www.bre.co.uk

Study of Over-Consuming Household Cold Appliances

Field trial report

Prepared for: Yehuda Lethbridge
Date: 19/01/2017
Report Number: HPR187-1003

Andrew Gemmell, Helen Foster, Busola Siyanbola, (BRE) and Judith Evans (RD&T)

BRE
Watford, Herts
WD25 9XX

Customer Services 0333 321 8811

From outside the UK:
T + 44 (0) 1923 664000
F + 44 (0) 1923 664010
E enquiries@bre.co.uk
www.bre.co.uk

Prepared for:
Yehuda Lethbridge
Department of Business, Energy & Industrial Strategy

Prepared by

Name Andrew Gemmell, Dr Helen Foster, Busola Siyanbola, Judith Evans (RD&T)

Date 19 January 2017

Signature A.J. Gemmell

Authorised by

Name Jack Hulme

Position Principal Consultant

Date 19 January 2017

Signature

Executive Summary

Improving the energy efficiency of Britain's housing stock forms a major part of the Government's energy and climate change policy. An important end use of energy in the housing stock is electricity consumed by household appliances, including fridges and freezers. In 2014, it was estimated that 10.5 TWh of electricity in England was consumed by domestic cold appliances (scaled from DECC 2015, ECUK Data Tables, Table 3.10). This is equivalent to 15.6% of the total electricity consumed by household domestic appliances in England.

Previous research has suggested that around 9% of domestic cold appliances may be over-consuming (i.e. using significantly more electricity than they were designed to). However these findings were based on a relatively small sample. The objectives of the current study were to identify:

- What proportion of cold appliances are over-consuming
- What types of appliances are most likely to over-consume
- Which kinds of households have over-consuming appliances
- The technical and non-technical reasons for over-consumption
- What might make householders more likely to notice and to act on over-consumption

To do this a large scale field trial was conducted in which 998 appliances were monitored in 766 properties across England. Electricity consumption and temperature data was collected over a 7 day period and occupant interviews were conducted to understand how appliances were used and maintained, and to understand their perceptions of over-consumption and how this could be reduced.

Of all the appliances monitored, 8% were found to be over-consuming. The average electricity consumption of an over-consuming cold appliance was 730 kWh/year (+/- 69 kWh/year), which was more than double that of all other cold appliances, where the average was 322 kWh/year (+/- 14 kWh/year). Over-consuming appliances are estimated to contribute almost 20% of household electricity consumption, compared to less than 10% of electricity usage for non-over-consuming appliances.

Replacing over-consuming appliances with appliances that operate 'normally' could represent a saving of approximately 408 kWh per appliance. This equates to £58/year, which is more than 10% of a household's electricity bill. Scaled up to the English housing stock, the removal of over-consuming appliances from the household stock could result in a saving of 1.4 TWh/year, approximately 0.65 mega tonnes of CO_2 and potential savings of over £199 million in electricity costs.

Over-consumption was caused by factors associated with;

1. Occupant operation
2. Appliance age, type, size and location
3. Faults or damage

The primary cause for over-consumption in the majority of cases (53%) was occupant operation. Occupants leaving the fast-freeze setting on all the time was found to be the main cause in almost a third of cases. Appliances being set to their coldest setting was the next most common primary cause. This result indicates that when attempting to address over-consumption in cold appliances efforts should focus on educating the end users and influencing how they use their appliances, as well as improvements in manufacturing to reduce faults with the appliance.

Table of Contents

1 Introduction and background

1.1 Background

Improving the energy efficiency of Britain's housing stock forms a major part of the Government's energy and climate change policy. An important end use of energy in the housing stock is electricity consumed by household appliances including fridges and freezers. In 2014, approximately 15.6% of electricity consumption from household domestic appliances in England was associated with the running of cold appliances, equating to approximately 10.5 TWh[1] (DECC 2015, ECUK Data Tables, Table 3.10).

A recent analysis of the Home Energy Use Study (HEUS) indicated that there may be significant numbers of cold appliances which are over-consuming, which was defined as using high power for more than 90% of the time (Palmer, Terry, Armitage and Godoy-Shimizu, 2014). In this HEUS analysis, DECC wanted to estimate how much additional electricity was being used by over-consuming cold appliances nationally.

The HEUS research suggested there are many possible reasons for over-consumption, including:

- Component faults (compressor, door seal, thermostat)
- Poor choice of control settings (e.g. fast-freeze)
- Householder maintenance (dust on the heat exchanger, appliance not defrosted)
- Householder behaviour (over-filling the appliance, not cooling food before refrigeration/freezing)
- Poor location (insufficient space for heat exchange behind the appliance, or located in a warm room)

DECC wanted to build on the data collected by the HEUS to better understand why cold appliances over-consume, to quantify the potential electricity that is being wasted and to understand what can be done about it. To do this DECC commissioned BRE to undertake a study which included a large scale field trial. This report outlines the findings from the field trial.

In addition to the field trial, the project also included the following pieces of work (published separately);

- A literature review to examine all the relevant research conducted to date
- An expert fridge engineer focus group exploring the most common causes of over-consumption
- An examination of 100 appliances sent for recycling to identify the most common faults and assess the proportion of appliances that would have been suitable for re-use
- Detailed examination of 26 appliances identified as suitable for re-use to understand the consumption rates and performance

[1] A conversion factor of 0.84 was applied to provide an approximate electricity consumption figure for England from the UK figure provided in the ECUK data tables.

The findings from this project form part of a wider body of work which includes research conducted by WRAP on extending the lifetimes of electrical and electronic products including domestic cold appliances. WRAP have commissioned and conducted both customer (Knight et al., 2013) and technical research (WRAP, 2014) examining in detail reasons for faults and how the lifetime of electrical appliance can be extended. Section 3.12.5 in this report that compares and consolidates the findings and recommendations of the WRAP projects with this project.

1.2 Aims and objectives of the field trial

Key aims and objectives of the field trial were to;

Objective 1. To determine which types of households have over-consuming appliances

Objective 2. To determine the technical and non-technical reasons for over-consumption and to make recommendations for manufacturers.

Objective 3. To investigate what might make householders more likely to notice and to act on over-consumption.

