine	50			1			0		0	0.50	0		0
Miscellaneous														**174**
106	Smoke alarm	3			8760			26		26	1.00	26		26
107	Carbon monoxide alarm	3			8760			26		26	0.10	3		3
108	Elderly assistance alarm	3			8760			26		26	0.01	0		0
109	Security alarm	30			8760			263		263	0.50	131		131
110	CCTV system	30			8760			263		263	0.01	3		3
111	Battery charger	5			2190			11		11	1.00	11		11
112	Compressor (car tyre)	200			1			0		0	0.01	0		0
112	Bottle steriliser	2000			10			20		20	0.01	0		0
113	Bottle warmer	200			10			2		2	0.01	0		0
114	Baby audio / video monitor	10			730			7		7	0.01	0		0
Heating and heating related														**1118**
115	Electric immersion heater	3000										500		500
116	Instant water heater	3000			52			156		156	0.01	2		2
117	Storage heater	3400			1589			5403		5403	0.08	454		454
118	Other electric space	2000			200			400		400	0.03	10		10
119	Boiler pump	92			975			90		90	0.80	72		72
120	Boiler fan	63		5	975		7785	61	39	100	0.80	49	31	80
TOTAL														**4847**

It is clear, by the abundance of red cells, that much of these data are uncertain.

The relative importance of each category, derived from the estimates made here, is shown in the following figure. This includes heating and heating related electrical energy use, to complete the whole-house picture.

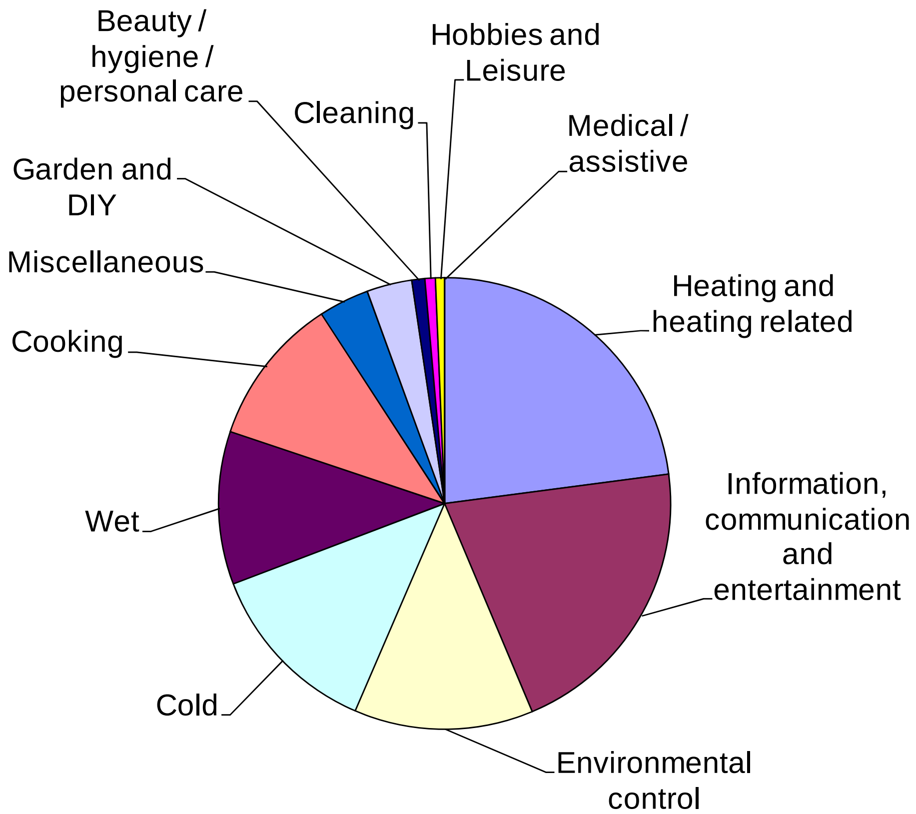


Figure 34. Relative domestic end-use electricity demand by category

From this, it can be seen that the energy demand from information, communication and entertainment appliances when grouped together forms a significant proportion. The demand as a result of environmental control, primarily lighting, is approximately equivalent to that from cold, wet and cooking appliances. Garden and DIY activities do not appear to form a significant energy using activity.

6.2 Appliance category results

Discussion of the energy demand for each appliance category is discussed in more detail in the following sections. The figures are all based on the estimates made as a result of this review.

6.2.1 Domestic cold appliances

Cold appliances are estimated to contribute 13% of the whole house electrical demand.

Table 38. Estimated cold appliance electricity demand

Appliance type	Mean in-use power demand (W)	Energy demand per cycle (kWh)	Standby demand (W)	Hours in-use per year (h/y)	Cycles per year (1/y)	Hours spent in standby per year (h/y)	Annual in-use demand per appliance (kWh)	Annual demand in standby per appliance (kWh)	Total annual energy demand per appliance (kWh)	Ownership	Annual in-use demand per household (kWh)	Annual demand in standby per household (kWh)	Total annual energy demand per household (kWh)
Fridge	23			8760			200		200	0.53	107		107
Fridge-freezer	57			8760			500		500	0.65	325		325
Freezer (various types)	46			8760			400		400	0.46	184		184
TOTAL													616

The cold appliances category includes refrigerators, freezers and combinations. Power consumption is very dependent on ambient temperature, installation details, age, condition (door seal etc), thermostat setting, door openings and loading. All of these factors give us moderate confidence in the available in-use power demand data. High confidence is held in the usage as these appliances are typically switched-on all the time. With a contribution of 616 kWh to the mean annual electricity demand of a household, this category of appliances is significant one.

6.2.2 Domestic wet appliances

Wet appliances are estimated to contribute 11% of the whole house electrical demand.

Table 39. Estimated wet appliance electricity demand

Appliance type	Mean in-use power demand (W)	Energy demand per cycle (kWh)	Standby demand (W)	Hours in-use per year (h/y)	Cycles per year (1/y)	Hours spent in standby per year (h/y)	Annual in-use demand per appliance (kWh)	Annual demand in standby per appliance (kWh)	Total annual energy demand per appliance (kWh)	Ownership	Annual in-use demand per household (kWh)	Annual demand in standby per household (kWh)	Total annual energy demand per household (kWh)
Washing machine		1			200		200		200	0.85	170		170
Tumble dryer		2.5			130		325		325	0.45	146		146
Washer dryer		1.75			130		228		228	0.13	30		30
Dishwasher		1.05			250		263		263	0.35	91		91
Electric shower	10000			23			230		230	0.40	92		92
TOTAL													529

Energy per cycle is very dependent on program choice and there is a shortage of surveyed data on this and on number of cycles per year. The washer dryer energy per cycle is given with low confidence due to lack of data regarding how often the combined cycle is selected. The drying cycle of these appliances can add a considerable amount of demand over and above the wash cycle usage. An assumption is made here that the dryer feature is used for 30% of the time. This category is therefore very behavioural led depending upon how the householder uses the appliance. At estimates of 529 kWh/y, this category is a significant group.

This category also includes electric shower appliances. These appliances typically have high power demands. The available usage data varies wildly and is difficult to interpret with any confidence.

6.2.3 Domestic cooking appliances

Cooking appliances are estimated to contribute 11% of the whole house electrical demand. Clearly gas cooking is commonplace in households, but these calculations have not included the energy associated with gas cooking.

Table 40. Estimated cooking appliance electricity demand

Appliance type	Mean in-use power demand (W)	Energy demand per cycle (kWh)	Standby demand (W)	Hours in-use per year (h/y)	Cycles per year (1/y)	Hours spent in standby per year (h/y)	Annual in-use demand per appliance (kWh)	Annual demand in standby per appliance (kWh)	Total annual energy demand per appliance (kWh)	Ownership	Annual in-use demand per household (kWh)	Annual demand in standby per household (kWh)	Total annual energy demand per household (kWh)
Electric Oven	1100		5	183		8000	201	40	241	0.56	112	22	135
Electric Hob	1000		2	365		8000	365	16	381	0.37	135	6	141
Microwave	800		5	3		8000	2	40	42	0.87	2	35	36
Toaster		0.07			365		26		26	0.74	19		19
Kettle		0.1			1825		183		183	0.88	161		161
Breadmaker		0.34	1		25	50	9	0	9	0.10	1	0	1
Juicer	100			1			0		0	0.13	0		0
Food mixer / processor	300			5			2		2	0.26	0		0
Blender	100			6			1		1	0.26	0		0
Grill	1000			25			25		25	0.10	3		3
Coffee maker	600			25			15		15	0.16	2		2
Coffee grinder	140			0			0		0	0.20	0		0
Sandwich toaster	750			8			6		6	0.45	3		3
Deep fat fryer	1250			10			13		13	0.20	3		3
Rice / slow cooker	100			100			10		10	0.20	2		2
Cooker hood	150			100			15		15	0.48	7		7
Hot plate	500			50			25		25	0.08	2		2
Ice cream maker	500			10			5		5	0.03	0		0
Steamer		0.2			50		10		10	0.16	2		2
TOTAL													516

This category including ovens, hobs and microwaves, together with a number of smaller cooking appliances. Whilst in many cases, the mean power demand of the appliances can be stated with moderate confidence (e.g. grill, slow cooker), the usage patterns of the appliances cannot. Surveyed usage data varies significantly. For example, whilst microwaves have a power demand typically in the range of 700 to 900W, the length of time that they are used is dependent on both the householders' preference to cook with a microwave, and the type of food. Hob power is very dependent on the number of rings in use, for which there are no data.

There is greater confidence in the ownership data for the larger kitchen appliances. Nevertheless, the smaller appliances are seen in the table to contribute an almost negligible amount to the energy demand of the average dwelling. The electric oven, hob and kettle are considered the most significant products. This category is estimated to contribute 516 kWh/y to the electricity demand of the average household, and is therefore considered significant.

6.2.4 Domestic information, communication and entertainment appliances

Information, communication and entertainment appliances are estimated to contribute 21% of the whole house electrical demand.

Table 41. Estimated information, communication and entertainment appliance electricity demand

Appliance type	Mean in-use power demand (W)	Energy demand per cycle (kWh)	Standby demand (W)	Hours in-use per year (h/y)	Cycles per year (1/y)	Hours spent in standby per year (h/y)	Annual in-use demand per appliance (kWh)	Annual demand in standby per appliance (kWh)	Total annual energy demand per appliance (kWh)	Ownership	Annual in-use demand per household (kWh)	Annual demand in standby per household (kWh)	Total annual energy demand per household (kWh)
Desktop computer	100		6	1460		1460	146	9	155	0.53	77	5	82
Laptop	30		6	1460		3650	44	22	66	0.30	13	7	20
Monitor	26		0.5	1460		1460	38	1	39	0.53	20	0	20
Printer / copier			12			4380	0	53	53	0.34	0	18	18
Fax machine			5			8760	0	44	44	0.03	0	1	1
Broadband modem / router	10			8000			80		80	0.60	48		48
Mobile phone	4		0	730		2000	3	0	3	0.89	3	0	3
Landline phone (line and cordless)			2			8760	0	18	18	0.64	0	11	11
PDA / personal organiser	4		0	730		2000	3	0	3	0.05	0	0	0
Clock			2			8760	0	18	18	0.45	0	8	8
Energy monitor			2			8760	0	18	18	0.01	0	0	0
Office shredder		0.0001	0.5		1000	4380	0	2	2	0.20	0	0	0
TV (CRT)	84		3.5	2373		2920	199	10	210	1.21	242	12	254
TV (LCD)	130		1	2555		2920	332	3	335	0.65	216	2	218
TV (Plasma)	350		1	2847		2920	996	3	999	0.14	136	0	136
DVD	25		3	730		4015	18	12	30	0.83	15	10	25
BlueRay DVD	25		3	730		4015	18	12	30	0.14	3	2	4
Video / VCR	25		6	730		4015	18	24	42	0.87	16	21	37
DTR (Digital TV recorder)	25		3.5	730		4015	18	14	32	0.19	3	3	6
STB / Sky Digibox	25		8	730		4015	18	32	50	1.00	18	32	50
Games console	14		1.5	2190		2190	31	3	34	0.44	13	1	15
Hi-fi music system	50		1	365		1000	18	1	19	0.94	17	1	18
Radio (digital and analogue)	5		5	1168		4380	6	22	28	0.95	6	21	26
Personal audio players	2			300			1		1	0.56	0		0
TOTAL													**1002**

This category includes information technology appliances such as personal computers, and entertainment appliances such as televisions. In the former case, usage patterns for information technology type products (particularly printer use and personal organiser/mobile telephone charging patterns) are not well surveyed. Despite this, there is in general a moderate level of confidence in typical power ratings. Laptops appear to use considerably less power than desktop PCs, yet they have a lower level of ownership. Standby is a concern in that there is little information on how much these products are actually switched off at the socket, as opposed to being left in standby mode. Of the products that are considered to be left switched on much of the time (e.g. phone, clock, energy monitor), only the broadband modem or router is considered relatively significant.

Power ratings for TV and entertainment appliances are given with some confidence. Whilst in-use/viewing time is well studied, the relative time between the appliance being in standby and full switched off is not. Additionally, the time when entertainment equipment is left on but not used is also poorly understood. The technology of the TV is highly significant in terms of power use and so the television and standby energy demand is significant.

The overall energy demand of this appliance category is very significant and likely to increase based on trends from recent expenditure analysis. Significantly better understanding of the issues in order to identify key interventions is needed.

6.2.5 Domestic garden and DIY appliances

Garden and DIY appliances are estimated to contribute only 3% of the whole house electrical demand.

Table 42. Estimated garden and DIY appliance electricity demand

Appliance type	Mean in-use power demand (W)	Energy demand per cycle (kWh)	Standby demand (W)	Hours in-use per year (h/y)	Cycles per year (1/y)	Hours spent in standby per year (h/y)	Annual in-use demand per appliance (kWh)	Annual demand in standby per appliance (kWh)	Total annual energy demand per appliance (kWh)	Ownership	Annual in-use demand per household (kWh)	Annual demand in standby per household (kWh)	Total annual energy demand per household (kWh)
Lawnmower (electric)	1000			10			10		10	0.60	6		6
Garden strimmer	320			5			2		2	0.35	1		1
Hedge trimmer	500			4			2		2	0.27	1		1
Shredder	2000			2			4		4	0.08	0		0
Chainsaw	1000			1			1		1	0.03	0		0
Garden vacuum / blower	1000			1			1		1	0.01	0		0
Water feature / pond pump	23			4380			101		101	0.01	1		1
Pond cleaner / filter / vacuum	100			4380			438		438	0.01	2		2
Green house heater	2500			200			500		500	0.01	5		5
Outdoor lighting	60			2920			175		175	0.80	140		140
Electric patio heater	2000			120			240		240	0.02	5		5
Power drill	500			1			1		1	0.50	0		0
Sander	500			1			1		1	0.20	0		0
Wallpaper stripper	2000			1			2		2	0.10	0		0
Power saw	500			1			1		1	0.10	0		0
Angle grinder	500			1			1		1	0.05	0		0
Electric screwdriver	200			1			0		0	0.20	0		0
Router	1000			1			1		1	0.01	0		0
Planer	500			1			1		1	0.01	0		0
Staple / nail gun	10			1			0		0	0.10	0		0
Heat gun	1500			1			2		2	0.10	0		0
TOTAL													**160**

The energy demands of this appliance category were previously poorly understood, and much of the data used in these calculations are based on limited data. However, on this basis, garden decorative and security outdoor lighting is considered to be the significant component, with the other garden and DIY appliances not using significant energy on an annual basis. The power ratings of DIY appliances in the category are known with some confidence, although equivalents for ponds and greenhouse heating are less reliable and are based only on knowledge of available products on the market. The small number of hours in use on an annual basis of most of the garden and DIY appliances, or the low market penetration of others means that the totals are relatively low.

6.2.6 Domestic environmental control appliances

Environmental control appliances are estimated to contribute 13% of the whole house electrical demand.

Table 43. Estimated environmental control appliance electricity demand

Appliance type	Mean in-use power demand (W)	Energy demand per cycle (kWh)	Standby demand (W)	Hours in-use per year (h/y)	Cycles per year (1/y)	Hours spent in standby per year (h/y)	Annual in-use demand per appliance (kWh)	Annual demand in standby per appliance (kWh)	Total annual energy demand per appliance (kWh)	Ownership	Annual in-use demand per household (kWh)	Annual demand in standby per household (kWh)	Total annual energy demand per household (kWh)
Indoor lighting											575		575
Air conditioning unit	2000			100			200		200	0.01	2		2
Kitchen ventilation	30			183			5		5	0.50	3		3
Fan	30			365			11		11	1.00	11		11
Air humidifier							0		0		0		0
Dehumidifier	300			2190			657		657	0.04	28		28
TOTAL													**619**

This category includes indoor lighting and is therefore significant. Lighting is a complex sub-category, including fixed wall and ceiling lights as well as separate appliance lights. Separating out issues relating to energy demand and usage of these two types of lighting is very difficult, as little data are available. Air conditioning units pose a potential future increase and are a high demand product, but their current market penetration means they are not yet significant on a national level. Dehumidifiers are a more significant issue, as our estimates suggest they are used for extended periods of time. The need for increased use of dehumidifiers may further increase if houses are made more airtight through efficiency measures to the building stock.

6.2.7 Domestic cleaning appliances

Cleaning appliances are estimated to contribute only 1% of the whole house electrical demand.

Table 44. Estimated cleaning appliance electricity demand

Appliance type	Mean in-use power demand (W)	Energy demand per cycle (kWh)	Standby demand (W)	Hours in-use per year (h/y)	Cycles per year (1/y)	Hours spent in standby per year (h/y)	Annual in-use demand per appliance (kWh)	Annual demand in standby per appliance (kWh)	Total annual energy demand per appliance (kWh)	Ownership	Annual in-use demand per household (kWh)	Annual demand in standby per household (kWh)	Total annual energy demand per household (kWh)
Vacuum cleaner	1200			25			30		30	0.95	29		29
Iron	200			25			5		5	0.96	5		5
Steam cleaner							0		0		0		0
Floor polisher							0		0		0		0
Water pump / jet wash	2000			6			12		12	0.20	2		2
TOTAL													36

This appliance category includes appliances with high power consumption but their relatively low use means that their electrical demand on an annual household perspective is, perhaps surprisingly, not significant.

6.2.8 Domestic personal care appliances

Personal care appliances, including those used for beauty and hygiene are estimated to contribute only 1% of the whole house electrical demand, so is not thought to be a significant category.

Table 45. Estimated personal care appliance electricity demand

Appliance type	Mean in-use power demand (W)	Energy demand per cycle (kWh)	Standby demand (W)	Hours in-use per year (h/y)	Cycles per year (1/y)	Hours spent in standby per year (h/y)	Annual in-use demand per appliance (kWh)	Annual demand in standby per appliance (kWh)	Total annual energy demand per appliance (kWh)	Ownership	Annual in-use demand per household (kWh)	Annual demand in standby per household (kWh)	Total annual energy demand per household (kWh)
Hair dryer	1000			20			20		20	0.94	19		19
Hair curler / rollers	400			25			10		10	0.20	2		2
Shavers	1			8760			9		9	0.35	3		3
Toothbrush	1			8760			9		9	0.50	4		4
Massager	1			8760			9		9	0.50	4		4
Sun bed	2400			9			21		21	0.00	0		0
Towel heater / rail	150			250			38		38	0.06	2		2
Electric blanket	100			250			25		25	0.40	10		10
TOTAL													45

These are typically small appliances used for short periods of time, even though some appliances such as hairdryers have a high individual power consumption. Appliances such as shavers and toothbrushes have a very low in-use energy demand, but are often left plugged in so have been estimated as always on. Domestic scale sun beds are not considered to have significant usage so even though these are relatively high power appliances, they are not considered significant on an annual national level.

6.2.9 Domestic medical / assistive appliances

Medical and assistive technology appliances are estimated to contribute less than 1% of the whole house electrical demand.

Table 46. Estimated medical and assistive appliance electricity demand

Appliance type	Mean in-use power demand (W)	Energy demand per cycle (kWh)	Standby demand (W)	Hours in-use per year (h/y)	Cycles per year (1/y)	Hours spent in standby per year (h/y)	Annual in-use demand per appliance (kWh)	Annual demand in standby per appliance (kWh)	Total annual energy demand per appliance (kWh)	Ownership	Annual in-use demand per household (kWh)	Annual demand in standby per household (kWh)	Total annual energy demand per household (kWh)
Stair lift	1000			26			26		26	0.00	0		0
Personal health monitoring	3			8760			26		26	0.00	0		0
Mobility scooter	200			500			100		100	0.01	1		1
Electric wheelchair							0		0		0		0
TOTAL													**1**

From the review, medical and assistive appliances have a very low ownership and so are insignificant on a national scale. However, increases in older people and preferences for care in the home mean that this category is likely to increase in the future.

6.2.10 Domestic hobbies and leisure appliances

Hobbies and leisure appliances are estimated to contribute only 1% of the whole house electrical demand.

Table 47. Estimated hobbies and leisure appliance electricity demand

Appliance type	Mean in-use power demand (W)	Energy demand per cycle (kWh)	Standby demand (W)	Hours in-use per year (h/y)	Cycles per year (1/y)	Hours spent in standby per year (h/y)	Annual in-use demand per appliance (kWh)	Annual demand in standby per appliance (kWh)	Total annual energy demand per appliance (kWh)	Ownership	Annual in-use demand per household (kWh)	Annual demand in standby per household (kWh)	Total annual energy demand per household (kWh)
Christmas decoration	50			120			6		6	1.00	6		6
Swimming pool heater / filter / pump	7500			1200			9000		9000	0.00	9		9
Hot tub / jacuzzi	500			4380			2190		2190	0.00	2		2
Pet related / fish tank	20			8760			175		175	0.02	4		4
Camera	20		2	208		1000	4	2	6	1.00	4	2	6
Video camera	20		2	208		1000	4	2	6	0.20	1	0	1
Digital photo frame	10			4380			44		44	0.05	2		2
Musical instrument	100			52			5		5	0.10	1		1
Sewing machine	50			1			0		0	0.50	0		0
TOTAL													**31**

Energy use from hobbies and leisure activities using appliances listed here is low, although there were little reliable data to inform these estimates. There are some areas of high energy demand uses (swimming pool, hot tub), but the low ownership of these mean they are not significant nationally.

6.2.11 Domestic miscellaneous appliances

Miscellaneous and other appliances are estimated to contribute only 4% of the whole house electrical demand.

Table 48. Estimated miscellaneous and other appliance electricity demand

Appliance type	Mean in-use power demand (W)	Energy demand per cycle (kWh)	Standby demand (W)	Hours in-use per year (h/y)	Cycles per year (1/y)	Hours spent in standby per year (h/y)	Annual in-use demand per appliance (kWh)	Annual demand in standby per appliance (kWh)	Total annual energy demand per appliance (kWh)	Ownership	Annual in-use demand per household (kWh)	Annual demand in standby per household (kWh)	Total annual energy demand per household (kWh)
Smoke alarm	3			8760			26		26	1.00	26		26
Carbon monoxide alarm	3			8760			26		26	0.10	3		3
Elderly assistance alarm	3			8760			26		26	0.01	0		0
Security alarm	30			8760			263		263	0.50	131		131
CCTV system	30			8760			263		263	0.01	3		3
Battery charger	5			2190			11		11	1.00	11		11
Compressor (car tyre)	200			1			0		0	0.01	0		0
Bottle steriliser	2000			10			20		20	0.01	0		0
Bottle warmer	200			10			2		2	0.01	0		0
Baby audio / video monitor	10			730			7		7	0.01	0		0
TOTAL													174

There are many possible other minor appliances that could be included in the home. Many of these are not considered significant due to their low market penetration. However, alarms are estimated to contribute 3% to the total as they have long running base loads, but a relatively low power consumption. They also have high estimated ownership levels, for example many households have several smoke alarms.

6.2.12 Domestic heating and heating related energy

Domestic heating and heating related appliances are estimated to contribute 23% of the whole house electrical demand.

Table 49. Estimated heating and heating related electricity demand

Appliance type	Mean in-use power demand (W)	Energy demand per cycle (kWh)	Standby demand (W)	Hours in-use per year (h/y)	Cycles per year (1/y)	Hours spent in standby per year (h/y)	Annual in-use demand per appliance (kWh)	Annual demand in standby per appliance (kWh)	Total annual energy demand per appliance (kWh)	Ownership	Annual in-use demand per household (kWh)	Annual demand in standby per household (kWh)	Total annual energy demand per household (kWh)
Immersion heater	3000										500		500
Instant water heater	3000			52			156		156	0.01	2		2
Storage heater	3400			1589			5403		5403	0.08	454		454
Other electric heater	2000			200			400		400	0.03	10		10
Boiler pump	92			975			90		90	0.80	72		72
Boiler fan	63		5	975		7785	61	39	100	0.80	49	31	80
TOTAL													1118

Much of this energy usage is attributed to devices that are part of the building fabric, rather than portable heaters, although some assumptions for these are included in these calculations. Heating is a very significant category, very dependent on installed capacity and usage, and is a major contribution to domestic electricity use. Trends in heating provision and usage could be of significant importance here but fall outside the scope of this review.

6.3 Priority areas

There are two ways to consider the priority areas for domestic appliances:

- On a household basis – where the market penetration, usage and energy consumption amount to a sufficiently high demand across households.
- On an appliance basis – where the market penetration may be low, but the usage and energy consumption of the appliance is high on an individual basis, and so particular sectors of the market could be targeted to reduce future resulting carbon emissions.

6.3.1 Priorities on a household basis

From the estimates and calculations presented in this report, the following domestic appliances appear to use the most energy on a household basis, given the numbers in use across the UK.

Table 50. Total annual energy demand per household – priority areas

Appliance type	Total annual energy demand per household - estimates (kWh)
Fridge-freezer	325
TV (CRT)	254
TV (LCD)	218
Freezer (various types)	184
Washing machine	170
Kettle	161
Tumble dryer	146
Electric Hob	141
Outdoor lighting	140
TV (Plasma)	136
Electric Oven	135
Security alarm	131
Refrigerator	107
Electric shower	92
Dishwasher	91
Desktop computer	82

Many of these products are already modelled as part of MTP, however, these data provide a relative importance of the energy consumption of the appliances within a household. They also attempt to include the wider perspective from studies of appliance use in the home, although as already discussed in this report, these are limited.

6.3.2 Priorities on an appliance basis

From the estimates and calculations presented in this report, the following domestic appliances appear to use the most energy on an appliance basis, although their market penetration may not be high.

Table 51. Total annual energy demand per appliance – priority areas

Appliance type	Total annual energy demand per appliance - estimates (kWh)
Swimming pool heater / filter / pump	9000
Hot tub / Jacuzzi	2190
TV (Plasma)	999
Dehumidifier	657
Fridge-freezer	500
Green house heater	500
Pond cleaner / filter / vacuum	438
Freezer (various types)	400
Other electric space heater	400
Electric hob	381
TV (LCD)	335
Tumble dryer	325
Security alarm	263
CCTV system	263
Dishwasher	263
Electric oven	241
Electric patio heater	240
Electric shower	230
Washer dryer	228
TV (CRT)	210
Refrigerator	200
Washing machine	200
Air conditioning unit	200
Kettle	183
Outdoor lighting	175
Pet related / fish tank	175
Desktop computer	155

Whilst only a small proportion of houses in the UK have a heated swimming pool or hot tub, their energy demand for those that have one is great (estimated up to 9000kWh annually). However, plasma screen televisions are becoming increasingly popular and use a significant amount of energy in use (estimated at 999kWh annually). Appliances at the top of the list that previously have not been the focus of attention include:

- Dehumidifiers
- Greenhouse heaters
- Pond equipment
- Security alarms and CCTV systems
- Air conditioners
- Outdoor lighting
- Pet enclosures (fish tanks etc)

Issues relating to better understanding of these areas and future changes are discussed in Section 9.

7.0 Policies that relate to energy-using products

Focusing on a range of energy-using products, the policy measures currently in place are implemented to:

- improve existing market efficiency;
- encourage sustainable innovations; and
- remove the poor-performance appliances from the markets.
  (Defra, 2009)

The manufacturers are now required to take responsibility for product sustainability more then ever before. Product information (such as energy labels), consumer guidelines, advice and support are strategically provided through local advice services; the web and the media; local authorities, communities, the workplace and voluntary groups (Energy Saving Trust, 2009), enabling people to make an informed choice at the point of purchase (sale). The following table summarised the range of policy measures in this area.

Table 52. Summary of current and forthcoming policy and activities

Energy-using Products Directive (EuP)
EuP establishes parameters, in particular minimum efficiency standards for products that use energy, and through revisions will in the future set standards on productsthat have a related effect on energy efficiency, even if they are not energy-using. The products that are or will soon be covered by measures have been identified as high priority in terms of their impacts. These have been a mixture of Minimum Energy Performance Standards (MEPS) and other aspects relating to energy (e.g. automatic switching to a lower energy mode after a given time period without interaction), or water consumption. These measures are expected to generate the largest energy savings.
Energy Labelling
This European Union Directive establishes mandatory energy labels for a variety of energy-using products. Where energy labels are already established, products have demonstrated steady improvement through the energy label class tiers (A-G). This effect is only partially due to consumers being influenced by the lower energy demand of more efficient products at the point of sale and that in addition: Consumers have tended to associate A-rating with quality; Financial support for A-rated goods has been available under the Carbon Emission Reduction Target (CERT) scheme and its predecessor the Energy Efficient Commitment (EEC); Retailers and manufacturers have pushed A-rated goods as part of their business and environmental plans (Defra, 2009).The label has a secondary virtue in that it stimulates competition within the supply chain towards improved products. The label is to be extended to new product areas over the coming years, including consumer electronics and non energy-using products which an effect on energy efficeiency.
ENERGY STAR
This voluntary labelling scheme for ICT products covering monitors, computers and imaging equipment (and soon to cover servers). As a best practice label, ENERGY STAR specifications aim to qualify the top performing 25% of products across the range on the market (at the time a new specification is agreed), influencing domestic buyers.
Carbon Emissions Reduction Target (CERT) & Supplier Obligation
CERT (2008 – 2011) is the third phase of the energy Supplier Obligation (formerly known as the Energy Efficient Commitment: EEC). This is a statutory obligation on energy suppliers to achieve carbon targets by encouraging households to take up energy efficiency and low carbon measures, including the promotion of energy-

efficient products. This can have a direct effect on increasing the market for more efficient products by taking advantage of economies of scale and pushing prices down, subsidising the purchasing of more efficient appliances through retailer, manufacturer and energy supplier agreement. There has been criticism over the way that energy suppliers have met their obligations to date, e.g. unsolicited postal delivery of large quantities of Compact Fluorescent Lamps (CFLs) but these have now been rectified.
Energy Saving Recommended (ESR)
ESR is a voluntary labelling scheme operated by the Energy Saving Trust, that demonstrate best practice in terms of energy efficiency, thus allowing consumers to identify the top 10-20% ofproducts more easily. Products meeting set criteria are able to display the ESR logo at point of sale and in promotional material. The scheme aims to review the criteria as the efficiency of appliances improves to maintain 'best practice' recognition for recommended appliances. It is not known with certainty to what extent the ESR label influences consumer purchases (Defra, 2009) though there is evidence to suggest it is widely recognised. However, the ESR label, covering many of the same products as the EU Energy Label, does have some advantages: it is frequently updated, so can act as an incentive to market parties to continuously improve their product range; it can address quality issues alongside energy efficiency.
Test standards
The establishment of agreed, robust test standards to measure the energy efficiency performance of products, acts as a supportive tool to ensure the effectiveness of the policies and measures employed. Coupled with effective compliance monitoring, test standards play an important underpinning role in energy-using product policy. Test standards have no direct savings effect but robust standards are essential for all the other policies listed (Defra, 2009).
Other policies may influence energy-using products
- Act on CO_2 and other consumer focused pro-environmental campaigns: e.g. A carbon calculator at www.direct.gov.uk/actonco2 allows an individual or household to calculate the carbon footprint resulting from their home, appliances use. - Smart metering: a number of policies on energy billing and metering are designed to reduce energy consumption. Effectiveness of these meters is still not proven. - Promoting energy/carbon savings in industry and commerce: Climate Change Agreements, the UK Emissions Trading Scheme and the imminent Carbon Reduction Commitment are all measures addressing energy and emissions saving in industry and commerce. Innovation in industrial products may stimulate enhancements in the design and manufacture of domestic products. Most of these policies increase awareness of both the advantages of energy efficiency and the availability of energy efficient products to meet them. As well having as some effect in their own right they support, and are supported by, the other policies discussed.

The policies and activities that affect the domestic appliances included in this review are detailed in the table below. It can be seen that the policy measures are very well established for the traditional large domestic appliances, such as fridges, washing machines and dishwashers. Only electric ovens in the cooking sector are currently covered by mandatory energy labelling requirements that came into force in the UK in 2003. With the penetration of small appliances, such as kettles, electric showers and vacuum cleaners, the research is underway to make some type of labelling to help consumers. Additionally, proposals to produce labels for other cooking products and consumer electronics are taking the stand-by power consumption into consideration.

There are few policy interventions in the diverse and exceedingly fast moving area of information and consumer electronics products. The Energy Star label covered monitors, computer and imaging equipment and EuP regulations were passed on External Power Supply Units (ESPUs) and, televisions, Simple Set-top Boxes (SSTBs) in 2008 and early 2009. Further measures on ICT, fans, lighting, air conditioning, heating and complex set-top boxes are expected in 2010/11.

Table 53. Policies and activities affecting domestic appliances categories in this review

Appliance category	Examples of products	Eup	Energy Labelling	Energy Star	CERT/SO	ESR	Building Regs
Cold	Fridge, Freezer, Fridge& freezer	✓	✓		✓	✓	
	Non traditional, e.g. cooler						
Wet	Washing machine, Dishwasher, Tumble dryer,		✓			✓	
	Electrical shower						
	Iron						
Cooking	Oven	soon	✓				
	Cooker, Hob, Microwave, Extractor fan, Toaster, Kettle, Bread maker, Juicer, Mixer, Grill, Coffee maker, Sandwich toaster	Extractor fan soon				kettle	
Information and Consumer electronics	Computer, Monitor,	soon		✓		✓	
	Printer, Scanner, Network and communications	soon		?		Imag-ing	
	Television, Simple Set-top Boxes, external power supply units	✓				✓	
	DVD, Games Consoles, Hi-fi, Radio (DAB, online and streaming), small portable devices			?			
Garden & DIY	Garden maintenance equipment, barbecues, garden and greenhouse heaters, garden lighting water gardening, swimming and spa pools	?	Light bulbs				
	Power tools: Drills, sanders, paint strippers, saws						
Environ. control	Free standing air conditioning unit,		✓				?
	Air treatment appliances						
Other	Cleaning, beauty health and hygiene, medical aids, hobbies and leisure, others						

The literature shows that the government have continued to seek active participation in the environmental debate of manufacturers, retailers and consumers mainly through the following four approaches. Polices are grouped according to the main levers and mechanisms they employ as described by the OECD typology (2002). In practice, many policies use levers that are interdependent or fall into more than one of these categories (Darnton et al., 2006). The following table illustrates the main types of policy instrument and provides some key exemplars as relating to environmental behaviour change.