To support these key objectives the field trial examined;

- The consumption and temperature profiles of a broad range of 'normal', 'high' and 'over'-consuming appliances
- The effect of different factors on consumption, internal temperatures and over-consumption, including:
    - Occupant behaviour, including how they use and maintain their appliances, shopping habits and what householders do if they notice faults
    - Appliance age, type and location (e.g. built-in, located in the house or garage)
    - Size and make-up of households
- The technical causes of over-consumption, including case-studies
- The total electricity consumption from cold appliances and the cost and carbon implications of over-consumption
- Where householders would go for information if problems developed with the cold appliance(s)?
- Householders perceptions as to the causes of over-consumption and their estimates of the extra annual financial cost
- Level of interest in receiving information to help householders understand if their cold appliance(s) are using more electricity than they should

2 Field trial methodology

2.1 Overview of field trial design

Data was collected over a period of 8 months, from March to November 2015. There were four waves of data collection, each lasting between three and five weeks (Table 1).

Table 1. Periods and season of data collection for each wave

	Data collection period	Season
Wave 1	March	Winter
Wave 2	April – June	Spring
Wave 3	July – August	Summer
Wave 4	October – November	Autumn

Simultaneous measurements of the electricity consumption and the temperature inside and outside of the appliances were made for a period of seven days. In addition, an interview was conducted with the householders to collect information about the cold appliances, to understand how they were used and maintained, and to understand their perceptions of over-consumption and how this could be reduced.

Valid and reliable monitoring data were collected from 998 cold appliances. Consumption data from 665 cold appliances and temperature data for 938 cold appliances were analysed. Interview data were collected from 766 households.

2.2 Sampling frame and recruitment

The sampling frame used was formed from cases originally surveyed as part of the English Housing Survey (EHS). This replicates a well-established and successful procedure used for previous similar surveys, such as the Energy Follow-Up Survey conducted in 2011 (Hulme, Beaumont and Summers, 2014).

In total, 115 surveys were conducted in wave 1, 138 in wave 2, 188 in wave 3 and 219 in wave 4. The sample for wave 1 was drawn from the 2011/12 EHS dataset (households originally surveyed between April 2011 and March 2012). The samples for the other three waves were drawn from the 2013/14 EHS dataset (originally surveyed between April 2013 and March 2014), as these more recent EHS datasets became available for these later survey waves.

For half of the sample, no additional filtering was applied. For the other half, targeting was applied in order to increase the chances of monitoring over-consuming appliances. To achieve this, filters were applied to select households in older dwellings (built pre 2000) with kitchens that were at least 15 years old or greater. Additionally, filters were added to select out the wealthiest families and younger households amongst middle income households (groups that had been identified through the literature review and focus group processes as least likely to have an over-consuming appliance).

Households who had indicated in the EHS interview that they were happy to be contacted for future research were contacted to ask if they would be happy to participate. A mix of methods was used to achieve this, specifically; telephone calls, letters and door knocking. Participants who took part in wave 1 and 2 were given a £5 high-street voucher as an incentive/thank you for taking part. This incentive was doubled for waves 3 and 4 in order to encourage a greater number of households to participate and increase the sample size.

2.3 Sample demographics

In total, data was collected at 766 households across England. Of this sample 660 households agreed for BRE to match the information collected with the data collected through the EHS. This figure does not include cases where the households had changed since the EHS interview survey. Table 2 shows the sample breakdown by tenure. The sample is further broken down by household type, age of household reference person (HRP) and household income in Appendix A.

Table 2. Sample breakdown by tenure

Tenure	Frequency	Percent	Cumulative percent
Owner occupied	370	56.1	56.1
Private rented	53	8.0	64.1
Local authority	107	16.2	80.3
RSL (Housing assoc.)	130	19.7	100.0
Total	660	100.0	

In order to produce household data at a national level, a weighting and grossing exercise was undertaken on all interviewed survey cases to reduce the effect of non-response within the sample which was controlled to national totals for tenure, household type and age of the household reference person.

The average number of occupants per household was 2.43. Table 3 shows the number of occupants in each household across the sample.

Table 3. Total number of occupants in each house

Number of occupants	Frequency	Percent	Cumulative percent
1	216	28.2	28.2
2	266	34.7	62.9
3	122	15.9	78.9
4	101	13.2	92.0
5+	61	8.0	100.0
Total	766	100.0	

bre

2.4 Data collection method

The installation of the monitoring equipment and household interviews were conducted by interviewers from the market research company GfK NOP. On the first visit to each property the interviewers installed the monitoring equipment and conducted the householder interview. One week later they returned to remove the equipment which was then sent back to BRE for analysis.

The appliances were monitored for seven days to ensure the data reflected the performance of the cold appliances as accurately as possible, including what happens when large amounts of food are put in at once. Previous experience of monitoring domestic refrigerators has indicated that there can be a significant effect on internal temperatures and performance as a result of the “weekly shop”, where a fresh load of goods are added once per week to fridges and freezers following a supermarket shop.

Minor adjustments were made to the design, occupant questionnaire and sampling method between waves to ensure the best and most useful data was collected.

2.4.1 Householder interview

The householder interviews were conducted face-to-face and the occupant responses were collected on a tablet PC using a Computer Aided Personal Interviewing (CAPI) system. The results from the CAPI were uploaded daily and stored at GfK NOP.

The interview questions were developed by BRE, with input from GfK NOP, RD&T and DECC. Minor amendments and additions were made between waves to collect any additional information required. The final version of the interview schedule used can be found in Appendix B.

The interview collected data on:

- Number and age of occupants
- Number, type and location of all the cold appliances in the property
- For appliances that were monitored information was collected on
  - How they were acquired
  - The age of the appliance
  - How often the temperature settings were adjusted
  - How often the appliances were opened per day
  - How full the appliances were kept
- Occupant food shopping habits
- How the occupants maintain their appliances
- Their use of manuals and what they would do if a problem developed with an appliance
- The perceived causes of over-consumption and estimate of the financial implications
- Their level of interest in receiving information which would help them to identify over–consumption and preferences for best format for this information

2.4.2 Monitoring equipment used

Watts Up electricity loggers

The electricity consumption data of each cold appliance were collected using a Watts Up PRO data logger. These are a type of "plug-in" logger – i.e. they are plugged into the wall socket, and the cold appliance plugs directly into the logger.

A photograph of the Watts Up logger, attached to a fridge, is shown below in Figure 1. The power lead from the fridge is plugged into the grey extension lead which attaches to the front of the logger. The black lead at the back of the logger is plugged into the wall socket.