Table 54. Main types of policy instrument and examples
(from OSTC, 2003; Jackson, 2005; Defra, 2006; Darnton et al, 2006; Lucas et al., 2008)

Approach	Description	Example	Effectiveness
Voluntary	Providing information, education and/or advice	Public education campaign, advertisements, leaflets or labelling	They often have a insignificant effect on people's actual behaviour. There is a gap between the information / education and awareness/intention, as well as between the awareness / intention and actual action. Information provision must be backed up by other approaches.
Regulatory	Incrementally introducing regulations	Minimum energy performance standards	It needs for greater involvement of target audiences early in the development of regulatory policies. This helps to reduce the perception of unfairness, improve compliance and improve policy effectiveness against targets.
Economic	Using environmental taxes and charges	Tradable permits and quotas: Carbon emissions trading scheme	Unless the reasons for increased taxation are clearly explained and the negative distributional impacts ameliorated, there can be widespread public resistance with the backlash presenting serious consequences for future policy.
Other	Providing infrastructure or stimulate technological innovation	Door-step recycling facilities; Warm Front Scheme	One interesting element of this approach is that it clearly demonstrates how positive environmental outcomes can be achieved without the need for a change in the attitudes of end users.

7.1.1 Suggestions for programmes and policies

Due to the complexity of pro-environment behaviour, it is argued that it is necessary to adopt multi-levelled and multi-instrument integrated policies across whole systems of delivery to reduce the impact of the domestic appliances (Darnton et al., 2006; Lucas et al., 2008). Additionally, a new approach to policy is advocated by OECD (2002), focusing on structure; use of life-cycle strategy and analysis; and an integrated, cross-sector policy approach that offers consistent messages to consumers. By using a system based approach (Hampshire County Council et al., 2005), four main points concerning environmental impact of all life stages of energy using products and a system based approach are suggested below.

1. Improving energy efficiency of the products:

- Accelerated and sustained tightening of product standards. EU standards for white goods have already banned some of the least efficient products and under EuP each measure sets out longer-term tightened standards which, when each measure is reviewed after five years, would aim to become the mandatory standards for the future. Energy Saving Trust (2006) suggested that “the UK Government could press for a long term EU-wide approach where the least efficient (e.g. bottom 25%) of the market is removed on a regular basis (e.g. every 3-5 years, depending on product). A sustained policy over a 15-20 year timescale would provide the necessary forward signals for manufacturers to innovate and improve their products”.
- Measures for standby power consumption. For products which spend a significant time in standby mode, full OFF function should be made available and easy for users to apply.
- Focus on overall energy consumption rather than efficiency may counter the tendency to purchase larger appliances, consuming more energy, e.g. a typical A rated American style fridge freezer demands on average 150 KWh per annum more than the typical average sized A rated appliance over its lifetime (Energy Saving Trust, 2006).
- Research and Development and accelerated technology deployment for energy efficient products.

2. Sustainable design innovation: after the point of sale, few policy instrument or actions are taken for regulating appliance use behaviour which of most are habitual behaviour and perform with little deliberations (Shove and Warde, 1998, Pantzar 1999, Jackson 2005, Tang and Bhrama, 2008). Impacts which occur during use, however, are often determined by consumer behaviour (Tang and Bhamra, 2009). In spite of over a decade of campaigns exhorting consumers to behave differently and greater product efficiency, consumers could not be make long-lasting behavioural changes (Scott, 2004. Jackson, 2005). Products, as the interface between consumers and consumption activities, can give immediate responses to users’ operations, constraining how it is perceived, learned, and used. Designing a product means designing a user experience with the product, which also determines the compound impacts of this experience (Tang and Bhamra, 2008). Therefore, suggestions to implementing behaviour intervention approach in product, system and service design are made in Tang and Bhamra (2009) and Tang (2010):

- Changing user behaviour through sustainable product design; e.g. applying “Eco-steer” and designing “ease doing” affordances and constraints for adopting the instinctive sustainable energy use habits or reforming existing unsustainable habits.
- Influencing user behaviour through sustainable system design; looking at appliance use environment, requirements on housing developers to only install the most efficient appliances and to consider the operating condition of appliance. Such as the modern kitchen design restricted the fridge and freezer locating next to cooker and oven.

3. Urging all players in the domestic energy efficiency sector: policies need to address consistently multiple factors, utilising a range of tools and intervention to achieve long-term normative change across all three behavioural levels (individual, organisational, systemic):

- Voluntary agreements with retailers, e.g. for consumer electronics; binding agreements with retailers/ service providers and placing obligations on retailers and/or service providers (Energy Saving Trust, 2006). Successes have already been made on TVs and lighting.
- Design energy saving schemes, for example a recycling/reuse service, facilitated by Industry, Public sector; Local authorities & Community.
- Consumer cost and benefit analysis, for example ‘scrappage’ schemes replacing older machines with newer, more efficient ones, could be beneficial in reducing energy consumption, but additional purchase cost easily outweighed by the lifetime savings in energy costs. Payback services need be designed to remove this barrier to improving energy efficiency.

4. Educating all, not only consumers but designers, manufacturers and retailers:

- Introducing sustainable design courses in Design Education.
- Developing tools and strategies to promoting sustainable design in SMEs .
- Developing a framework or dialogue from an holistic perspective for all actors to actively participate and co-operate in the mission of reducing domestic CO_2 emissions.

The following table shows the suggestions for future policy actions and programmes (in blue) which could promote energy efficiency of the product and pro-environmental behaviour. As an example, the current instrument, CERT highlighted in grey, illustrates how to link the distribution stage of the product life cycle to the consumer purchase behaviour. It has a direct effect on the take up of more energy efficient products in the domestic sector by distributing them for free or offering a cash discount. The detailed eco-efficient solutions are targeting the three main actors in the life cycle of the product: designers and manufacturers, retailers and consumers. All players in the domestic energy efficiency sector should take actions to reduce ever increasing energy consumption in the home.

Table 55. Policy actions to affect the behaviour of different players in the lifecycle of products

Engage with audience through existing networks, partnerships and local organisations						
Business &Industry	Public sector	Local authorities	Community	Education	Government	Project Integra

Energy-Using Product Life cycle	Manufacturers &designers	Retailers	Consumers
Design& development	- Government: grant for sustainable innovations; - Government: EuP cover entire range of products; - Education: sustainable design		
Manufacturing Distribution			e.g. CERT can have a direct effect on the take up of more energy efficient products in the domestic sector by distributing them for free or offering a cash discount.
Sales	- Government: Product information, such as, energy labelling, energy star, cover entire range of products; - Government & Public sector: labelling for behaviour changing product;		
			Government & Public sector: standardize product information, e.g. removing conflicting messages;
Use	- Industry: Design for sustainable use/behaviour changing product;		Public sector, Local authorities & Community: Providing infrastructures:
Recycling/reuse	- Industry, Business: Design energy saving/reward recycling/reuse system		
	- Industry, Public sector; Local authorities & Community: energy saving/reward recycling/reuse service		
Disposal	- Government: labelling for lifespan for efficiency performance		
	- Industry & Government: design for reward/punishment for keeping least sustainable product, e.g. inserting chips		Public sector, Local authorities& Community: Providing infrastructures

8.0 Behaviour change

‘Design for Sustainable Behaviour’ is a new field of enquiry exploring how design can influence user behaviour to reduce negative social and environmental use impacts. These design intervention strategies, whilst providing interesting considerations for designers, have not been widely applied and there is a lack of real data on the effectiveness in both theoretical and practical dimensions

Design interventions are classified by the degree of power for decision making between the user and product. It is important to develop a balanced and ethical approach: weighing up the determinates of behavioural and habitual change and designing sustainable products to bridge this gap.

8.1 Design interventions for more sustainable behaviours

Designers are in a position to reduce use impacts by purposefully shaping behaviour towards more sustainable practices (Lockton et al., 2010, Lilley, 2009, Tang and Bhamra, 2009, Bhamra et al., 2008, Wever et al., 2008, Elias et al., 2008). As part of multi-disciplinary teams designers can draw on economic, technical, social and behavioural factors to plan and shape the way in which consumption occurs as well as to bridge the considerable intention - behaviour gap between values and everyday user actions (Sustainable Consumption Roundtable, 2006).

Agendas are beginning to shift from issues of production to those of consumption in design (Richardson et al., 2005), however, sustainable consumption tends to focus largely on purchasing behaviours and not use. Consumption is not only purchasing, but developing routines and rituals of use and modifying the product concretely or symbolically. According to Koskijoki (1997), consumption involves the selection, purchase, use, maintenance, repair, disposal and recycling of any product or service, as opposed to their design, production and marketing. Multi sociological and psychological motivators behind consumption behaviour impel people to consume insatiable quantities of products and services. Environmental and social benefits of the wider global community, compared with the desires of the individual are not strong enough to motivate a different lifestyle. On the other hand, the manner of consumer interaction with the product has large impacts. Products, as the interface between consumers and consumption activities, can give immediate and direct responses to users’ operations: how it is perceived, learned, and used. Designing a product means designing a user experience with the product, which also determines the compound impacts of this experience. A better understanding of what users do with, and how they interact with products as well as the hidden factors behind the daily decision-making process should be gained in order to develop a valid critique of environmentally and socially significant consumption.

Design for sustainable behaviour aims to reduce environmental and social impact of goods through moderating the way in which users interact with them. Early research identified Ecofeedback (McCalley and Midden, 2006), Behaviour Steering (Akrich, 1992, Jelsma and Knot, 2002) and Persuasive Technology or Captology (Fogg, 2003) as potential strategies which could be integrated into product design to influence user behaviour (Lilley, 2007).

Further research by Bhamra, Tang and Lilley drawing on behaviour models in social-psychological theories (Ajzen, 2006; Triandis,1977; Jackson, 2005; Verplanken and Aarts, 1999 in: Verplanken & Wood, 2006; Jager, 2003 in: Jackson, 2005 and Andersen, 1982) resulted in the development of seven strategies to facilitate Design for Sustainable Behaviour (shown below) and an enhanced understanding of the breakthrough points that potentially enable design to influence behaviour and habits.

Table 1: Design Intervention Strategies and Examples (Bhamra et al., 2008)

Eco-Information – design oriented education	
Aim: to make consumables visible, understandable and accessible to inspire consumers to reflect upon their use of resources.	
How it works: 1. Product expresses the presence and consumption of resources e.g. water, energy	***Examples:*** Power Aware Cord - Seeing Personal Energy Consumption (Interactive Institute, 2004).
2. Product encourages the user to interact with resource use.	Tyranny of the Plug Kitchen Machines - Being involved in powering the product (Van Hoff, 2003).
Eco-Choice – design oriented empowerment	
Aim: to encourage consumers to think about their use behaviour and to take responsibility of theirs actions through providing consumers with options.	
How it works: Users have a choice and the product enables sustainable use to take place	***Example:*** Domestic Energy Display - household system level concept (Design Council, 2005).
Eco-feedback – design oriented links to environmentally or socially responsible action	
Aim: to inform users clearly about what they are doing and to facilitate consumers to make environmentally and socially responsible decisions through offering real-time feedback	
How it works: The product provides tangible aural, visual, or tactile signs as reminders to inform users of resource use.	***Example:*** Wattson - wireless energy monitor which raises awareness of energy used in the home (DIY Kyoto, 2005).
Eco- spur – design oriented rewarding incentive and penalty	
Aim: to inspire users to explore more sustainable usage through providing rewordings to “prompt” good behaviour or penalties to “punish” unsustainable usage	
How it works: The product shows the user the consequences of their actions through “rewarding incentives” and “penalties”	***Example:*** Flower Lamp - Rewarding Energy Behaviours (Interactive Institute, 2004).

<table>
<tr><th colspan="2">Eco-steer – design oriented affordances and constraints</th></tr>
<tr><td colspan="2">Aim: to facilitate users to adopt more environmentally or socially desirable use habits through the prescriptions and/or constraints of use embedded in the product design.</td></tr>
<tr><td>How it works:
The product contains affordances and constraints which encourage users to adopt more sustainable use habits or reform existing unsustainable habits.</td><td>Example:
Unilever Powder Tablet - Counteracting excessive amounts of washing powder consumption by prescribing correct dose (Unilever, 2000).</td></tr>
<tr><th colspan="2">Eco-technical intervention – design oriented technical intervention</th></tr>
<tr><td colspan="2">Aim: to restrain existing use habits and to persuade or control user behaviour automatically by design combined with advanced technology</td></tr>
<tr><td>How it works:
The product utilises advanced technology to persuade or control user behaviour automatically.</td><td>Example:
Energy Curtain -Interacting with Daily Light Cycles (Interactive Institute, 2004).</td></tr>
<tr><th colspan="2">Clever design</th></tr>
<tr><td colspan="2">Aim: to automatically act environmentally or socially without raising awareness or changing user behaviour purely through innovative product design</td></tr>
<tr><td>How it works:
The design solution decreases environmental impacts without changing the user’s behaviour.</td><td>Example:
Integrated toilet and washbasin – decreases water use by re-using water for hand-washing to flush toilet.</td></tr>
</table>

Intention, habits and controls are considered important to immediate and mediate antecedents of behavioural change. Due to the complexity of motivations for shifting behaviour, different levels of interventions need to be designed accordingly to ensure behavioural and habitual change. The understanding of the behaviour disintegration and formation and relationship between antecedents of change in behaviour/habit and different levels of design intervention have been presented here.

Using this model, design interventions can be classified by the degree of power for decision making between the user and product. Influence can be exerted to a greater or lesser extent through the selection of appropriate strategies. At one end of the scale, *informative products* seek to achieve a *voluntary* changes in behaviour; whilst at the other end of the scale, *coercive technologies*, *force* behavioural change (Fogg, 2003). Eco-Information, for example, makes consumables visible, understandable and accessible to inspire consumers to reflect upon their use of resources and make more informed decisions. Eco-technical Intervention on the other hand restrains existing use habits and controls user behaviour automatically. It is important to develop a balanced and ethical approach: weighing up the determinates of behavioural and habitual change and designing sustainable products to bridge this gap.

The intended outcome of design for sustainable behaviour is to reduce negative environmental and societal impacts. However, designers' ability to passively or actively influence user behaviour and the resulting tension between choice and control raises some interesting ethical issues. Whilst several viable strategies for designing sustainable behaviour have been developed, the criterion for selecting appropriate strategies has yet to be defined and there is not, as yet, a clear consensus as to what is an acceptable level of intervention, or how to rate the severity of consequences enacted by different behaviours.

Coercive interventions, such as Eco Steer or Eco Technology may prove more successful in altering behaviour, but consumer acceptance of devices employing these strategies is most likely to be low and therefore manufacturers' willingness to adopt these approaches limited. Additionally, classifying what is, and what isn't, socially acceptable behaviour may prove challenging as social norms are constantly evolving.

To holistically critique design for sustainable behaviour from an ethical perspective, designers need to envision potential use contexts and the ethical scenarios they produce (Albrechtslund, 2007). However, exploration of the ethical dimensions of influencing behaviour through industrial / product design is limited (Pettersen and Boks, 2008), therefore few tools for Industrial Designers exist to facilitate ethical analysis. Research exploring technology and ethics in other disciplinary fields, from a number of authors, (DeVries, 2006, Berdichevsky and Neuenschwander, 1999, Brey, 2006, Verbeek, 2006, Jelsma, 2006) could, however, provide guidance for designers who wish to question their role in promoting and facilitating changes in society and evaluate their practice with respect to social, environmental and ethical impacts.

Design intervention strategies are useful and inspirational tools enabling designers to begin to address issues of use behaviour. Design for sustainable behaviour is, however, still a relatively underdeveloped research area and more extensive testing is needed to demonstrate their potential in prompting more sustainable and sustained behavioural changes.

8.2 Product life span / end of life issues

There have been several attempts to categorise different forms of relative obsolescence (technological, economic and psychological are perhaps most frequently cited), but none have proven entirely satisfactory (Cooper 2004). In the case of consumer products, influences upon product lifetimes cannot be understood by considering products in isolation, as if their value to users resides solely in functionality and lifetimes are determined simply by physical ability to withstand 'wear and tear'. In order to understand the process of obsolescence and the potential for action to slow this down, it is necessary to consider users and their situational and socio-cultural contexts. It follows that the criteria that influence the potential of specific products for environmental improvement through increased product lifetimes can only developed in the context of a wider discussion on the full range of influences upon lifetimes.

The basic motivations for increasing product life in relation to current policy demands is broadly related to reduced environmental impacts that might ensue. As a consequence, a very simple categorisation might therefore be on the basis of:

- Static Products i.e. those whose impact is largely in their manufacture and disposal, since they consume or emit no resources during their use; an example might be a piece of furniture or clothing. Benefits will accrue through reduced replacement, rate driving down absolute resource abstraction, and with consequent benefits for the waste stream.
- Energy Using Products (EUPs) i.e. those for which a significant or majority of impact further occurs during the use phase. EUPs are a current target of EU legislation, but for the purposes of this work the concept might be usefully generalised to Resource Using Products. In the consumer domain this will relate to electrical goods, IT and motor vehicles. Lifetime extension in the case of EUPs will have the benefit of lower impact amortized across total life; however, this should be tempered by the superior benefits that might accrue from replacement by improved, more efficient technologies. An optimal solution will be extension coupled with upgrade.

On top of this basic partitioning, finer levels of typology may be applied which will serve to characterise the magnitude of benefits or approach taken to effect change in the product life-spans. A number of such features are briefly described below, but it will be one of the early tasks to pool the perspectives of collaborators and the literature review to determine a practical partitioning. On top of this basic partitioning, finer levels of typology may be applied which serves to characterise the magnitude of benefits or approach taken to effect change in the product life-spans. The table overleaf illustrates the range of different approaches which can be applied by companies and government to encourage longer life products. The potential impacts of these approaches are also highlighted.