The electric power in watts was monitored every 30 seconds for the period the appliance was plugged in.

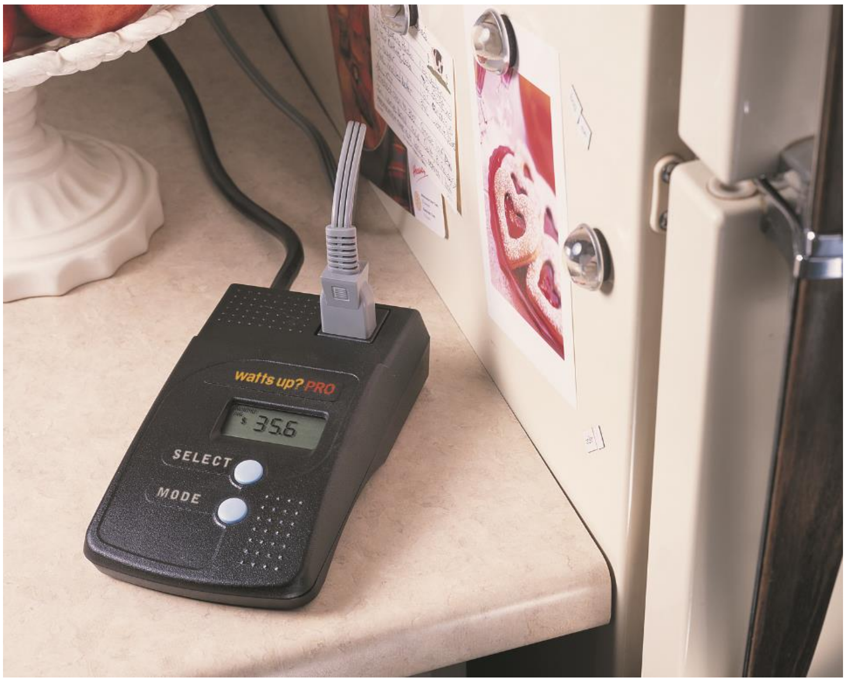


Figure 1. Watts Up PRO energy logger attached to refrigerator.

TinyTag temperature loggers

The temperatures both inside and outside the appliance were monitored using TinyTag Transit data loggers. One was placed on the middle shelf of each appliance in a plastic bag and one was attached to outside of the door. A photograph of one of these loggers is shown below in Figure 2.

Figure 2. TinyTag transit 2 temperature logger.

Types of appliances monitored

The cold appliances monitored in this field trial included;

- Fridges with ice-boxes;
- Fridges without ice-boxes (also referred to as larder fridges);
- Fridge-freezers;
- Upright freezers;
- Chest freezers.

The sample included both free standing and built-in appliances, however only 11% of the sample was made up of built-in appliances. This is because far fewer of the built-in appliances had accessible plug sockets meaning consumption could not be monitored. In waves 1 and 2 of the field trial only appliances with an accessible plug socket were monitored, however, in order to increase the number of built-in appliances in the sample, temperature data was collected from built-in appliances for waves 3 and 4.

A full breakdown of the appliances monitored is provided in the results section.

2.5 Cleaning and analysis of data

Householder interview data

The household interview data was scaled up to represent the national population using weighting factors which were calculated to align with national totals for tenure, household type and age of household reference person. The grossing factor was added to the analysis of all interview questions about the household, occupant perceptions and behaviours. The grossing factor was not applied to the analysis of questions related to a specific appliance that was being monitored as not all appliances were monitored in each house. All the reported results are therefore based on the weighted data for household level questions and based on sample data for questions specifically about appliances that were monitored.

Physical monitoring data

The data collected by the Watts Up and TinyTag loggers for every appliance monitored were examined in detail and, where necessary, the data was cleaned to ensure that only valid and reliable data were included in the analysis. Any data which did not accurately reflect the performance of the appliance was removed (for example if the appliance was turned off or loggers removed from the appliance) prior to analysis. The data cleaning was always applied to give the longest possible period of continuous data within the profile. Note, for the purposes of the analysis conducted in this report, only appliances for which there was at least 24 hours of continuous valid and reliable data were included in the sample.

Cleaning of the consumption data recorded by the Watts Up loggers was required in some cases due to; loggers being unplugged and plugged back in, appliances being switched off and on by the occupant and occasional faulty periods of monitoring. Faults in monitoring were evident in the data as periods where the consumption profiles recorded extreme values or zeros for portions of the data, and was observed due to the calibration data in the meter becoming corrupt due to cycling on an off at high loads.

Cleaning of the temperature profiles was also necessary where the appliances had been turned off or the loggers had been removed from the appliances. There was also evidence that the TinyTag loggers were moved around to different parts of the appliance (e.g. different shelves in a fridge). However, where this was found the data was not cleaned as the data did still reflect the temperature within the appliance.

Analysis and reporting of data

The final appliance dataset contains 998 cases – of which there was data on the electricity consumption of the appliance in 665 cases and data on appliance temperatures in 938 cases. For a description of the variables assessed, the distribution of the data and the analysis conducted see Appendix C.

2.6 Matching of cold appliances to the product database

Wherever possible the cold appliance consumption recorded in the field was compared with the manufacturers' reported consumption figures. This information is held for a large number of appliances on GfK NOP's unique database of design consumption figures as part of the GfK Etilize data catalogue of product information. Precise comparisons were made for a sub sample of 94 appliances. For most of the appliances it was not possible to match to the Etilize dataset as the exact model number could not be obtained in the field.

One limitation of this method of comparison is that the standard conditions under which electricity consumption is calculated by the manufacturers are quite different to the typical use conditions measured in the field. For example, the performance of all new cold appliances is measured in a temperature controlled room set to either 25 or 32°C. The test is run for 24 hours during which the door of the appliance is not opened and the appliance has to go through a defrost cycle. Following the test, weightings and other factors are added before a final figure is reached (for more information on the standard methods used for the testing of new appliances see ADEME, 2000, and CSN EN 62552, 2013). In contrast, the electricity consumption of the appliances monitored in the field was measured over seven days in 'real life' conditions. The appliances were all monitored in-situ in various heated and unheated spaces at the properties, and the occupants were asked to use the appliances as normal.

2.7 Defining 'normal', 'high' and 'over'-consumption

Palmer et al (2014) identified malfunctioning and over-consuming cold appliances using a simple heuristic to define 'normal' and 'over'-consuming appliances. They stated that 'normally' an appliance draws significant power for no more than half the time. If it is drawing a high power for 90% of the time it is considered to be 'over'-consuming.

To enable the comparison of the findings from this field trial with the work of Palmer et al (2014) the same basic definition was used for all subsequent analysis in this report. However, for the purposes of this study one fixed threshold was used at 20W to identify when the compressor was running. In addition to Palmer et al's definition of 'normal' and 'over'-consumption, a third category has been added in this report which identifies 'high' consuming appliances.

'Normal' consumption was defined as a compressor running for < 50% of the time, 'high' consumption was defined as running for ≥ 50% and <90% of the time, and 'over'-consumption was defined as running for ≥ 90% of the time. The monitored electricity consumption of cold appliances was compared with the compressor run-time, and the classification based on this run-time.

2.8 Follow up investigation of cold appliances

Identifying cases for further inspection

At the end of each wave of measurements, the data from the appliances were assessed and a selection of cases were identified as suitable for further follow-up inspection. A total of 90 appliances were inspected. Of these, a mixture of 'normal', 'high' and 'over'-consuming were inspected, with typical 'normal' consumption and temperature profiles to act as controls.

Three methods were used to identify a range of different cases which were 'high' or 'over'-consuming. The first was to examine the consumption data. Cases were selected if the consumption data showed;

- High run times (i.e. the compressors were running for a significantly high proportion of time)
- Long periods of high consumption
- A regular high baseload (usually above 10W)

The second was to compare the measured consumption figures with those reported by the manufacturers using GfK's Etilise dataset (described above). The final method looked at the relationships between the recorded temperature and electricity data. The analysis focused on appliances which were found to have relatively high internal temperatures and high electricity consumption, and ones which have relatively high consumption despite low external temperatures. Both of these scenarios indicate the appliance has to work harder than it should to achieve the internal temperatures recorded.

Re-visiting and diagnosing the causes of over-consuming appliances:

Details of suspected over-consuming appliances were passed to experts at RD&T for their assessment of the data. The experts at RD&T interrogated the data sent by BRE and assessed if the appliance required further investigation. They then attempted to make contact with the occupants and arrange times to examine the appliance.

Several challenges were encountered in re-contacting and revisiting households. The main ones being,

- Over a quarter of the sample (26%) said they would not be happy for an engineer to visit
- Of those who agreed to an engineer visit and were found to have over-consuming appliances, many could not be re-contacted via telephone to arrange a revisit (initial contact with these households had often only been made by door knocking, which was not feasible to repeat for this engineers visit)
- Some of the households identified as having over-consuming appliances had changed the appliance by the time they were contacted for a second visit by an engineer. This was likely due to the performance of the original appliance dropping further, or faults causing the appliance to stop working altogether. However, it is possible that in some cases this may have been prompted by the first visit (i.e. the monitoring drew the householder's attention to the poor performance)
- A few households who had originally agreed to an engineer visit declined appointments when re-contacted

Method for assessing selected appliances

Prior to visiting the households RD&T developed a procedure to assess the appliances. Information collected as part of a previous inspection of 100 recycled appliances was incorporated into the assessment. This piece of work was completed earlier in the project, separate to the field trial. The procedure was tested in a laboratory environment initially and then in a small number of households. The data collection template can be found in Appendix D. The first part of the template collated data from the initial visit and the second part listed information collected during the second visit by RD&T to assess the appliance.

3 Results

3.1 Cold appliance information

On average each household had 1.47 cold appliances with a standard deviation of 0.720 and a range of between zero and six (two households were reported to have no cold appliances). Table 4 shows the proportion of the population who have at least one appliance (broken down by each type of appliance). The fridge-freezer was found to be the most common cold appliance in people's homes, with 70% of households owning at least one fridge-freezer. Standalone fridges with an ice-box were the least common appliance with just 7.3% of households having one or more.

Table 4. Percentage of households who have at least one appliance (by type)

Appliance type	Number of households (000s)	Percent
Fridge with ice-box	1,659	7.3
Fridge without ice-box (larder fridge)	5,353	23.8
Fridge-freezer	15,760	70.0
Upright freezer	5,907	26.2
Chest freezer	1,511	13.4

*Households can have more than one type of appliance so there is no cumulative percentage

Significant differences in the average number of cold appliances per household when spit by tenure, household type, total number of occupants and household income are shown in Appendix E.

3.2 Sample of monitored cold appliances

Valid data was collected from a total of 998 cold appliances. Consumption data from 665 cold appliances and temperature data for 938 cold appliances was analysed. Table 5 below shows the breakdown of the appliances monitored by type.

Table 5. Breakdown of appliances monitored

Appliance type	Frequency	Percent	Cumulative percent
Fridge with ice-box	57	5.7	5.7
Fridge without ice-box	145	14.5	20.2
Fridge-freezer	524	52.4	72.7
Upright freezer	186	18.6	91.4
Chest freezer	86	8.6	100.0
Total	998	100.0	

The vast majority of the cold appliances (75%) were in the kitchen/kitchen-diner. The utility room (7%) and garage (6%) were the next most popular places. In total, 89% of the appliances monitored were free standing and just 11% were built-in. The sample of appliances that were monitored was biased towards free standing appliances, as to measure the electricity consumption required access to the plug socket. This was not possible on the majority of built-in appliances.

The majority of appliances were bought new (78%), however, 7.6% were purchased second-hand, 7.2% were received from family or friends and 6.4% came with the property. Figure 3 shows where the occupants got their appliances from split by tenure. As can be seen in the figure the vast majority of owner occupiers (87%) purchase their cold appliances new, compared with just 54% of those privately renting. In contrast 27% of appliances in private rented accommodation came with the property (compared to just 2-4% for the other groups). Almost a third (31%) of local authority tenants had second hand appliances (either bought second-hand or received from friends and family), which is a much higher proportion than the owner occupiers (9%), RSL tenants (15%) or private renters (18%).