Table 56. Approaches to product Life Extension and potential Impact

Dimension	Impact
Value/size	Higher value/large products imply higher resource investment; failure or end-of-life represent a more natural opportunity for value recovery by some agent with a good trade-off against labour costs.
Design basis	Design issues have a major impact and are strongly related to prevailing business or production models. • Products may be intentionally designed to force frequent replacement e.g. a year's guarantee on cheap small electrical goods may signify the working life expectation. • Products may be over-designed for their actual use-life e.g. mobile phones. • Products may be designed for ease of manufacture but not for efficient disassembly or repair. • Products may be designed well (e.g. by modularity) for disassembly, upgrade and eventual recycling; this may be utilised often (e.g. photocopiers, cars) or to a lesser degree (e.g. PCs and laptops).
Technology	High rates of technology change are not conducive to life extension unless the core technology is stable, and modular upgrade and improvement is possible.
Fashion churn	Fashion applies to a wide range of products beyond clothing and promotes a sense of emotional detachment that stimulates new purchase. It is a deep-set social phenomenon.
Service elements	Products that are (or can be) 'servicized' induce reinforcing consumer/producer feedback loops, generally favouring life extension or cascaded product reuse e.g. car hire or fleet management.
Dispersal and tracking	Items that are dispersed within the market and where the OEM or retailer has a transient connection to the customer present obstacles to recovery for potential reuse (and also responsible recycling).
Agency	Retailers and insurance companies are examples of intermediaries who, by power of market position, may promote resource-efficient behaviours. Courtauld-type agreements, coupled to standards, may raise performance thresholds; insurance agents, through stronger engineering standards, can promote reuse and reduce costs by, for example, legitimising repair.

The most substantive published findings on product life spans are from E-SCOPE, a research project on household appliances undertaken in The United Kingdom that generated data through a quantitative survey of over 800 households in 1998 and a series of focus groups in 1999. Data collected included expectations for appliance life spans, the age and condition of discarded appliances, the means by which they are discarded, factors that deter consumers from purchasing longer lasting appliances, and attitudes and behaviour relating to repair (Cooper and Mayers 2000).

Table 57. Mean ages of discarded appliances (Cooper and Mayers (2000)

Product category	Mean age, 1993–1998 (UK)
Electric cookers	12
Refrigerators and freezers	11
Televisions	10
Washing machines, dishwashers, and tumble dryers	9
Hi-fi and stereo	9
Vacuum cleaners and carpet cleaners	8
Video equipment	7
Home and garden tools	7
Microwave ovens	7
Computers and peripherals	6
Telephones, faxes, and answering machines	6
Radio and personal radio, stereo, and CD	6
Small work or personal care appliances	4
Mobile phones and pagers	4
Toys	4

The quantitative survey revealed that the average life span of discarded appliances ranged from 4 to 12 years, depending on type. It also found the stock of appliances in people's homes to be young, partly reflecting a growth in possessions. More than half (57%) were less than 5 years old and nearly nine in ten (88%) were under 10 years old.

This research (Cooper 2004) revealed that the UK population is divided, almost evenly, on whether or not appliances last long enough: 45% responded that they do not, whereas 50% stated that they do (the remaining 5% expressed no opinion). People's opinions appeared to be reflected by their behaviour. Those who were satisfied with product life spans were significantly more likely to purchase premium range appliances and attempt to get products repaired. Asked how long appliances should last, householders revealed expectations that appeared realistic but not quite fulfilled. The average age of discarded appliances was just below the age considered "reasonable".

Interestingly this research (Cooper 2004) found that respondents were deterred from buying longer life products by a fear that such items would become "out of date" (30%) than by price (23%). Men were significantly more concerned about advancing technology than women, who were more price-conscious.

The research also looked at repair work and concluded that this has declined in the UK, in part because labour costs are high, while manufacturing has increasingly relocated to countries with low costs (Cooper 2005).
Cooper (2004) found that one-third of discarded appliances were still functional and of those that were broken, a third were classified as "in need of repair" as distinct from "broken beyond repair."

This conclusion is reinforced by another research study, which assessed the condition of bulky items discarded at civic amenity sites and concluded 60% of domestic appliances could theoretically be refurbished and reused (Anderson 1999).

It appears that the increasing cost of repair relative to replacement plays an important part in user behaviour. Cooper and Mayers (2000) found that 38% of people they rarely or never had appliances repaired, and 68% cited cost as a factor that discouraged them. This ties in closely to a Finnish study that showed that from 1981 to 1994 the price of new televisions increased by 20%, whereas the cost of repair work rose by over 150%; the figures for washing machines were 40% and 165%, respectively (Consumers International 1998).

When replacing functional appliances, consumers want to see them utilized rather than disposed of as waste (Cooper & Mayers 2000). It was found that almost one-quarter of all discarded appliances (24%) were donated or sold and the reuse of computers (67%), hi-fi and stereo (44%), and video equipment, microwave ovens, and toys (around 35% in each case) was particularly high (Cooper & Mayer 2000)

A study by Evans and Cooper (2003) involving a survey of 711 householders in Sheffield 2000 and a series of in-depth interviews in 2002, explored consumers' intentions and behaviour during successive phases in the consumption cycle (acquisition, use, discard) for. The study concluded that most people do not adopt a consistent approach toward product life spans. In each of the three phases some behaved in such a way as to encourage a long life span, such as making durability a priority at acquisition, taking good care of the product during use, or ensuring reuse if it still functioned when discarded. Only a very few people, however, exhibited such behaviour in all three phases. Moreover, the research found that most people did not have the intention of behaving in such a way that products have long life spans. Even among those that did, their actual behaviour during the use phase was often not consistent with their intentions.

8.2.1 Policy approaches to extended product lifespan

The policy actions to extended product lifespan include, but are not limited to:

- Purchaser standards: addressing the role of purchasers in exploiting opportunities, and being informed enough to answer relevant life-time ownership questions of suppliers. Public purchasing may be a significant "pump primer" in this respect.
- Fiscal measures: use of variable VAT or capital incentives; incentivisation of deposit/return or guarantee extensions, as advocated by the Green Alliance; incentives for the repair / re-use sectors.
- Purchaser responsibility: using enforced whole-life responsibility tactics to promote 'design for life' by manufacturers, while simultaneously tackling end-of-life management issues.

- Supply chain initiatives: Selecting high impact or iconic products and garnering support by a coherent set of actors to redesign products, businesses and messages to consumers. This has been successfully applied by WRAP in the Courtauld Agreement, for example.
- Labelling: use of labels (e.g. as by Carbon Trust and Ecolabel, or perhaps life-span labels) to raise standards, create supplier competition and flag to consumers. N.B. this is perceived as a 'quick win' since OHL/TUVNEL are already pushing for cross-product Ecolabel clauses that boost repairability and life-extension as well as ease of disassembly.
- Guarantees and warranties: longer guarantees were proposed in the earlier OECD report and advocated in more recent studies, sometimes in connect with a more toward product service systems.
- Advocacy and awareness: approaches that might be spearheaded by (for example) WRAP and EST that target consumer behaviour with respect to key products. These might need to be in concert with one or more messages above.
- Facility and skill investment: tackling a range of capacity-building initiatives e.g. through RDAs to promote reuse centres cf. BioRegional's ReIY; promoting specific design-led initiatives that optimize product design life-cycles; promoting reuse and repair models as valid business models in business schools (already a current element of CRR's work plan).

9.0 Conclusions - appliance priority areas

This review has identified a number of areas where appliance energy consumption at a household level is estimated to be significant. Although a number of assumptions have been required to form these opinions, the data is based on the best available information gathered in the review.

Appliances that appear to have a high energy demand as a result of high ownership and / or usage across the UK include:

- Fridge-freezer
- TV (LCD)
- Washing machine
- Tumble dryer
- Outdoor lighting
- Electric oven
- Refrigerator
- Dishwasher
- TV (CRT)
- Freezer (chest and upright)
- Kettle
- Electric hob
- TV (Plasma)
- Security alarm
- Electric shower
- Desktop computer

Appliances that appear to have a high individual energy demand include:

- Swimming pool equipment
- TV (Plasma)
- Fridge-freezer
- Pond cleaner / filter / vacuum
- Other electric space heater
- TV (LCD)
- Security alarm
- Dishwasher
- Electric patio heater
- Washer dryer
- Refrigerator
- Air conditioning unit
- Outdoor lighting
- Hot tub / Jacuzzi
- Dehumidifier
- Green house heater
- Freezer (various types)
- Electric hob
- Tumble dryer
- CCTV system
- Electric oven
- Electric shower
- TV (CRT)
- Washing machine
- Kettle
- Pet related / fish tank

Whilst many of these appliances have been the subject of MTP modelling and the focus of EuP preparatory studies, the available research on detailed usage is limited. Some of these appliances have already been tackled through the setting of EU minimum standards and energy labels, in particular freezers, fridge-freezers and plasma and LCD televisions There are very few behavioural studies to understand the real and complex issues of use; nearly all are self-reported questionnaire surveys of ownership and daily usage. Whilst these provide insight, such studies may be inaccurate (as they usually rely on recollection of household behaviour, often from only one household member). Neither do they provide enough understanding of the underlying behavioural issues in order for effective intervention strategies to be implemented.

Specific issues requiring further investigation are discussed below.

9.1 Cold appliances

- All cold appliances (refrigerators, freezers and fridge-freezers) have a high energy demand within the household, with fridge-freezers being the appliance using most energy in the home on average across the UK.
- Some very old appliances still in use and it is common to own several cold appliances in combination. There is likely to be a reluctance to replace what consumers perceive as a ‘perfectly good’ freezer and the cost savings of a more efficient model are small compared with the initial cost of a new appliance.
- Improved understanding of how people use their cold appliances could lead to better future designs and better practice with existing appliances.

9.2 Televisions

- The energy consumed by entertainment appliances in general was significant, with televisions forming the main component in this group. The power consumption of new technology TVs is increasing, and CRTs contribute a significant energy use across the UK households, because of their numbers still in use rather than unit power consumption.
- It is common for households to have several television sets, and for these to be on simultaneously. However, little is understood about why people leave the television on whilst undertaking other activities and whether these needs could be met in a less energy consuming way. Use of the TV as a radio, as a focal point to a room, or just for company are all examples where a better understanding is required before an intervention can be recommended.

9.3 Kitchen appliances

- Several kitchen appliances were in our priority list: washing machines, tumble dryers, dishwashers, kettles, ovens and hobs. These provide convenient and effective solutions to everyday living requirements, but again there are areas that are poorly understood:
    - why clothes are washed so frequently;
    - why tumble dyers are used even when gardens are available for outside drying;
    - which programmes are actually used on dishwashers and whether they effectively get dishes clean;
    - why people re-boil kettles repeatedly;
    - how ovens are used in terms of what is cooked or heated, when and why?
- Understanding of these issues could lead to, for example, intelligent cooker programmes that switch off before the final cooking time, so that residual heat is used to complete the cooking; insulated kettles that do not cool down quickly between boils; changes in perceptions about acceptable cleanliness of clothes or effectiveness of lower temperature washes.

9.4 Garden items

- Garden maintenance appliances do not appear to be a major user of energy in the home, however there are some areas of garden use that that the potential to consume significant amounts of energy, even if they are not widespread across the UK.
- Swimming pools and hot tubs are estimated to use significant energy to heat, filter and clean and there could be improvements to the efficiency of these. Investigation of how these products are used would help understand whether they need to be left on all the time or only for specific periods and whether current designs allow a more energy efficient practice.
- Use of outdoor lighting is a more widespread practice and has the potential to grow for security and comfort. The use of high energy using lights triggered by movement sensors mean that energy consumption from these can be significant. Knowledge of the reasons why people use outdoor lighting together with the patterns of use would inform future strategies.
- Significant energy demands were estimated from this review for greenhouse heaters, pond equipment and patio heaters. Patio heaters are declining in numbers are awareness of their energy consumption has spread and actions from retailers to stop stocking them will further reduce their impact. Greenhouse heaters and pond equipment could be improved through specific interventions targeted at consumers or product manufacturers in this area.

9.5 Security alarms and CCTV

- The use of security alarms and associated equipment is small, but their always on use contributes to a significant energy demand. Whilst these systems need to be working at all times to be effective, there may be improvements to be made in the efficiency of the equipment.

9.6 Electric showers

- Showering is an activity that meets complex behavioural needs, not just associated with getting clean. Policies or interventions at reducing the energy demand from this activity would need to ensure the wider needs are still being met in order to be effective.

9.7 Desktop computers

- Computer use is increasing and likely to increase further, as market penetration of computers increases, coupled with increases in usage.
- Desktop computers, whilst much less efficient that laptops, are still in abundance in UK households, and are likely to have a longer lifespan than their equivalents at work.
- Second lifetime (passing old computers onto other people) appears commonplace, but little robust data on the nature and scale of this were found. Usage of computers, in particular reasons for leaving them running but not used, needs more investigation.

9.8 Dehumidifiers and air conditioners

- The use of dehumidifiers and air conditioners in the home is limited currently, but could increase significantly, making this a high priority area on a national level.
- The effects of other improvements in building stock need to be understood, in order to ensure they do not necessitate further requirements for air conditioning or dehumidification. The use of external insulation and more tightly sealed houses may increase internal humidity, increasing the need for dehumidifiers.
- An understanding of behavioural reasons for these products and how / where they are used is necessary before effective policies can be recommended.

9.9 Pet equipment

- Although not identified as a key priority area, energy used as a result of pet equipment, (e.g. lighting, heating and filtration of fish tanks or reptile vivariums) could be improved through better product design or changed practice. However, the animal needs still need to be maintained, and so the intervention strategy is constrained by these performance requirements. Investigations of current practice and future needs would inform this area further.

10.0 Recommendations

This review has highlighted issues relating to domestic appliances ownership and use, drawing conclusions about energy demand in the home from this sector. Issues relating to how this information is best used towards modelling appliance energy demand, particularly at a household level have been considered and a number of recommendations are made:

- More detailed investigations taking measurements in the home are needed. Recent developments in sensor and wireless sensor technology are beginning to make monitoring of appliance energy use, at frequent time intervals a realistic possibility. Such monitoring would significantly enhance our understanding of what happens in practice. The Defra, DECC and Energy Saving Trust's Product Usage Study recently commissioned will provide good, initial data in this area, through its 10 minute interval measurement of individual appliances in 200 homes across the UK, which will fill some of the gaps identified in this review. However, the underlying behaviours driving the appliances usage may not be captured; an understanding of these is critical to making effective recommendations.

- Rich, qualitative and detailed data are needed on use and behaviour in relation to household activities and practices, particularly in the areas of high energy demand within households or across the UK, e.g. use of the television for watching, as a radio, focal point or to provide company, cooking practices, use of lighting in and outside the home, washing practices (clothes and personal), security and safety requirements and the impact on appliance use. These need to extend to the wider population, not just small samples in order to ensure intervention strategies can be targeted at all relevant consumers. This practice orientated approach is commonplace in social sciences and focuses on the activities of the consumer to achieve a goal rather than the devices used (e.g. Scott et al, 2009) and so might allow the emphasis to be taken away from the use of the appliance towards a more energy efficient approach.

- The proposed National Household Model (NHM) needs to include an appliance component in order to predict future domestic energy consumption: as homes are better insulated, appliance energy use is likely to represent a greater fraction of total home energy demand; electric space and water heating, using for example heat-pumps may be more prevalent.

- Future models will also require demand profiling to make best use of an energy supply system which has a higher proportion of intermittent generators using renewable sources.

- However, the requirements and desirable features of an appliance component are multiple and there is risk of an over-ambitious specification being defeated by lack of data. The immediate priority is to develop a rigorous core of data that can underpin more detailed modelling activities.

- Further analysis of existing data sets could help enhance understanding of appliance use. Household appliance surveys and measurement programmes already underway provide the potential for greater understanding. Capitalising on these for the specific purpose of populating the NHM would provide initial data before more extensive behavioural studies could be undertaken, although issues of data protection and confidentiality would need to be addressed.

- Data sharing from future studies should be encouraged to enable an open household appliance data archive to be established. It could become a requirement of future research programmes to supply data to a central archive for all to access. Defra's energy appliance usage data collection programme would provide a significant start to this process.

- A quantified way of representing behavioural change following intervention strategies could be developed as part of the household model so it can more accurately assess the impact of future policies, from forced changes to consumer driven action.

- Better ways are needed to communicate behavioural understating to designers and manufacturers, to ensure they are designing for end user needs. The current focus is on technical performance in standard conditions, rather than covering issues relating to real practice. This may include the use of exemplar design concepts to inspire manufacturers and designers, and to demonstrate value in terms of effective behavioural change and a successful product.

11.0 References

4M (2010) Measurement, Modelling, Mapping and Management: An Evidence-based Methodology for Understanding and Shrinking the Urban Carbon Footprint. EPSRC funded project. Principal Investigator: Professor Kevin Lomas, Loughborough University.

AEA (2009) Energy Efficiency Policies and Measures in the UK 2009, Monitoring of Energy Efficiency in EU 27, Norway and Croatia (ODYSSEE-MURE), UK, October 2009, http://www.odyssee-indicators.org/publications/PDF/UK_nr.pdf (Accessed November 2009).

Ajzen, I (2006) Theory of Planned Behaviour (TPB) http://www.people.umass.edu/aizen/tpb.diag.html (Accessed June 2007)

Akrich, M, (1992) The De-Scription of Technical Objects, In: Shaping Technology: Building Society, Bijker, W. E. and Law, J. (Eds.), Massachusetts Institute of Technology (MIT), Cambridge, Massachusetts, pp. 205-224.

Albrechtslund, A, (2007) Ethics and technology design, Ethics and Information Technology, Vol. 9, pp. 63-72.

Anderson BR, Chapman PF, Cutland NG, et al. (2002a) BREDEM-12 model description: 2001 update. BRE Press; Report 438.

Anderson BR, Chapman PF, Cutland NG, et al. (2002b) BREDEM-8: Model description: 2001 update. BRE Press; Report BR 439.

Anderson, C, (1999) Recycle, reuse, bury or burn? Bristol: The SOFA Project.

Anderson, J. R (1982) Acquisition of cognitive skill, Psychological Review, Vol. 89, pp. 369-403.

Aydinalp-Koksal M, Ugursal VI, Fung AS. (2003) Modelling of residential energy consumption at the national level. International Journal of Energy research.;27:441-453.

Aydinalp-Koksal M, Ugursal VI. (2008) Comparison of neural network, conditional demand analysis, and engineering approaches for modeling end-use energy consumption in the residential sector. Appl Energy.;85:271-296.

Bain, J. Beton, A. Schultze, A. Mudgai, S. Dowling, M, Holdway, R and Owens, J. (2009) Reducing the environmental impact of clothes cleaning. Department for Environment, Food and Rural Affairs. EV0419. December 2009

Barker, T. and Jenkins, K. (2007) The Domestic Energy: Sub-Model in MDM-E3. UKERC Report UKERC/WP/ESM/2007/008. Working Paper, May 2007, http://www.ukerc.ac.uk/Downloads/PDF/07/0705ESMDomEnSub-Model.pdf.

Berdichevsky, D. and Neuenschwander, E., (1999) Towards an Ethics of Persuasive Technology, Communications of the ACM, Vol. 42, No. 5, pp. 51-58.

Bertoldi, P. and Atanasiu, B. (2007) Electricity Consumption and Efficiency Trends in the Enlarged European Union, Status report 2006, European Commission Joint Research Centre Institute for Energy, , Luxembourg: Publications Office of the European Union, http://re.jrc.ec.europa.eu/energyefficiency/pdf/EnEff%20Report%202006.pdf (Accessed December 2009).

Bertoldi, P. and Atanasiu, B. (2009) Electricity Consumption and Efficiency Trends in European Union, Status Report 2009, European Commission Joint Research Centre Institute for Energy, Luxembourg: Publications Office of the European Union, http://ie.jrc.ec.europa.eu/press/electronic_press_pack/Status%20Report%202009.pdf (Accessed December 2009).

Bhamra, T. A., Lilley, D. and Tang, T., (2008) Sustainable Use: Changing consumer behaviour through product design, In: Changing the Change: Design visions, proposals and tools, Turin, Italy, 10th-12th July 2008

Biddle, S. Marshall, S, Gorely, T, Cameron, N, Murdey, I and Whitehead, S. (2005) Sedentary behaviour among Scottish youth: prevalence and determinants. Published by NHS Health Scotland, Woodburn House, Canaan Lane, Edinburgh,

Boardman, B. (1997) Cold Labelling - the UK Experience of Energy Labels, Oxford Environmental Change Unit, Oxford University.

Boyny, J. (2006). "CE and IT - Market continuously driven by new technologies and by the development of changing consumer approach, Proceedings of 4th International Conference on Energy Efficiency in Domestic Appliances and Lighting (EEDAL'06), 21-23 June 2006, London, United Kingdom."

Brey, P., (2006) Ethical Aspects of Behavior-Steering Technology, In: User Behavior and Technology Development: Shaping Sustainable Relations Between Consumers and Technologies, Verbeek, P.-P. and Slob, A. (Eds.), Springer, The Netherlands, pp. 357-364.

BRMB (2010) Half of GB adults play electronic games. Market Research World website, accessed February 2010 http://www.marketresearchworld.net/index.php?option=com_content&task=view&id=908&Itemid=77

Buchholz, R. A. (1998) The ethics of consumption activities: A future paradigm? Journal of Business Ethics, 17(8), 871-882.

Climate Change Act (2009). http://opsi.gov.uk/acts/acts2008/ukpga_20080027_en_1

Coleman, M, Wright, A., Brown, N and Firth, S. (2009) Domestic information, communication and entertainment (ICE) appliance monitoring: A practical perspective and implications for inter-disciplinary research. Proceedings of the 5th International Conference EEDAL'09 (Energy Efficiency in Domestic Appliances and Lighting). Editors: Paolo BERTOLDI, Rita WERLE 16-18 June, Berlin, Germany.

Consumers International. (1998). Green guidance. London: Consumers International.

Cooper T. (2004) Inadequate Life? Evidence of Consumer Attitudes to Product Obsolescence, Journal of Consumer Policy 27: 421–449, 2004

Cooper, T. (2005) Slower Consumption: Reflections on Product Life Spans and the "Throwaway Society", Journal of Industrial Ecology Vol. 9(1-2): pp.51-67.

Cooper, T. and Kieren, M. (2000) Prospects for household appliances, the E-SCOPE study: Electronics industry - Social Considerations Of Product End-of-life.

Cooper, T. and Mayers, K. (2000). Prospects for household appliances. Halifax, Canada: Urban Mines.

Crosbie, T. (2008) Household energy consumption and consumer electronics: The case of television. Energy Policy, 36 (6), pp. 2191-2199.

Darnton, A., Elster Jones, J., Lucas, K., Brooks, M., (2006). Promoting pro-environmental behaviour: existing evidence to inform better policy making (Summary report). Defra, London.

DECC (2008) Energy Consumption in the United Kingdom, Domestic data tables, 2008 Update, Department for Energy and Climate Change.

DECC (2009a) Energy Consumption in the United Kingdom, Domestic data tables, 2009 Update, Department for Energy and Climate Change. http://www.decc.gov.uk/en/content/cms/statistics/publications/ecuk/ecuk.aspx

DECC (2009b) Digest of UK Energy Statistics 2009. http://www.decc.gov.uk/en/content/cms/news/pn085/pn086.aspx

DECC (2009c) UK Low Carbon Transition Plan Emission Projects. Department of Energy and Climate Change. URN 09D/678.

DECC (2009d) Heat and Energy Saving Strategy: Consultations, Feb 2009.

Defra (2006). Power devolved is energy released, speech by the Rt Hon David Miliband MP at the Local Government Association annual conference, Bournemouth, Tuesday 4, July 2006.

Defra (2008) Policy Brief: Improving the energy performance of domestic cold appliances July 2008.

Defra (2009) Saving Energy Through Better Products and Appliances, A consultation on analysis, aims and indicative standards for energy efficient products 2009 - 2030, December 2009.

Defra (2010) Factors influencing the penetration of energy efficient appliances into national markets in Europe, January 2010

Design Council (2005) Home Monitoring Display, RED Future Currents,, http://www.futurecurrents.org/HM_home_monitoring.php, (Accessed October 2008)

Development Research Network. London: Policy Studies Institute.

DeVries, M. J., (2006) Ethics and the complexity of technology: a design approach, Philosophia Reformata, the international scientific journal of the Association for Reformational Philosophy, Vol. 71, No. 2, pp. 118-131.

DIY Kyoto (2005) Wattson, www.diykyoto.com, (Accessed 2007)

DTI (2003) TABLE 3.10: Total electricity consumption by household domestic appliances 1970-2002.

DUKES (2009) Annual tables: ‘Digest of UK energy statistics’ (DUKES) Table 5.1.2.http://www.decc.gov.uk/en/content/cms/statistics/source/electricity/electricity.aspx

Ecodesign Directive (2009) Directive 2009/125/EC of the European Parliament and of the Council of 21 October 2009. Establishing a Framework for the Setting of Ecodesign Requirements for Energy-Related Products.

E.ON information sheet (2010) Ever wondered how much electricity you use? E.ON Energy Limited.

Element Energy (2010). National Household Model Scoping Study Final Functional Specification. Draft v1 24 March 2010 (not published).

Elias, E. (2009) User-Efficient Design: Improving the Energy Efficiency of User Behaviour, Behaviour Design Case Study: The Domestic Refrigerator, University of Bath: Innovative Design and Manufacturing Research Centre.

Elias, E. W. A., Dekoninck, E. A. and Culley, S. J. C. (2008a) Assessing User Behaviour for Changes in the Design of Energy Using Domestic Products, In: IEEE International Symposium on Electronics and the Environment ISEE, San Francisco, California, US, May 19-22.

Elias, E. W. A., Dekoninck, E. A. and Culley, S. J. C., (2008b) Prioritisation Methodology for User-Centred Design of Energy Using Domestic Products, In: International Design Conference – Design 2008, Dubrovnik, Croatia, 19th-22nd May 2008

ELIMA European Research Project (2005) Refrigeration product trials: Hallam University, Sheffield.

Energy Saving Trust (2006). The rise of the machines. A review using products in the home from 1970s to today. Paula Owen, Energy Saving Trust, 2006.

Energy Saving Trust (2007). The ampere strikes back: How consumer electronics are taking over the world. Paula Owen, Energy Saving Trust, 2007.

Energy Saving Trust. (2009). Achieving our mission, The Energy Saving Trust Strategy 2009–2014

Environmental Change Institute. (2005). 40%house, Oxford University, Oxford, UK.

Environmental Change Unit (1994) University of Oxford. DECADE: Domestic equipment and carbon dioxide emissions, first year report..

Environmental Change Unit (1997a) 2MtC - DECADE: Domestic Equipment and Carbon Dioxide Emissions, Oxford: Oxford University.

Evans, S. and T. Cooper. 2003. Waste not, want not? An exploration of the effect of consumer behaviour on the service life of three categories of household product. Paper presented at the Chartered Institution of Wastes Management conference, Paignton, June.

Fawcett, T, Lane K, Boardman, B et al, 2000. Lower Carbon Futures for European Households, Environmental Change Institute, Oxford.

Firth SK, Lomas KJ, and Wright A, J. (2010) Targeting household energy efficiency measures using sensitivity analysis. Building Research and Information. 2010;38:25-41.

Firth SK, and Lomas KJ. (2009) Investigating CO2 emission reductions in existing urban housing using a community domestic energy model. Eleventh International IBPSA Conference: 2098-2105.

Firth, SK, Lomas, KJ, Wright, AJ and Wall R. (2008). Identifying trends in the use of domestic appliances from household electricity consumption measurements. Energy and Buildings, 40, pp.926–936.

Fogg, B. J., (2003) Persuasive Technology; Using Computers to Change What We Think and Do, Morgan Kaufmann, San Fransisco.

Fung AS, Aydinalp-Koksal M, Ugursal VI, Farahbakhsh H.(2001) A residential end-use energy consumption model for canada. ESIM 2001..

Gatersleben and Vlek in Noorman, K., Uiterkamp T.S. (1998), Green households? Domestic consumers, environment and sustainability, Earthscan Publications Ltd., UK.

Gruber, E and Schlomann, B (2006) The current and future electricity demands of appliances in German households. EEDAL 06. International Energy Efficiency in Domestic Appliances and Lighting Conference. 21-23 June 2006, Millennium Gloucester Hotel and Conference Centre, London.

Gupta R. (2009) A new geographical information system-based approach to map and reduce energy-related CO2 emissions from UK dwellings. Eleventh International IBPSA Conference. 2114-2121.

Gutberlet, KL (2009) Domestic Appliances: progress & potential. In: The 5th International Conference on Energy Efficiency in Domestic Appliances and Lighting EEDAL'09 in Berlin, Germany, 16th – 18th June 2009

Hampshire County Council et al., (2005). More from less: a stakeholder perspective. Hampshire County Council Material Resources Strategy.

Hawkes AD & Leach MA (2008) Energy Policy 36 2973–2982

Herring, H. (1995) Electricity use in minor appliances in the UK. Energy, 20 (7) 705-710.

Household Projections to 2031, England (2009). Accessed March 2010 http://www.communities.gov.uk/publications/corporate/statistics/2031households0309

HTA (2006) The Great British Gardener: A Profile of Gardeners in 2006.The Horticultural Trades Association - Garden Industry Monitor.

HTA (2007) Garden Industry Monitor. Retail garden analysis for 2007. The Horticultural Trades Association - Garden Industry Monitor.

HTA (2009) Green Gardening: Gardens, gardeners and the environment. The Horticultural Trades Association - Garden Industry Monitor.

HTA (2010) Data provided by HTA for purposes of this review. The Horticultural Trades Association.

Interactive Institute, (2004) Static! Increasing Energy Awareness, http://www.tii.se/static/index.htm, (Accessed December 2006)

Jackson, T., (2005). Motivating Sustainable Consumption: A Review of Evidence on Consumer Behaviour and Behavioural Change, a Report to the Sustainable Development Research Network. SDRN, London.

James S.J., Evans J. And James C., (2008) A Review of the Performance of Domestic Refrigerators, Journal of Food Engineering 87, 2–10.

Jelsma, J. and Knot, M., (2002) Designing environmentally efficient services; a 'script' approach, The Journal of Sustainable Product Design, Vol. 2, pp 119-130.

Jelsma, J., (2006) Designing 'Moralized' products: theory and practice, In: User Behaviour and Technology Development, Verbeek, P.-P. and Slob, A. (Eds.), Springer, Berlin, pp. 221–231.

Johnston D, Lowe R, Bell M. (2005) An exploration of the technical feasibility of achieving CO2 emission reductions in excess of 60% within the UK housing stock by the year 2050. Energy Policy ; 33:1643-1659.

Johnston D. (2003) A physically based energy and carbon dioxide emission model of the UK housing stock. [Doctor of Philosophy]. Leeds Metropolitan University;.

Jones PJ, Lannon S, Williams J. (2001) Modelling building energy use at urban scale. Seventh International IBPSA Conference. 2001:175-180.

Lader, D, Short, S, Gershuny, J. (2006) Amendment, The Time Use Survey, 2005. National Statistics.

Lilley, D., (2007) Designing for Behavioural Change: Reducing the Social Impacts of Product Use through Design, Doctoral Thesis, Department of Design and Technology, Loughborough University, Loughborough.

Lilley, D., (2009) Design for sustainable behaviour: strategies and perceptions,, Design Studies, Vol. 30, No. 6, pp. 704-720.

Lockton, D., Harrison, D. J. and Stanton, N. A., (2010) The Design with Intent Method: a design tool for influencing user behaviour, Applied Ergonomics, Vol.41, No. 3, pp. 382-392.

Lockwood, M. & Murray, R. (2005). RED Future Currents: Designing for a changing climate.

Loveday, D, Bhamra, T, Tang, T, Haines, VJA, Holmes, MJ and Green, RJ. (2008) The energy and monetary implications of the '24/7' 'always on' society. Energy Policy 36, 4639-4645.

Lucas, K., Brooks, M., Darnton, A., Elster Jones, J., (2008). Promoting pro-environmental behaviour: existing evidence and policy implications, environmental science & policy 11 (2008) 456 – 466.

Mansouri, I, Newborough, M and Probert, D. (1996) Energy consumption in UK households: Impact of domestic electrical appliances. Applied Energy 54 (3) 211-285.

Market Transformation Programme (2006) BNXS19: Changing Consumer lifestyles and their possible effects on future patterns of energy consumption, January 2006, Defra. http://www.mtprog.com/ApprovedBriefingNotes/PDF/MTP_BNXS19_2006September19.pdf.

Market Transformation Programme (2006b) Monitoring Home Computer. Report ID RPICT01/06. September 2006, Defra.

Market Transformation Programme (2007a) BNC11: Domestic refrigerator test standard vs. real-use energy consumption, Defra.

Market Transformation Programme (2007b). BNC07: Domestic cold appliances, Market Transformation Programme, Supporting UK Government policy on sustainable products, Defra.

Market Transformation Programme (2008a) BNC08: Assumptions underlying the energy projections for domestic cold appliances, Defra.

Market Transformation Programme (2008b) BNC16: Innovation Briefing Note: Vacuum insulated panels for refrigerated appliances, Defra.

Market Transformation Programme (2008c) BNW05: Assumptions underlying the energy projections for domestic washing machines, Defra.

Market Transformation Programme (2008d) BNW06: Assumptions underlying the energy projections for domestic tumble driers, Defra.

Market Transformation Programme (2008e) BNW07: Assumptions underlying the energy projections for domestic dishwashers, Defra.

Market Transformation Programme (2008f) BN DW Shower: Actions to improve shower design and efficiency, Defra.

Market Transformation Programme (2010) “What if?” tool, Defra, http://whatif.defra.gov.uk/ (Consulted 26th February 2010);

McCalley, L. T. and Midden, C. J. H., (2006) Making Energy Feedback Work, In: User Behavior and Technology Development: Shaping Sustainable Relations Between Consumers and Technologies, Verbeek, P.-P. and Slob, A. (Eds.), Springer, The Netherlands, pp. 127-135.

Meier A., (1995) Refrigerator energy use in the laboratory and in the Field, Energy and Buildings 22 (1995) 233-243

Mennink B.D. & Berchowitz D.M. (1994). Development of an Improved Stirling Cooler for Vacuum Super Insulated Fridges with Thermal Store and Photovoltaic Power Source for Industrialized and Developing Countries, IIR Conference - New Applications of Natural Working Fluids in Refrigeration and Air Conditioning, Hanover, Germany.

Mennink, B D and Berchowitz, D.M (1998) Development of an improved stirling cooler for vacuum super insulated fridges with thermal store and photovoltaic power source for industrialized and developing countries, Innovatiebureau Mennink, 7201 AE Zutphen, The Netherlands, 1998

Middle Layer Super Output Area (MLSOA) electricity and gas estimates 2006, East Midlands Government Office Region, Publication URN 08/477

Middle Layer Super Output Area (MLSOA) electricity and gas estimates 2007:East Midlands Government Office Region, Publication URN 09/477

Mintel (2001) Air Treatment – UK

Mintel (2004a) Conservatories – UK

Mintel (2004b) The Consumer - UK

Mintel (2007a) Fridges and Freezers – UK

Mintel (2007b) Gardening Review - UK

Mintel (2007c) Gas and Electric Cookers - UK

Mintel (2007d) Portable Technology Retailing - UK

Mintel (2008a) Radio – UK

Mintel (2008b) Garden Products Retailing - UK

Mintel (2008c) Digital Cameras - UK.

Mintel (2008d) Laundry and Dishwasher Appliances - UK.

Mintel (2008e) PC Hardware - UK

Mintel (2008f) Video and Computer Games - UK.

Mintel (2008g) Bath and Shower Products - UK

Mintel (2008h) Vacuum Cleaners - UK.

Mintel (2008i) Garden Products Retailing - UK

Mintel (2009a) Domiciliary Care (Industrial Report) – UK.

Mintel (2009b) Outdoor living – UK.