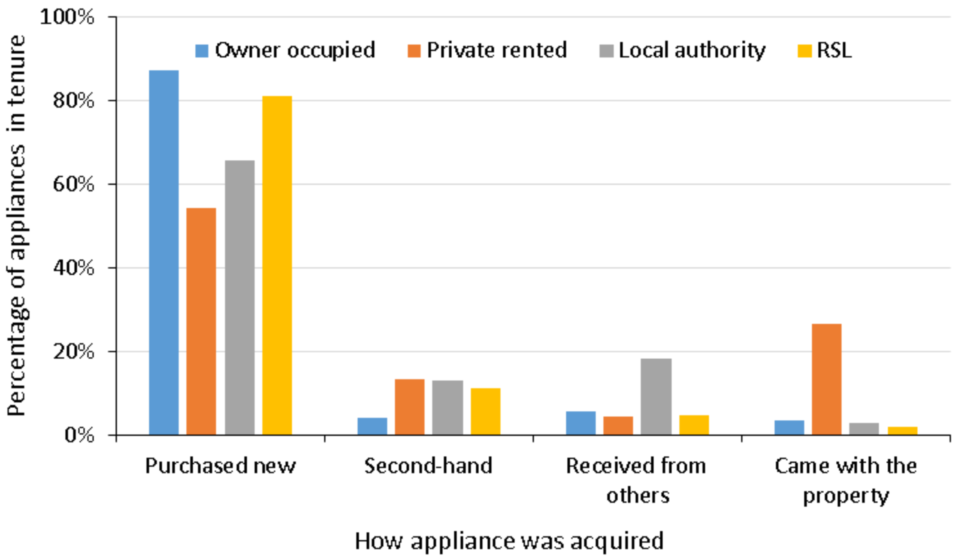


Figure 3. Acquisition of cold appliances by tenure

Of those which had an energy label (287 appliances) 89% were 'A' rated or above, 7% were B rated and just 4% were C or lower.

Householders were asked the age of each of the appliances being monitored, their responses are shown below in Figure 4 . Often, if the householders were not able to remember the exact year they estimated the age to the nearest 5 years, hence the spikes at 5, 10, 15, 20 and 25 years. The age of the appliances was banded as follows for further analysis (less than 2 years, 2-4 years, 5-7 years, 8-11, 11 plus years).

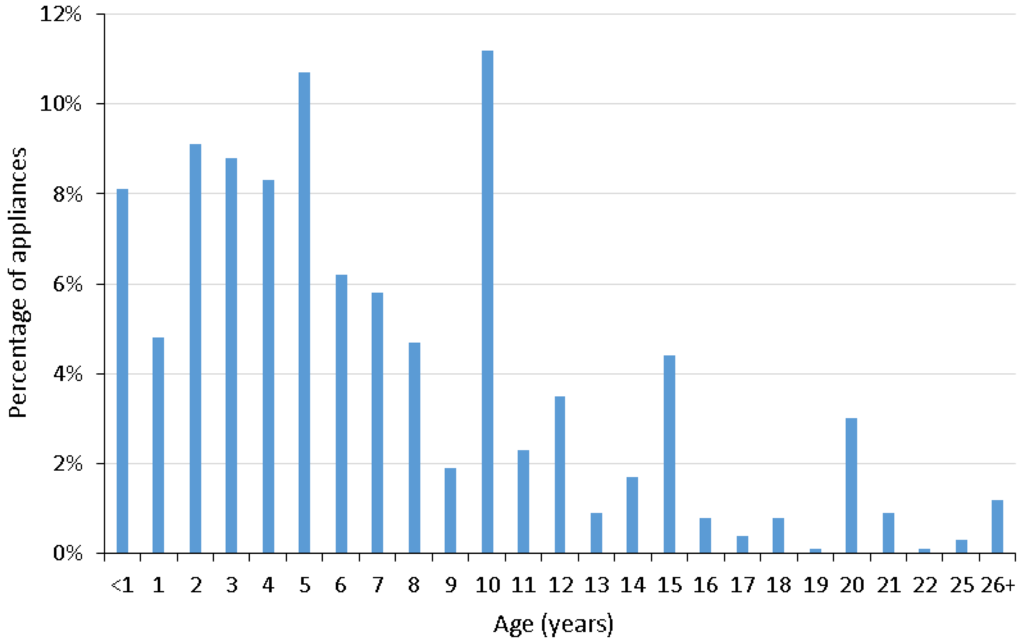


Figure 4. Reported ages of the appliances monitored

3.3 Use and maintenance of cold appliances

Householders were asked about how often they open their appliance, how frequently the temperature is adjusted and how full the appliance is kept. These three questions were asked for each of the monitored appliances in a household, as well as the individual compartments (fridge and freezer) in the case of a fridge-freezer.

With regards to how full appliances are kept, Figure 5 shows 40% of appliances were kept completely full, 35% were kept three quarters full, 19% were kept half full while only 6% were kept a quarter or less full.

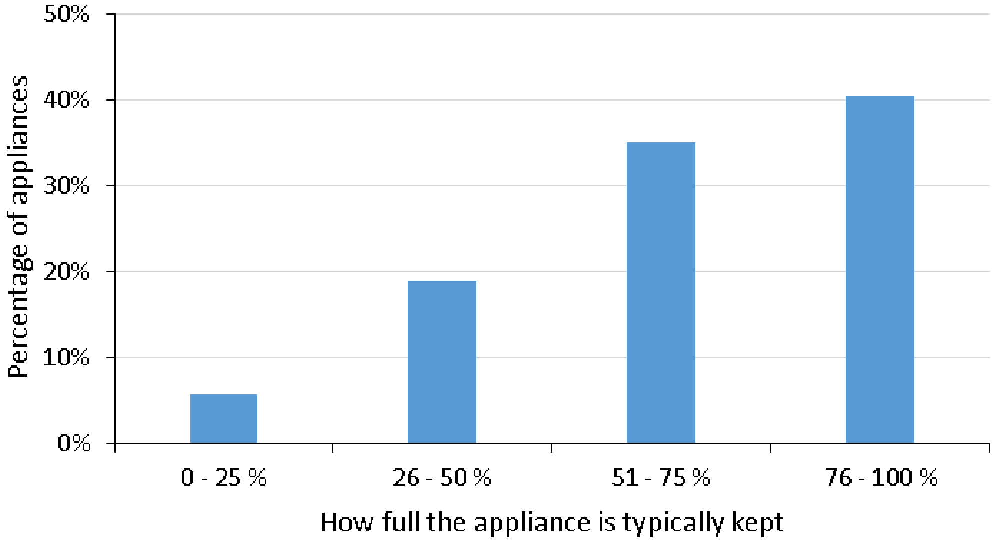


Figure 5. Proportion of the appliance that is typically filled

Aside from when householders defrost their appliances and carry out any maintenance, the temperature setting was never adjusted for 68% of appliances. On 24% of appliances, the temperature setting was adjusted occasionally and on 6% of appliances it was adjusted every 6 months. Only 1% of appliances reported having their temperature setting adjusted weekly or monthly.

Figure 6 shows most appliances (41%) were opened 1-4 times a day while 11% of appliances were opened less than once a day. The majority of these can be attributed to freezers or the freezer section of fridge-freezers. About 48% of appliances were opened more than 5 times a day; these are generally fridges or the fridge section of fridge-freezers.

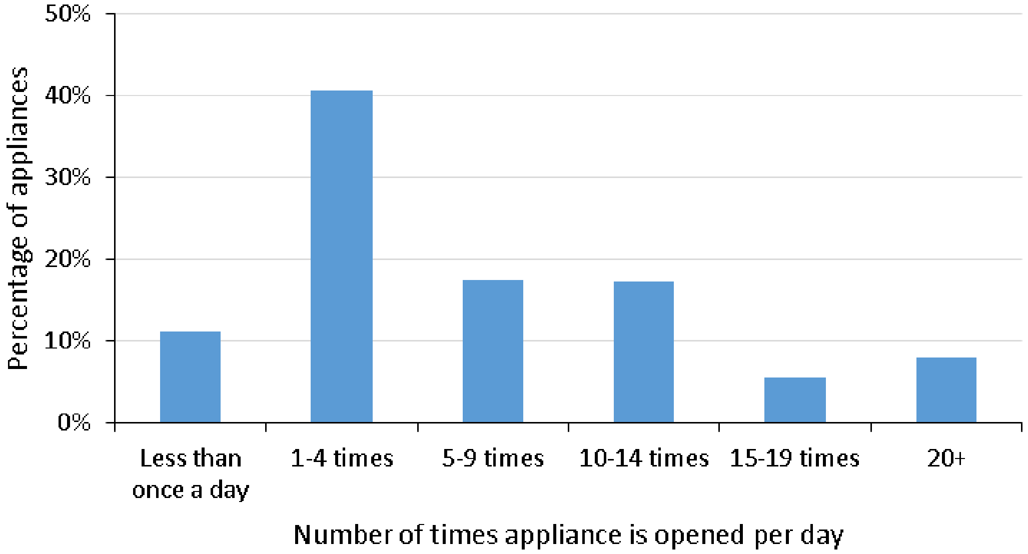


Figure 6. Number of times a day the appliance is opened.

Householders were asked how frequently they put warm/hot food in their cold appliances. The majority of householders (90%) said they 'never' did, 8% said they did occasionally and just 2% said they did often or always. No significant differences were found based on the household income, number of occupants or age of householders. Those with dependent children were found to be more likely to put warm food in their cold appliance than other households, however, this difference was not found to be statistically significant.

Figure 7 shows the frequency with which households clean and maintain their cold appliances. A large proportion (42%) of households said they regularly cleaned the door seals on their appliances, compared with 14% who regularly unblock their drains and 7% who remove dust from the back of the appliance. Over half the households (56%) said they occasionally or regularly defrosted their appliances, however, almost a third (32%) said they never did.

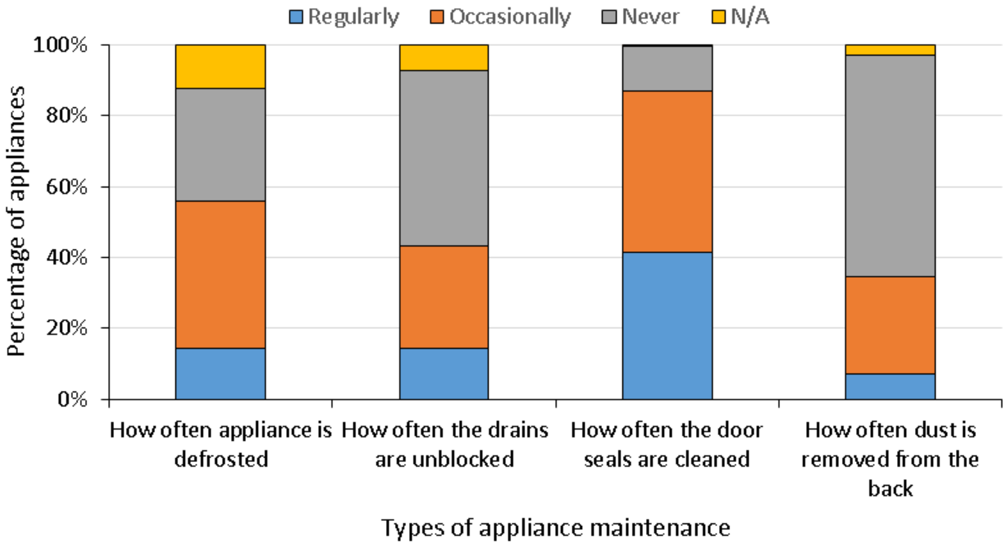


Figure 7. Frequency of maintenance and cleaning

3.4 Cold appliance temperature data

The mean temperature of the room containing the appliance, based on 900 appliances, was 18.5°C (+/- 0.22°C). Recommended appliance temperatures are less than 5°C for fridges and no warmer than -18°C for freezers (WRAP, 2009). In this study the mean internal fridge temperature was slightly warmer than the recommended fridge temperature, at 5.3°C (+/- 0.2°C) based on 671 fridges, as seen in Figure 8. The mean internal freezer temperature was -20.3°C (+/- 0.33°C), based on 745 freezers, and therefore colder than the recommended freezer temperature. Warmer fridge temperatures may be caused by high temperature set points on the appliance, and indeed of the 59 fridges monitored in the household re-visits to diagnose reasons of over-consumption, more than 50% had a low set point (less than or equal to 50% of the available settings on the appliance).This may explain why 54% of monitored fridges had a temperature greater than 5°C (as typical fridge temperatures can range between 0 to 8°C), however only 26% of freezers had a temperature warmer than -18°C (Figure 8).