Mintel (2009c) Customising the TV Viewing Experience - UK.

Mintel (2009d) Film Viewing Habits - UK.

Mintel (2009e) Garden Equipment – UK.

Mintel (2009f) PCs and Laptops - UK.

Mintel (2009g) Televisions - UK.

Mintel (2009h) White Goods – UK.

Mintel (2009i) Satellite Navigation Systems - UK

Mintel (2009j) Household Cleaning Products - UK

Mintel (2010) Bathroom Equipment (Industrial report) - UK

Moll, H. C., Noorman, K. J., Kok, R., Engström, R., Throne-Holst, H., and Clark, C. (2005) Pursuing more sustainable consumption by analyzing household metabolism in European countries and cities. Journal of Industrial Ecology, 9(1–2), pp.259– 275.

Natarajan S, Levermore GJ. (2007) Domestic futures—Which way to a low-carbon housing stock? Energy Policy.;35:5728-5736..

Natarajan S, Levermore GJ. (2007) Predicting future UK housing stock and carbon emissions. Energy Policy.;35:5719-5727.

OECD (Organisation For Economic Co-Operation And Development) (2002) Towards Sustainable Household Consumption? Trends And Policies In OECD Countries Paris: OECD

Ofcom (2009) Communications Market Report 2009 – English Regions. Accessed February 2010. http://www.ofcom.org.uk/research/cm/cmr09/

Office for National Statistics (2007). Social Trends.

Office for National Statistics (2008a) Consumer Trends. Accessed Mar 2010. http://www.statistics.gov.uk/statbase/product.asp?vlnk=242

Office for National Statistics (2008b) General Lifestyle Survey, 2008. Overview Report.

Office for National Statistics (2010a) Household estimates and projections, United Kingdom, 1961-2031 Table 401. Accessed March 2010 http://www.communities.gov.uk/documents/housing/xls/table401.xls

Office for National Statistics (2009) Retail Sales.

Office for National Statistics, (2010b) Households. accessed March 2010 http://www.statistics.gov.uk/CCI/nugget.asp?ID=1162&Pos=3&ColRank=2&Rank=480.

Openlearn website Accessed November 2009 http://openlearn.open.ac.uk/mod/resource/view.php?id=94560-

OSTC (2003) Criteria and impulses for changes towards a sustainable consumption: approach per sector, first intermediary report, Jan. 2003, on behalf of the Federal Office for Scientific, Technical and Cultural Affairs (OSTC), Support plan for sustainable development (SPSD)

Page J, Robinson D, Morel N, Scartezzini J. (2008) A generalised stochastic model for the simulation of occupant presence. Energy Build.;40:83-98

Page J, Robinson D, Scartezzinin J. (2007) Stochastic simulation of occupant presence and behaviour in buildings. 10th International Building Performance Simulation Association Conference 2007:757-764.

Pantzar, M. (1999) Do Commodities Reproduce Themselves through Human Beings? Man vs. Nature vs. Technology: Problems and New Conceptualisations, Consumption, Everyday Life and Sustainability Summer School 1999, Department of Sociology, University of Lancaster, Lancaster.

Parker D.S. and Stedman T.C. (1993) Refrigerator replacement in Florida: a case study. Home Energy;10 (1):20–2. Accessed December 2009. http://www.homeenergy.org/archive/hem.dis.anl.gov/eehem/93/930110.html

Peacock, A. and Newborough, M (2004) The 40% house project, Task 4: power and demand, Heriot Watt University, Edinburgh

Pettersen, I. N. and Boks, C., (2008) The ethics in balancing control and freedom when engineering solutions for sustainable behaviour, International Journal of Sustainable Engineering, Vol. 1, No. 4, pp. 287-297.

Residential Buildings Energy Consumption Survey (RECS) (2001). Housing Characteristics Data Tables. US Energy Information Administration, http://www.eia.doe.gov/emeu/recs/recs2001_hc/

Richardson, J., Irwin, T. and Sherwin, C., (2005) Design & Sustainability: A Scoping Report for the Sustainable Design Forum, Design Council, UK.

Roberts, S. (2008). Demographics, energy and our homes. Energy Policy 36, 4630-4632.

Robinson D, Haldi F, Kampf J, et al. (2009) CITYSIM: Comprehensive micro-simulation of resource flows for sustainable urban planning. Eleventh International IBPSA Conference. 1083-1090.

Rodriguez, E & Boks, C (2005) How design of products affects user behaviour and vice versa: the environmental implications. Ecodesign, pp.54-61, 2005 4th International Symposium on Environmentally Conscious Design and Inverse Manufacturing, 2005.

Rylatt M, Gadsden S, Lomas K. (2003a) Using GIS to estimate the replacement potential of solar energy for urban dwellings. Environment and Planning B: Planning and Design; 30:51-68.

Rylatt M, Gadsden S, Lomas K. (2003b) Methods of predicting urban domestic energy demand with reduced datasets: A review and a new GIS-based approach. Building Services Engineering Research and Technology; 24:93-102.

Saidur R., Masjuki H.H., Choudhury I.A., 2002, Role of ambient temperature, door opening, thermostat setting position and their combined effect on refrigerator freezer energy consumption, Energy Conversion and Management 43 (2002) 845–854

Saidur, R., Masjuki H.H., Hasanuzzaman M. And Kai G.S., 2008, Investigation of Energy Performance and Usage Behaviour of Domestic Refrigerator Freezer Using Clustering and Segmentation, Journal of Applied Sciences 8 (21): 3957 3962, ISSN 1812 5654

Sanne, C. (2002) Willing consumers - or locked-in? Policies for a sustainable consumption, Ecological Economics, Vol. 42, pp. 273-287.

SAP 2005: The government's standard assessment procedure for energy rating of dwellings: 2005 edition, revision 2; Published on behalf of DEFRA by BRE; 2008.

SAP 2009 (DRAFT): The government's standard assessment procedure for energy rating of dwellings: Version 9.90; Published on behalf of DECC by BRE; 2009.

Schiellerup, P. (2002) An examination of the effectiveness of the EU minimum standard on cold appliances: the British case, Energy Policy 30: pp.327–332.

Scott, F (2004) Behaviour change e believing you can make a difference! in: BTCV, Global Action Plan and The Environment Council Workshop, London 20th July 2004.

Scott, K, Quist, J and Bakker, C (2009). Co-design, social practices and sustainable innovation: involving users in a living lab exploratory study on bathing. Joint Actions on Climate Change Conference, Aalborg, Denmark, 8-10 June 2009.

Scottish Government Social Research. (2009) Modelling greenhouse gas emissions from Scottish housing: Final report. 2009.

Shiels, M. (2010) DTV is being billed as possible industry saviour. BBC News website, Accessed from http://news.bbc.co.uk/1/hi/8447432.stm, March 2010.

Shorrock LD, Dunster JE. (1997) The physically based model BREHOMES and its use in deriving scenarios for the energy use and carbon dioxide emissions of the UK housing stock. Energy Policy.;25:1027-1037.

Shove, E & Warde, A (1998) Inconspicuous consumption: the sociology of consumption, lifestyles and the environment, in Gijswijt A, Buttel F, Dickens P, Dunlap R, Mol A & Spaargaren G (eds.), *Sociological Theory and the Environment: Part 2: cultural and social constructivism. Proceedings of the Second Woudschoten Conference*. Amsterdam, SISWO, University of Amsterdam, 1998) 135-52.

Shove, E. (2003) Changing human behaviour and lifestyle: a challenge for sustainable consumption? Department of Sociology, University of Lancaster, Lancaster.

Shove, E. and Warde, A. (1998) Inconspicuous consumption: the sociology of consumption and the environment, Consumption, Everyday Life and Sustainability Summer School 1999: Department of Sociology, Lancaster University, Lancaster.

Smith, T (2010) Sony backs away from OLED TV future. 16th February 2010. Reg Hardware. http://www.reghardware.co.uk/2010/02/16/sony_oled_exit_japan/ Accessed March 2010.

Stamminger R., Suljug A. and Hillenstedt A., 2007, Prepartory Studies for Eco Design Requirements of EuPs, Lot 13: Refrigerators and Freezers, Task 3: Economic and Market Analysis, Energy Using Products Directive 2005/32/EC, EU.

Sustainable Consumption Roundtable, (2006) I will if you will: Towards sustainable consumption, The National Consumer Council (NCC) and The Sustainable Development Commission (SDC), UK.

Sustainable Development Unit (2005) Green guide for buyers – Ozone depleting substances (action sheet)

Swan L and Ugursal VI, (2009) Modelling of end-use energy consumption in the residential sector: A review of modelling techniques. Renewable and Sustainable Energy Reviews 13, 1819-1835.

Swan L, Ugursal VI, Beasuoleil-Morrison I. (2009) Implementation of a canadian residential energy end-use model for assessing new technology impacts. Eleventh International IBPSA Conference.:1429-1436.

Swedish Energy Agency (2008) End-use metering campaign in 400 households in Sweden. Assessment of the potential electricity savings. Contract 17-05-2743. Enertech.

Tang T (2008) Creating Sustainable Behaviour: An Exploration of Environmental Impacts of Household Cold Appliance Use, 13th Sustainable Design Network Seminar, 17th October 2008, Loughborough University

Tang T and Bhamra T (2008) Understanding Consumer Behaviour to Reduce Environmental Impacts through Sustainable Product Design, Design Research Society Conference 2008 Sheffield Hallam, July, 2008

Tang, T. and Bhamra, T. A. (2009) Improving Energy Efficiency of Product Use: An Exploration of Environmental Impacts of Household Cold Appliance Usage Patterns, In: The 5th International Conference on Energy Efficiency in Domestic Appliances and Lighting EEDAL'09 in Berlin, Germany, 16th – 18th June 2009

Tang, T., (2010) Towards Sustainable Use: Designing Behaviour Intervention to Reduce Household Environmental Impact, unpublished PhD thesis, Department of Design and Technology, Loughborough University, Loughborough, UK

Treehugger survey. How Often Do You Shower? http://www.treehugger.com/files/2009/01/survey-how-often-do-you-shower.php Accessed March 2010.

The Business Book (2003). Independent Electrical Retailer.

Triandis, H.C (1977) Interpersonal Behaviour, Brooks/Cole, Monterey, CA,

TSO (2008a) Climate Change Act. Accessed 29/5/09. http://www.opsi.gov.uk/acts/acts2008/pdf/ukpga_2 (0080027_en.pdf

TSO (2008b) Committee on Climate Change 2008 Building a low-carbon economy - the UK's Contribution to Tackling Climate Change. http://hmccc.s3.amazonaws.com/pdf/TSO-ClimateChange.pdf Accessed 17/02/09.

Tsurusaki , T, Iwafune, Y, Shibata, Y, Murakoshi, C, and Nakagami, H. (2006). Actual Energy Consumption of Top-Runner Refrigerators in Japan, Jyukankyo Research Institute, Inc., Japan.

Ugursal VI, Fung AS. (1996) Impact of appliance efficiency and fuel substitution on residential end-use energy consumption in Canada. Energy Build; 24:137-146.

UK Ecology (2010) UK Ecology: British Garden Shed website. Articles accessed January 2010 http://www.britishgardenshed.co.uk/

UK Department for Business Innovation and Skills (2007) Local Authority consumption statistics, Electricity and Gas Consumption Data at Middle Layer Super Output Area and Intermediate Geography (MLSOA/IG), Publication URN 08/477, 2007.

Unilever, (2000) Tablet Detergents: Towards A More Sustainable Future, Prepared and issued by Unilever HPC - Europe, June 2000

Van de Velden, R. (2003) Creating Awareness through Function Innovative Product Design to Facilitate Sustainable Behaviour, Institute for Product Design, Norges Tekniske Naturvitenskapelige Universitet, Trondheim.

Van der Wal J. and Noorman, K. J, (1998) Analysis of Household Metabolic Flows. In: Green households? Domestic consumers, environment, and sustainability, edited by Noorman, K. J, and Uiterkamp T. S., 1998, London, Earthscan.

Van Diepen A. M. L, (1998) Developments in Household Composition in Europe, In: Green households? Domestic consumers, environment, and sustainability, edited by Noorman, K. J, and Uiterkamp T. S., 1998. London: Earthscan.

Van Hoff, D., (2003) The tyranny of the plug; kitchen machines that do not need to be plugged, http://www.vanhoffontwerpen.nl, Accessed December 2005.

Van Holsteijn en Kemna BV (2005) Refrigerators and Freezers, product case 5, Methodology Study Eco-design of Energy-using Products (MEEUP) for European Commission, final report, Delft, Retrieved June 15, 2007 from http://www.vhknet.com/download/MEEUP_Methodology_fin.pdf.

Verbeek, P.-P., (2006) Persuasive Technology and Moral Responsibility, In: PERSUASIVE 2006 First International Conference on Persuasive Technology for Human Well-Being, Eindhoven, The Netherlands,, 18th-19th May 2006

Verplanken, B., and Wood, W (2006) Interventions to break and create consumer habits, Journal of Public Policy and Marketing, Vol. 25, pp. 90-103.

Waterwise (2008) Water and energy consumptions of dishwashers and washing machines: An analysis of efficiencies to determine the possible need and options for a water efficiency label for wet white goods. Waterwise 1 Queen Anne's Gate, London SW1H 9BT, United Kingdom.

Waterwise (2009) Shower Power - Women are faster in the shower than we think. Press release 3 Sept 2009. http://www.waterwise.org.uk/reducing_water_wastage_in_the_uk/press_releases/shower_power_press_release.html accessed March 2010.

Wever, R., van Kuijk, J. and Boks, C., (2008) User-centred Design for Sustainable Behaviour, International Journal of Sustainable Engineering, Vol. 1, No. 1, pp.9-20.

What-If Tool. Defra, Department for Environment, Food and Rural Affairs. http://whatif.defra.gov.uk/

Yao, R. and Steemers, K. 2005. A method of formulating energy load profile for domestic buildings in the UK. Energy and Buildings, 37 p663-671.

Yohanis, Y.G., Mondol, J.D., Wright, A and Norton, B. (2008) Real-life energy use in the UK: How occupancy and dwelling characteristics affect domestic electricity use. Energy and Buildings 40, 1053-1059.

Appendix A

Changing households – data tables

UK Household size, 2003-13 (ONS 2009)

	2003 m	2008 m	2013 m	% change 2003-08	% change 2008-13
UK households	25.24	26.54	27.74	5.12	4.52
One-person households	7.4	8.23	8.72	11.22	5.95
2 person	8.86	9.42	9.93	6.32	5.41
3 person	3.96	3.95	4.11	-0.25	4.05
4 person	3.32	3.27	3.34	-1.51	2.14
5+ person	1.7	1.66	1.65	-2.35	-0.6
Average household size UK	**2.36**	**2.31**	**2.29**	**-2.12**	**-0.87**

Trends in the age structure of the UK population, by gender, 2004-14 (ONS, 2009)

	2004		2009 (est)		2014 (proj)		% change	% change
	000's	%	000's	%	000's	%	2004-09	2009-14
Under 5	3,391	5.7	3,763	6.1	3,977	6.2	11	5.7
5-14	7,475	12.5	7,104	11.5	7,192	11.2	-5	1.2
15-24	7,739	12.9	8,248	13.3	7,981	12.5	6.6	-3.2
25-34	7,954	13.3	8,064	13	9,042	14.1	1.4	12.1
35-44	9,185	15.3	9,027	14.6	8,208	12.8	-1.8	-9.1
45-54	7,634	12.8	8,337	13.5	9,039	14.1	9.2	8.4
55-64	6,899	11.5	7,300	11.8	7,239	11.3	5.8	-0.8
65+	9,570	16	10,105	16.3	11,413	17.8	5.6	12.9
Total	**59,846**	**100**	**61,858**	**100**	**64,091**	**100,0**	**3.4**	**3.6**

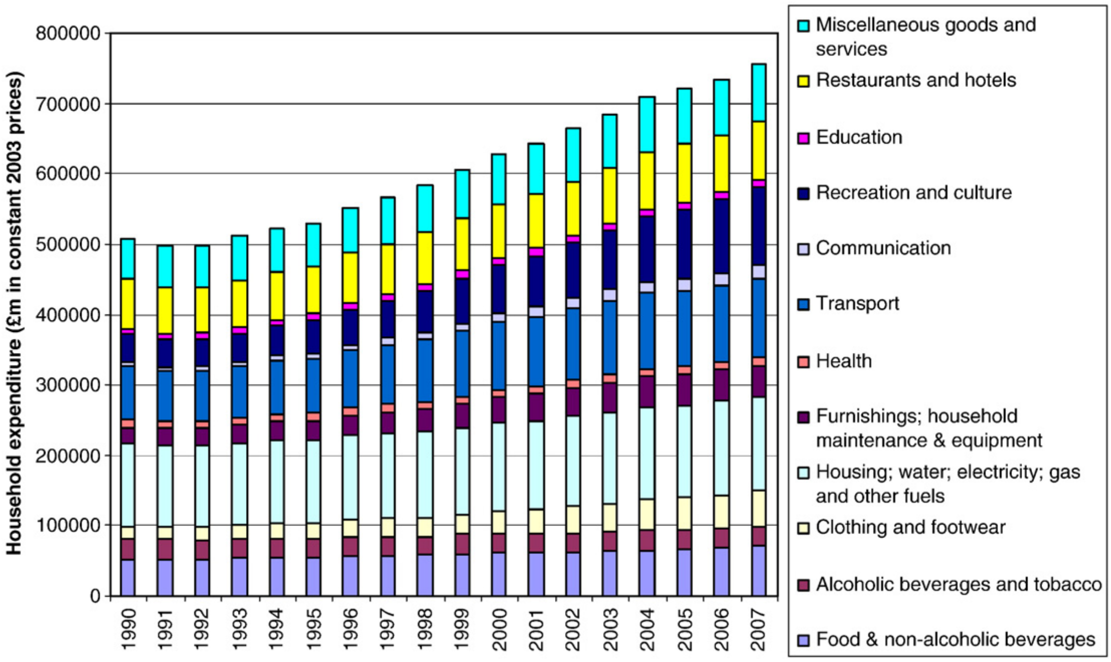
Forecast adult population trends, by lifestage, 2003-13 (ONS, 2008)

	2003	**2008**	**2013 (proj)**	**% change 2003-08**	**% change 2008-13**
	000	000	000		
Pre-/no family	13,434	13,951	14,372	3.8	3
Families	13,384	13,796	13,741	3.1	-0.4
Third age	12,333	13,037	13,366	5.7	2.5
Retired	9,474	9,889	11,101	4.4	12.3
Total	**48,626**	**50,673**	**52,580**	**4.2**	**3.8**

Forecast adult population trends, by socio-economic group, 2003-13 (ONS, 2008)

	2003	**2008 (proj)**	**2013 (proj)**	**% change 2003-08**	**% change 2008-13**
	000	000	000		
AB	12,123	13,583	15,334	12	12.9
C1	14,008	14,999	16,007	7.1	6.7
C2	10,127	10,178	9,910	0.5	-2.6
D	7,956	7,938	7,656	-0.2	-3.6
E	4,412	3,974	3,673	-9.9	-7.6
Total	**48,626**	**50,673**	**52,580**	**4.2**	**3.8**

UK household expenditure 1990–2007 (ONS 2008a)



Appendix B

Building stock models summaries

This appendix outlines thirteen physically based, bottom-up, housing stock models, in particular noting how they calculate appliance energy use. These appliance energy use sub-model include:

- BREDEM based (BREDEM-8, BREDEM-12 or SAP)
- DECADE based
- Conditional demand analysis (CDA)
- Statistical
- Stochastic

BREDEM based

BREDEM based calculations are the most commonly used in modelling the UK housing stock. While having a common root source, there are some variations between the current BREDEM-8 &12 and SAP 2005, and the draft SAP 2009. In all cases, electricity consumption from appliances can be calculated from the dwelling's total floor area (TFA, m^2) alone. In BREDEM-8 and BREDEM-12, the number of occupants can be, optionally, included.

BREDEM-12 (Anderson et al, 2002a) is the annual version of the BREDEM calculation. The energy consumed by lights and appliances (E_{LA}, GJ/year) are not separated. They can be calculated by a simple linear approximation based on floor area, as shown in equation 1.

$$E_{LA} = 2.24 + 0.087 \times TFA \qquad \textbf{(1)}$$

An alternative method is provided, based on actual occupancy (N, number of occupants), to give "a more accurate prediction" as shown in equations 2 to 4.

$$E_{LA} = 4.47 + 0.0232TFA \times N \qquad TFA \times N < 710 \qquad \textbf{(2)}$$

$$E_{LA} = 11.98 + 0.0146TFA \times N - 2.78 \times 10^{6}(TFA \times N)^{2} \qquad 710 \le TFAxN < 2400 \qquad \textbf{(3)}$$

$$E_{LA} = 31.01 \qquad 2400 \le TFAxN \qquad \textbf{(4)}$$

BREDEM-12 provides a method for calculating the number of occupants from the total floor area, as shown in equations 5 and 6.

$$N = 0.0365 \times TFA - 0.00004145 \times TFA^{2} \qquad TFA \le 450 \qquad \textbf{(5)}$$

$$N = \frac{9}{\left(1 + \frac{54.3}{TFA}\right)} \qquad TFA > 450 \qquad \textbf{(6)}$$

There is also a method for reducing this figure to account for the installation of low energy lights. The method assumes that lighting comprises 16%, and appliances 84% of the total figure. Therefore, for the purposes of the comparison in this appendix, the annual electricity consumed by appliances alone (E_A, GJ/year) was calculated from equation 7.

$$E_{A} = 0.84 \times E_{LA} \qquad \textbf{(7)}$$

The BREDEM-12 model is used by BREHOMES (Shorrock and Dunster, 1997), though the final result is modified to agree with the results of the DECADE model.

BREDEM-8 (Anderson et al, 2002b) includes the same equations along with a simple equation to proportion monthly usage equally, by the number of days. Annual totals are the same, however. The BREDEM-8 model is used by CDEM (Firth and Lomas, 2009; Firth et al, 2010), DeCorum (Gupta, 2009), and SEP (Rylatt et al, 2003a; 2003b).

SAP calculations do not include energy use for appliances, but provision is made to add them in support of the stamp duty land tax savings that are available to zero carbon homes. The SAP model is used in DEMScot (in a modified form) (Scottish Government Social Research, 2009), EEP (Jones et al 2001) and the Johnston model (Johnston 2003; Johnston et al, 2005).

For SAP 2005, the CO_2 emissions ($kgCO_2/m^2$/year) from appliances and cooking are calculated together, as shown in equation 8.

$$CO2 = \left[99.9 \times (TFA \times N)^{0.4714} - 3.267 \times TFA + 32.23 \times N + 72.65\right] / TFA \quad \textbf{(8)}$$

If TFA<43, N=1.464

If TFA>+43, N=2.844x(1-exp(-0.000391xTFA^2))

For SAP 2009, the energy use (kWh) by electrical appliances is calculated separately, as shown in equation 9.

Annual consumption:

$$E_A = 207.8 \times (TFA \times N)^{0.4714} \quad \textbf{(9)}$$

The consumption in each month, m, follows a sinusoidal pattern, rather than the simple linear relationship of BREDEM, as shown in equation 10.

$$E_{A,m} = E_A \times [1 + 0.157 \times \cos(2\pi(m - 1.78)/12)] \times n_m / 365 \quad \textbf{(10)}$$

The assumed number of occupants, N, is calculated from equation 11.

$$N = 1 + 1.76 \times \left[1 - \exp\left(-0.000349 \times (TFA - 13.9)^2\right)\right] + 0.0013 \times (TFA - 13.9) \quad \textbf{(11)}$$

for TFA>13.9, $N = 1$ for TFA<=13.9

DECADE

DECADE (Environmental Change Unit, 1994) uses a disaggregated approach to appliance types, with categories that include all uses of electricity except for space and water heating. However, the results are aggregated to the level of the entire UK housing stock, rather than the individual house.

The electrical energy consumed by all appliances in the UK (kWh/year) is expressed as a summation of the energy consumed by each appliance, based on number of households that own each appliance (ownership% x households) and the unit energy consumption (UEC, kWh/year), as shown in equation 12. The UEC is the average amount of electricity that is used by an average appliance, of that type, in one year. It therefore includes all of the technical and behavioural components of consumption.

$$\text{Electricity\_consumption} = \sum_{1}^{\text{number\_appliances}} \text{ownership\%} \times \text{Households} \times \text{UEC} \qquad \textbf{(12)}$$

The total electricity consumption figure is tuned to measured or projected UK totals. The model uses a wide variety of data sources, including Gfk, MRGB, GHS data on appliance ownership and historical electricity consumption.

Both the BREHOMES and DeCarb (Natarajan and Levermore, 2007a, 2007b) models use the DECADE forecasts.

Conditional demand analysis (CDA)

Conditional demand analysis is a statistical bottom-up method based on the analysis of extensive measured electricity demand data along with weather data and surveyed appliance ownership data.

For CREEM (Aydinalp-Koksal et al, 2003; Fung et al, 2001; Ugursal and Fung, 1996), utility bills were used along with appliance saturation surveys, to estimate usage on a house by house basis.

Statistical

Statistical models can be used to relate features of the dwelling and occupants to the electricity consumption. They need existing data to train the model. CHREM (Swan et al, 2009; Aydinalp-Koksal and Ugursal, 2008) used a calibrated neural network to calculate appliances and lighting energy use from the appliance inventory, dwelling characteristics and socioeconomic/demographic information. While the results may fit the historical data well, statistical techniques cannot be relied on in forecasts, as new technology or behaviour cannot be included.

Stochastic

CitySim (Robinson et al, 2009) takes a stochastic approach, simulating appliance energy demand using probabilities and random behaviours. A behavioural model of occupants presence, which uses the Markov Chain approach, is central to the model. If an occupant is present then their interaction with lights and appliances can be simulated using further stochastic models (see Page et al, 2007, 2008). This approach is required by CitySim in order that the energy demand can be calculated on an hourly basis.

Building stock models summaries

Model	BREHOMES
Institution	BRE
Vintage	1991
What the model predicts	Annual energy consumption/GHG emissions from domestic housing in the UK
Physical basis of the model	BREDEM-12 calculations on over 1000 building/occupant archetypes
What it is used for and by whom	Developed and used by BRE on behalf of DEFRA, to explore policy implications
Form of the model	Coding unknown
The appliance sub-model	Lights and appliances based on BREDEM and adjusted by scaling factors to reconcile with the DECADE UK total
Comments	The results are tuned to DECCs published figures on energy consumption in the UK

Model	CDEM
Institution	Loughborough University
Vintage	2007
What the model predicts	Monthly energy consumption/GHG emissions for domestic housing in the UK at numerous output levels (e.g. Local Authority, England)
Physical basis of the model	BREDEM-8 calculations on 47 dwelling archetypes
What it is used for and by whom	Developed and used by DMU for the EPSRC funded CaRB project and adopted by Loughborough University for the EPSRC funded 4M project, to explore technological intervention and sensitivity analysis
Form of the model	Microsoft Excel
The appliance sub-model	Lights and appliances from BREDEM-8

Model	CHREM
Institution	Dalhousie University, Canada
Vintage	2008
What the model predicts	Annual energy consumption from domestic housing stock in Canada
Physical basis of the model	ESP-r dynamic simulation using a detailed database of 17,000 houses
What it is used for and by whom	Used by Canadian Universities for evaluating the impact of new technologies when applied to the Canadian housing stock
Form of the model	Database, neural network and ESP-r batch processing (2 days to run)
The appliance sub-model	A calibrated Neural Network (statistical) for lights and appliances

Model	**CitySim**
Institution	LESO-PB, Ecole Polytechnique, Switzerland
Vintage	2009
What the model predicts	Hourly resource (energy) flows at different levels from a few buildings to an entire city of tens of thousands, in the UK
Physical basis of the model	Lumped parameter (RC network)
What it is used for and by whom	Research tool (under development) for "sustainable planning of urban settlements"
Form of the model	Java based GUI
The appliance sub-model	Appliances energy demand from a behavioural (stochastic) sub-model that uses either deterministic occupant profiles or stochastic Markov Chain occupancy model of presence linked with Page et al electrical appliance use
Comments	IBPSA 2009 paper refers to the stochastic presence model being disabled at present

Model	**CREEM**
Institution	Dalhousie University, Canada
Vintage	1998
What the model predicts	Annual energy consumption and CO_2 emissions from domestic housing stock in Canada
Physical basis of the model	HOT2000 using 16 archetypes to describe a database of 8,767 houses
What it is used for and by whom	Developed and used by Canadian Universities for evaluating the impact of new technologies when applied to the Canadian housing stock
Form of the model	Batch input to HOT2000
The appliance sub-model	Conditional demand analysis (CDA)

Model	**DeCarb**
Institution	Bath and Manchester Universities
Vintage	2007
What the model predicts	Monthly energy consumption from domestic housing in UK
Physical basis of the model	BREDEM-8 calculations on 8064 dwelling archetypes in each of 6 historical age classes
What it is used for and by whom	Developed and used by Bath and Manchester Universities for evaluating the impact of future scenarios
Form of the model	Open framework, object oriented, Java code
The appliance sub-model	DECADE

Model	**DeCoRuM**
Institution	Oxford Brookes University
Vintage	2006
What the model predicts	Mapping energy use and CO_2 emissions at Local Authority level in the UK
Physical basis of the model	BREDEM-8 calculations at the level of individual houses
What it is used for and by whom	Developed and used by Oxford Brookes University for mapping GHG emissions, designed for planners.
Form of the model	Microsoft Excel, dynamically linked to MapInfo GIS, house by house calculation
The appliance sub-model	Not explicit but assumed BREDEM-8

Model	**DEMScot**
Institution	Cambridge Architectural Research, Cambridge Econometrics, Roger Talbot and Associates Ltd, Alembic Research
Vintage	2009
What the model predicts	Annual energy consumption and embodied CO_2 in Scottish housing
Physical basis of the model	SAP 2005 based calculations on archetypes taken from the 3,146 records in the Scottish House Condition Survey and new build assumptions
What it is used for and by whom	Used by the developers on behalf of the Scottish Government for exploring housing stock policy and CO_2 reductions
Form of the model	Microsoft Excel
The appliance sub-model	Lights, appliances and cooking based on SAP2005 but modified to account for number of occupants, increased use over time, potential for more efficient appliances and different user behaviour (high medium and low users)

Model	**EEP**
Institution	Welsh School of Architecture, Cardiff University
Vintage	2001
What the model predicts	Mapping of CO_2 emissions in the UK at different levels, up to City wide
Physical basis of the model	SAP based calculations on 100 dwelling archetypes
What it is used for and by whom	Used by the developer and applied to a number of UK cities to calculate city wide carbon emissions including modules for non-domestic buildings and transport
Form of the model	MapInfo GIS and PC Windows interface
The appliance sub-model	Not explicit but assumed SAP

Model	**Johnston**
Institution	Leeds University
Vintage	2003
What the model predicts	Annual energy consumption and CO_2 emissions for the UK
Physical basis of the model	SAP based calculation for 2 dwelling archetypes
What it is used for and by whom	Used by the developer for future casting and comparison with other models
Form of the model	Spreadsheet
The appliance sub-model	SAP disaggregated by ECI 2000

Model	**PDEM (+LSSAT)**
Institution	UCL Bartlett
Vintage	2009
What the model predicts	Mapping the spatial distribution of heating energy demand across London, aggregated at MLSOA
Physical basis of the model	SAP 2005 based calculations using the English House Condition Survey and GIS measurements
What it is used for and by whom	Used as a research tool within the LUCID project to explore spatial variation in heating energy at the aggregate level of MLSOA (about 3,000 houses)
Form of the model	Spreadsheet dynamically linked to GIS
The appliance sub-model	No appliances: only primary fuel is considered i.e. gas

Model	**SEP (EMERALD)**
Institution	IESD, DMU
Vintage	2003
What the model predicts	Solar energy potential and energy consumption of individual dwellings at an urban scale in the UK
Physical basis of the model	BREDEM-8 calculations at the level of the individual house
What it is used for and by whom	Developed and used by DMU and applied to the City of Leicester
Form of the model	MapInfo GIS and database with interface
The appliance sub-model	Lights and appliances from BREDEM-8

Model	**UKDCM**
Institution	ICE, University of Oxford
Vintage	2006
What the model predicts	Projecting energy use and carbon emissions from the UK housing stock into the future
Physical basis of the model	BREDEM-8 calculations on 20,000 dwelling archetypes
What it is used for and by whom	Used by the developer and applied to the 40% house project
Form of the model	MS Access (to be re-written in IDL)
The appliance sub-model	DECADE

Appendix C

4M survey details

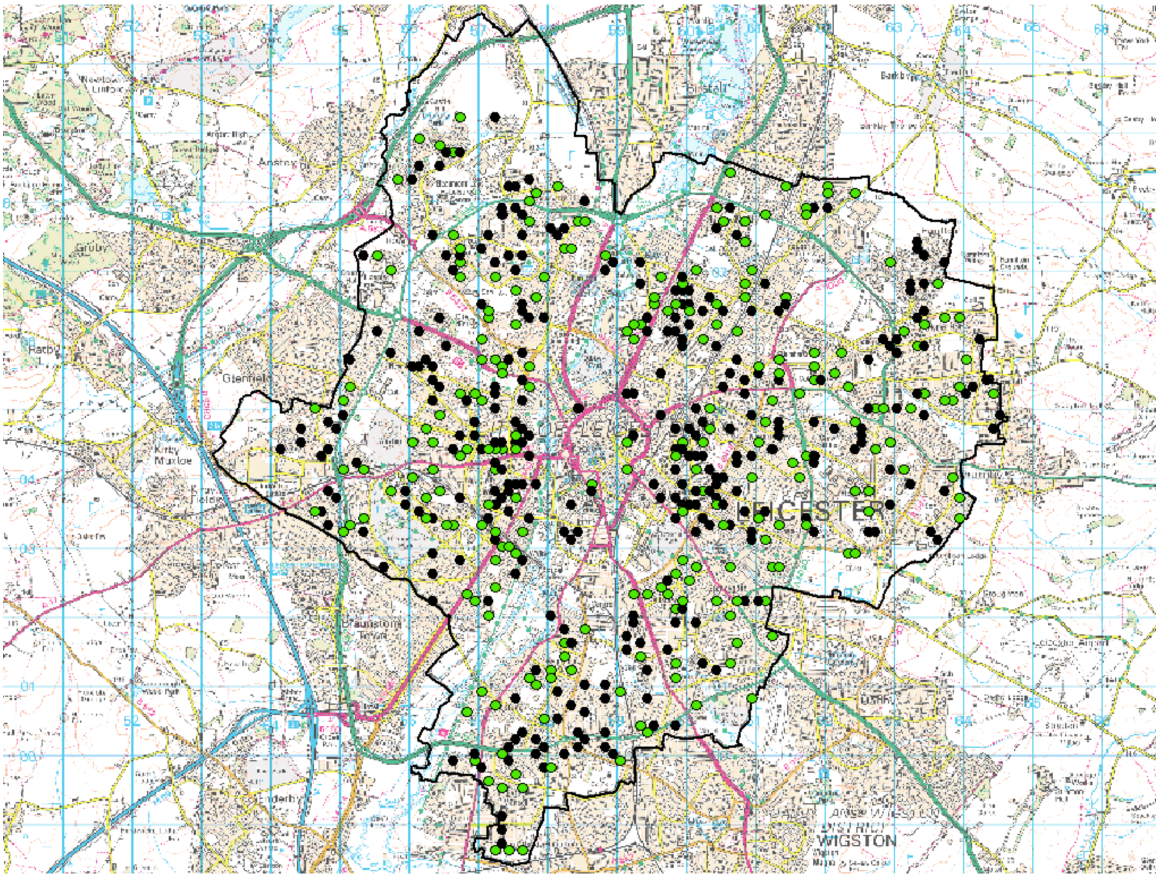
Purpose:
To better understand the ownership and usage of electrical appliances in households and their influence on energy consumption and carbon footprint of residential buildings.