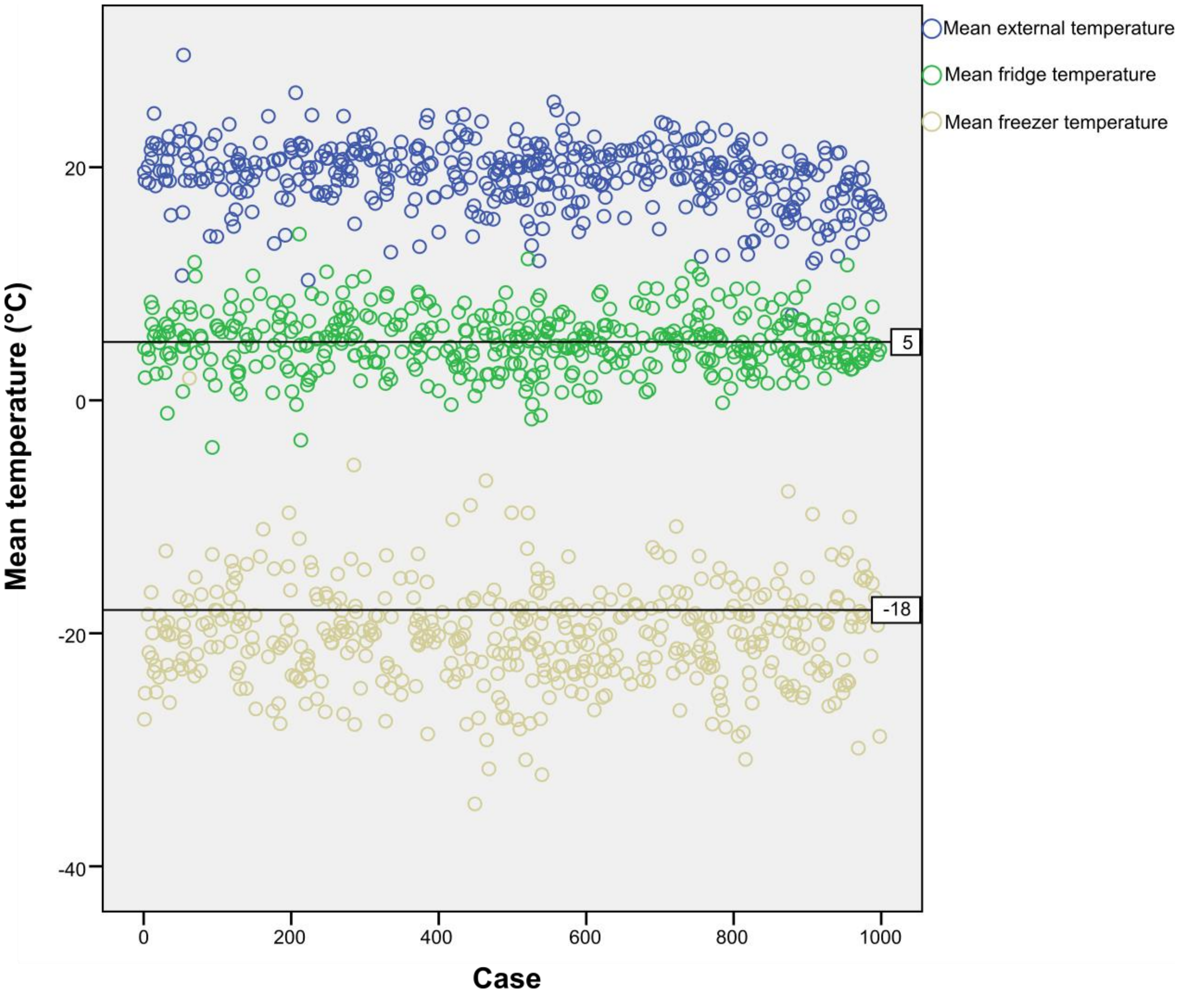


Figure 8. Mean temperatures (°C) of the appliance and the room in which it is placed, with reference lines showing recommended fridge and freezer limits

3.4.1 Room temperature

Unsurprisingly, the room temperature was found to be significantly different according to the wave of the study (Kruskal-Wallis, X^2 = 157.99, DF=3, N=900, p<0.001), with the lowest temperatures observed in wave 1 (mean = 16.1°C +/- 0.6°C), higher temperatures in wave 2 (18.5°C +/- 0.42°C) and wave 4 (18.5°C +/- 0.36°C), and the highest temperatures in wave 3 (20.4°C +/- 0.28°C), as shown in Figure 9. These differences are due to the waves being carried out at different times of the year (see Table 1). The wave was therefore used as a factor (in place of the room temperature), in further analysis of internal appliance temperature and electricity consumption, and is indicated throughout the report by the season in which the wave took place.