Team:
The Building Services Engineering 4M team (led by Professor Kevin Lomas) at Loughborough University.

Dates:
The questionnaire was piloted during November to December 2009.
The initial survey was sent out on 5th Jan 2010.
A reminder was sent out on 3rd Feb 2010.

Samples:
494 houses in Leicester (sub-sample from 575 participants in the Living in Leicester Survey, which was the main survey of the 4M project and conducted by NatCen)

Distribution of houses:



Houses replied to the Appliances Survey   Other houses in the Living in Leicester survey

Response rate to 9th March 2010

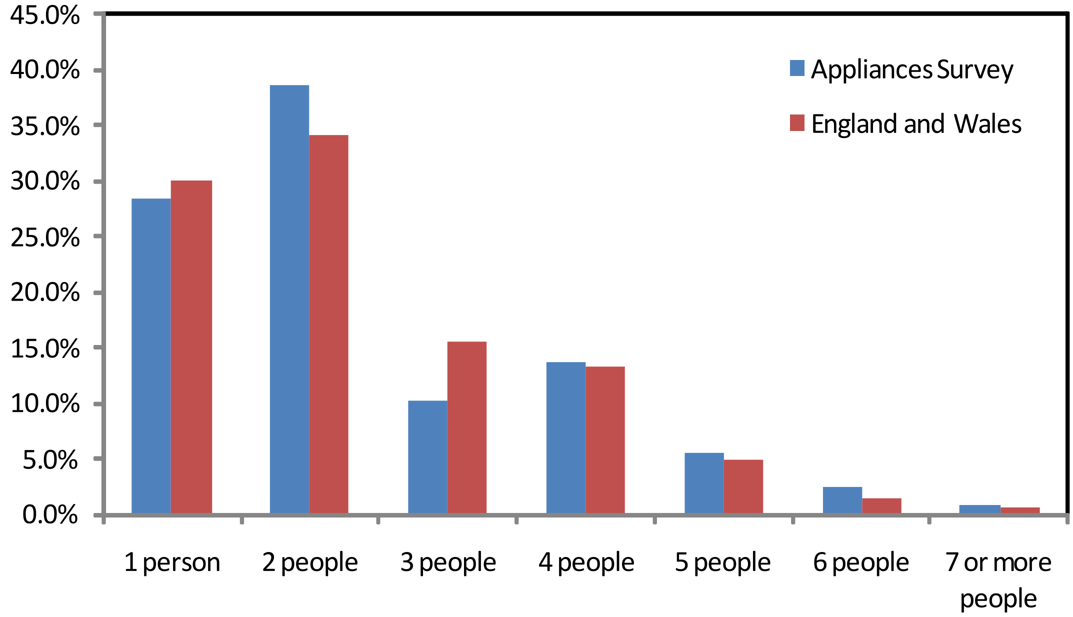
Initial survey (5th Jan 2010)				Reminder (3rd Feb 2010)				
1st week	2nd week	3rd week	4th week	5th week	6th week	7th week	8th week and later	Total response
25.7%	9.1%	2.6%	1.0%	6.1%	1.6%	1.4%	1.0%	48.6%
190 houses				50 houses				240 houses

Contents of the survey

Categories	Ownership	Usage	Size and Age
Cold appliances	Refrigerator, fridge-freezer, upright freezer, Chest freezer Small drink coolers		Refrigerators, fridge-freezers, upright freezers, Chest freezers
Wet appliances	Washing machine, tumble dryer, washer-dryer, dishwasher	Washing loads, temperature, dryer loads	Washing machine, tumble dryer, washer-dryer, dishwasher
Home Entertainment	TV, VCR, set-top box, DVD, DTR, digital radio, hi-fi system/music centres, home cinema/home theatre, record player, game console	Working hours of TVs (1st, 2nd, 3rd and 4th), VCRs, DVDs, home cinema and video games	TVs (1st, 2nd, 3rd and 4th)
Computers and communications	PC, laptop, printer, scanner, copier, telephone, mobile, broadband/router	PC (1st, 2nd and 3rd) and laptop (1st, 2nd and 3rd) working hours	
Cooking appliances	Oven, hob, kettle, toaster, deep fat fryer, steamer, slow cooker, health grill, bread maker, ice-cream maker, hot drink maker, juicer, food processor, blender/mixer	Cooking hours using oven or hob on a typical weekday or weekend	
Gardening	Strimmer, hedge trimmer, shredder, chainsaw, lawnmower, patio heater	Usage of lawnmower	
Miscellaneous	Electric shower, iron, vacuum cleaner, cooker hood, home security system, hair styling, electric towel rail, electric blanket, hot tub/spa, power tools, dehumidifier, extractor, fans, air-conditioning	Frequency of electric shower use	

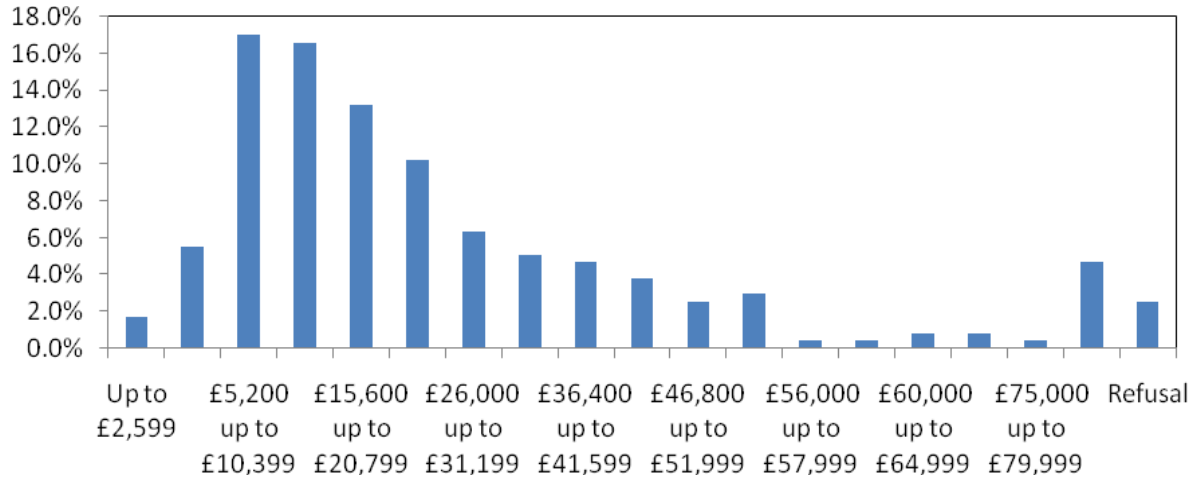
Summary of samples (235 valid samples)

Household size



The relationship between the survey data and the 2001 CENSUS data is not statistically significant using the chi-square test and a probability of 0.05. Average household size of the survey samples is 2.4 people per household.

Household income

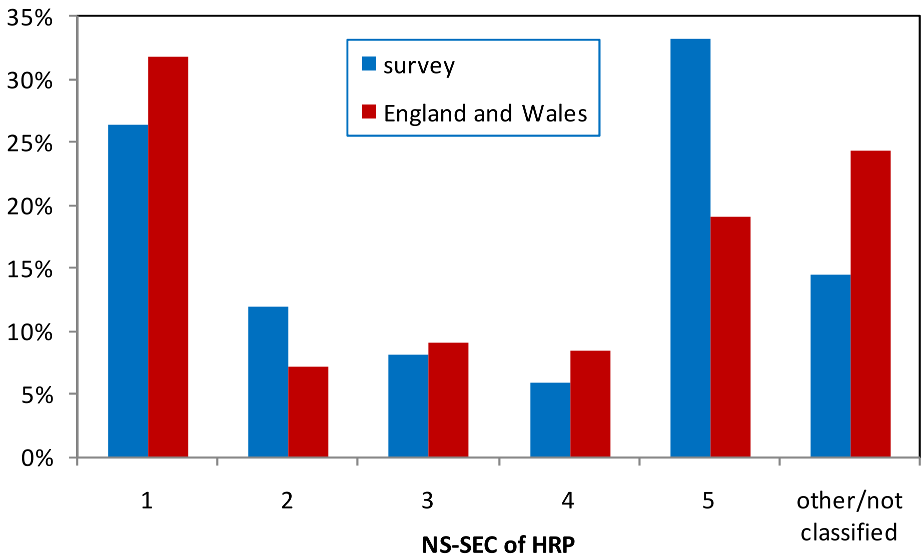


The average annual household gross income is £21940.

National Statistic Social Economics Classification (NS-SEC) of Household Representative Person (HRP)

The survey used NS-SEC 5 classes version, while CENSUS2001 used NS-SEC 8 classes version. So CECSUS data were regrouped to make a cross comparison.

NS-SEC of HRP	survey		England and Wales	
	n	%	n	%
1 Managerial and professional occupations	62	26.4	6,103,521	31.9
2 Intermediate occupations	28	11.9	1,376,983	7.2
3 Small employers and own account workers	19	8.1	1,728,629	9.0
4 Lower supervisory and technical occupations	14	6.0	1,624,715	8.5
5 Semi-routine and routine occupations	78	33.2	3,664,765	19.1
Other or not classified	34	14.5	4,644,791	24.3
Total	235	100	19143404	100

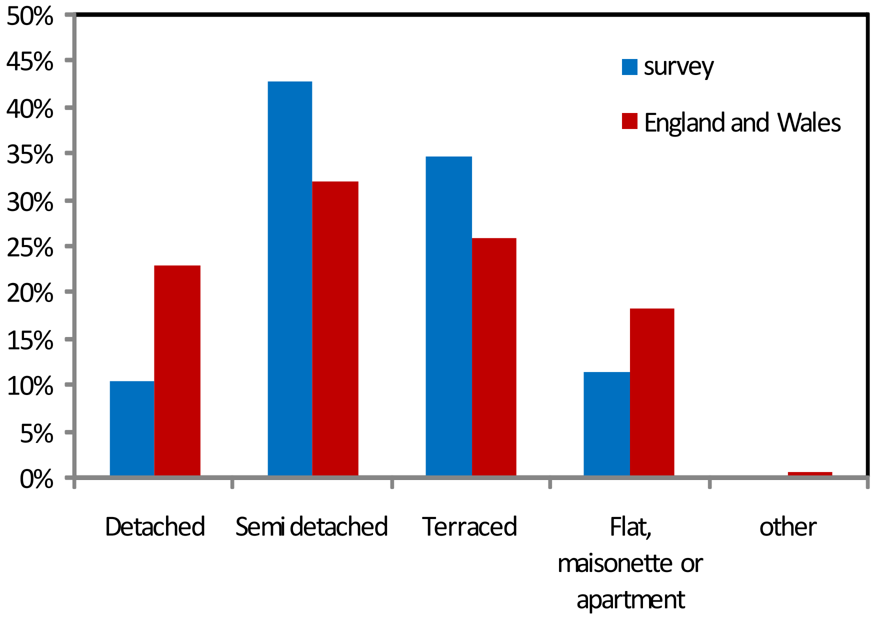


The relationship between data from the appliances survey and CENSUS 2001 (England and Wales) are not statistically significant using the chi-square test and a probability of 0.05.

Tenure

The relationship between data from the appliances survey and CENSUS 2001 (England and Wales) are not statistically significant using the chi-square test and a probability of 0.05.

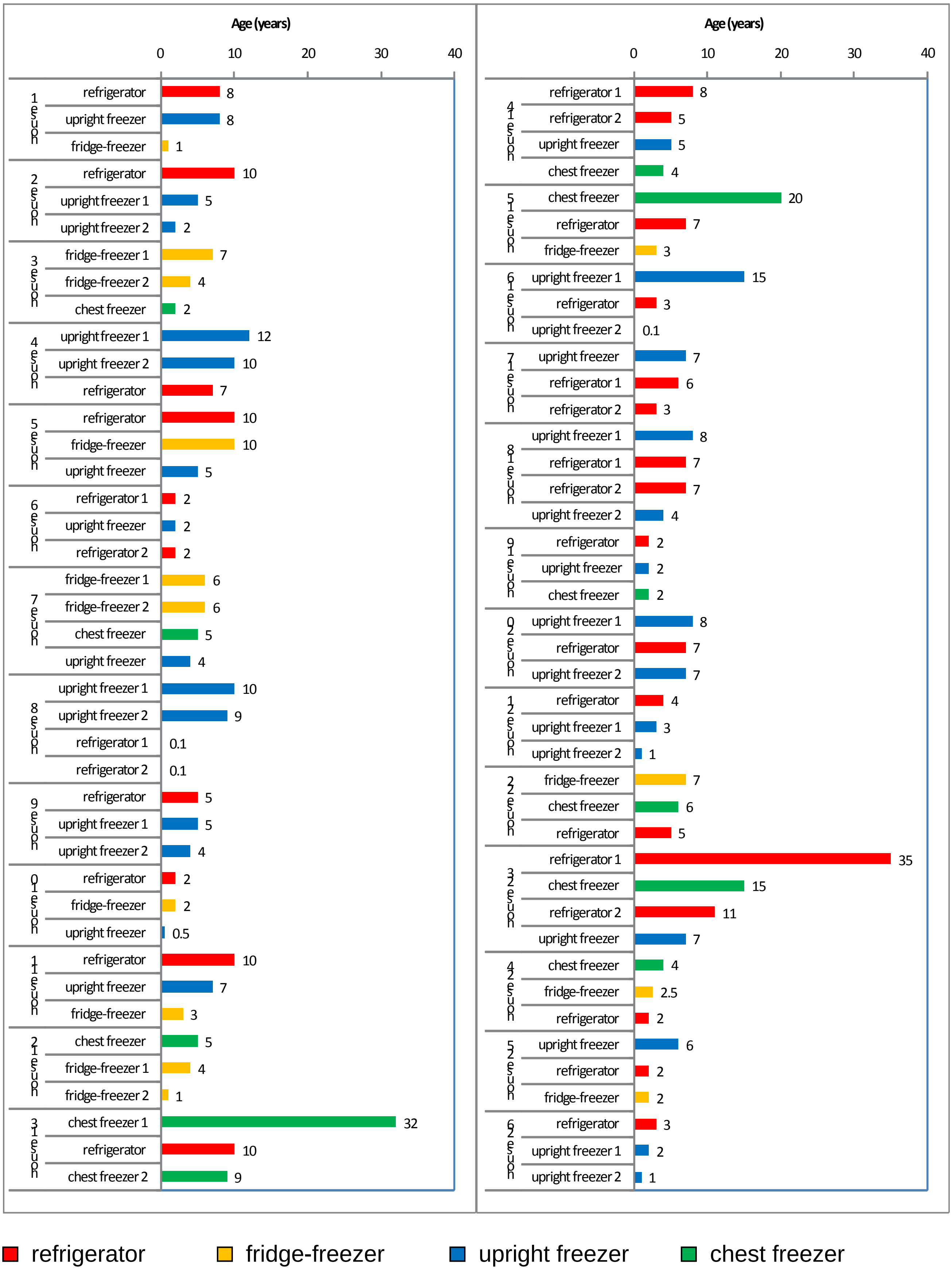
House type



The relationship between data from the appliances survey and CENSUS 2001 (England and Wales) are not statistically significant using the chi-square test and a probability of 0.05.

Appendix D

Ages of cold appliances in combination from 4M households



Age (years)
0
10
20
30
40
house 1
refrigerator 8
upright freezer 8
fridge-freezer 1
house 2
refrigerator 10
upright freezer 1 5
upright freezer 2 2
house 3
fridge-freezer 1 7
fridge-freezer 2 4
chest freezer 2
house 4
upright freezer 1 12
upright freezer 2 10
refrigerator 7
house 5
refrigerator 10
fridge-freezer 10
upright freezer 5
house 6
refrigerator 1 2
upright freezer 2
refrigerator 2 2
house 7
fridge-freezer 1 6
fridge-freezer 2 6
chest freezer 5
upright freezer 4
house 8
upright freezer 1 10
upright freezer 2 9
refrigerator 1 0.1
refrigerator 2 0.1
house 9
refrigerator 5
upright freezer 1 5
upright freezer 2 4
house 10
refrigerator 2
fridge-freezer 2
upright freezer 0.5
house 11
refrigerator 10
upright freezer 7
fridge-freezer 3
house 12
chest freezer 5
fridge-freezer 1 4
fridge-freezer 2 1
house 13
chest freezer 1 32
refrigerator 10
chest freezer 2 9
house 14
refrigerator 1 8
refrigerator 2 5
upright freezer 5
chest freezer 4
house 15
chest freezer 20
refrigerator 7
fridge-freezer 3
house 16
upright freezer 1 15
refrigerator 3
upright freezer 2 0.1
house 17
upright freezer 7
refrigerator 1 6
refrigerator 2 3
house 18
upright freezer 1 8
refrigerator 1 7
refrigerator 2 7
upright freezer 2 4
house 19
refrigerator 2
upright freezer 2
chest freezer 2
house 20
upright freezer 1 8
refrigerator 7
upright freezer 2 7
house 21
refrigerator 4
upright freezer 1 3
upright freezer 2 1
house 22
fridge-freezer 7
chest freezer 6
refrigerator 5
house 23
refrigerator 1 35
chest freezer 15
refrigerator 2 11
upright freezer 7
house 24
chest freezer 4
fridge-freezer 2.5
refrigerator 2
house 25
upright freezer 6
refrigerator 2
fridge-freezer 2
house 26
refrigerator 3
upright freezer 1 2
upright freezer 2 1
refrigerator
fridge-freezer
upright freezer
chest freezer