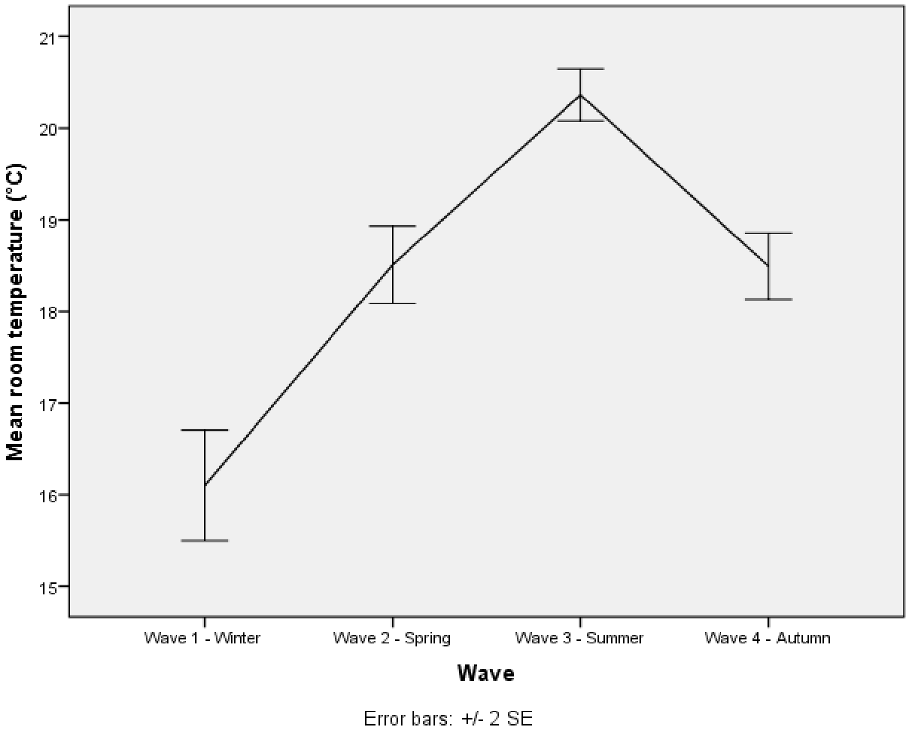


Figure 9. Mean room temperature by data collection wave

3.4.2 Fridge temperature

Few significant factors were found to affect internal fridge temperatures, however the appliance type was found to have a significant effect on the fridge temperature (Kruskal-Wallis, X^2=13.88, DF=2, N=671, p=0.001). Figure 10 illustrates that cooler temperatures were observed in the fridge sections in fridge-freezers (mean 5.0°C +/- 0.22°C), compared with fridges without an ice-box (mean 5.8°C +/- 0.41°C).

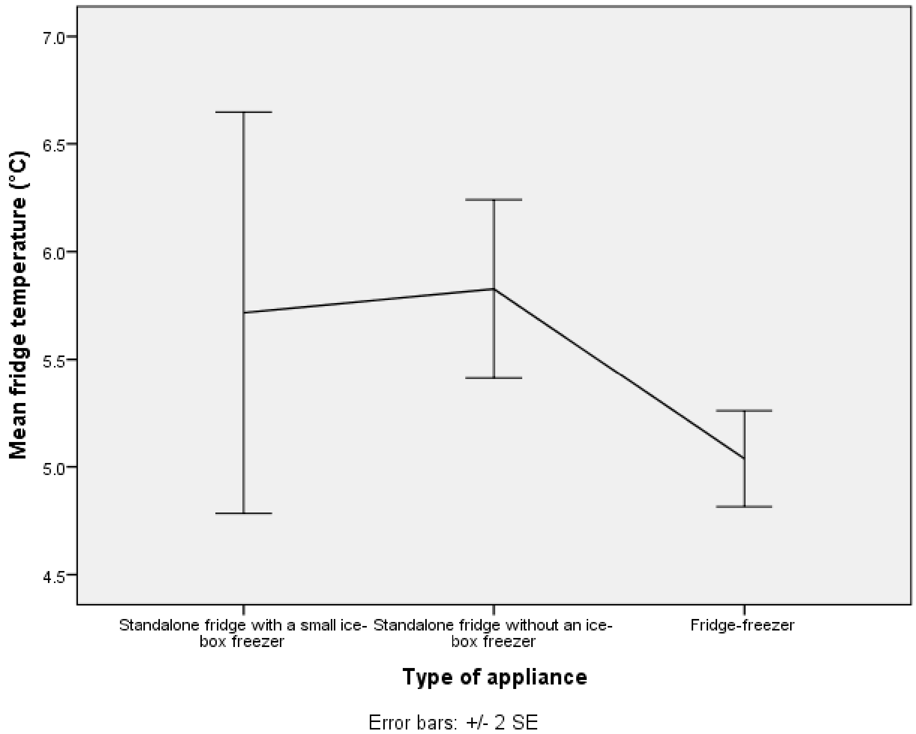


Figure 10. Mean fridge temperature by appliance type

3.4.3 Freezer temperature

The freezer temperature, like the fridge temperature, was found to be dependent on the appliance type. In addition the season (using the wave as a proxy for room temperature), was also found to be significant (ANOVA, R^2=0.053, appliance type (DF=3, p<0.001, 59% of model), season (DF=3, p=0.001, 41%). The main differences in the data were observed between the ice-box freezer, and all other types of freezer (Figure 11). As well as this, the mean temperature in winter (-19.3°C +/- 0.70°C) was significantly higher than mean temperatures in summer or autumn (-21.1°C +/- 0.66°C and -20.5°C +/- 0.53°C), yet still colder than the recommended temperature of -18°C and it should be noted that colder temperatures were observed in the waves with warmer room temperatures (Figure 12).

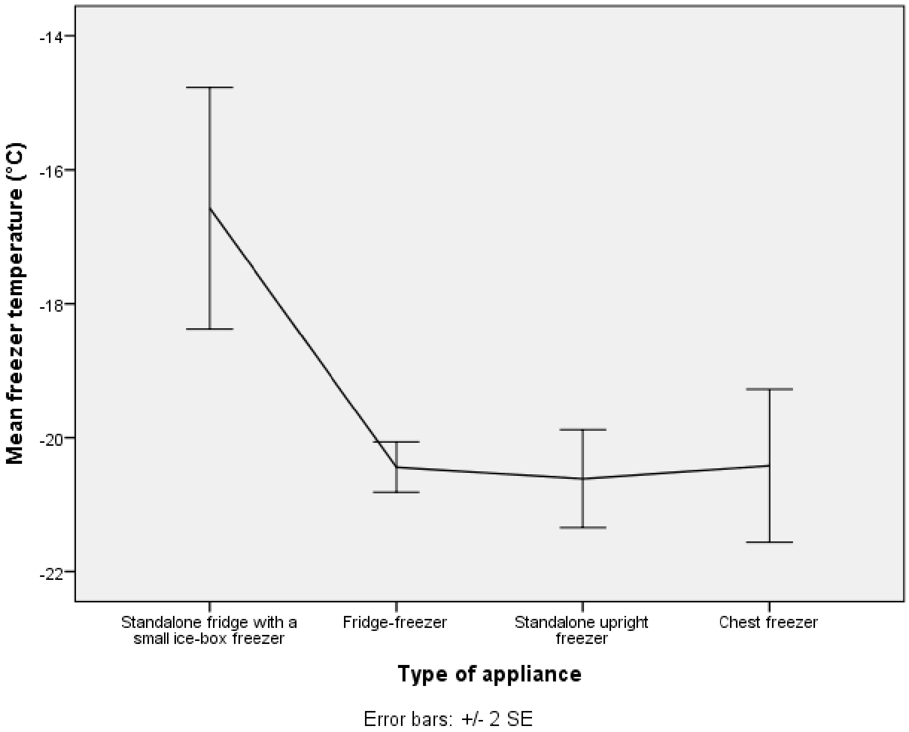


Figure 11. Mean freezer temperature by appliance type

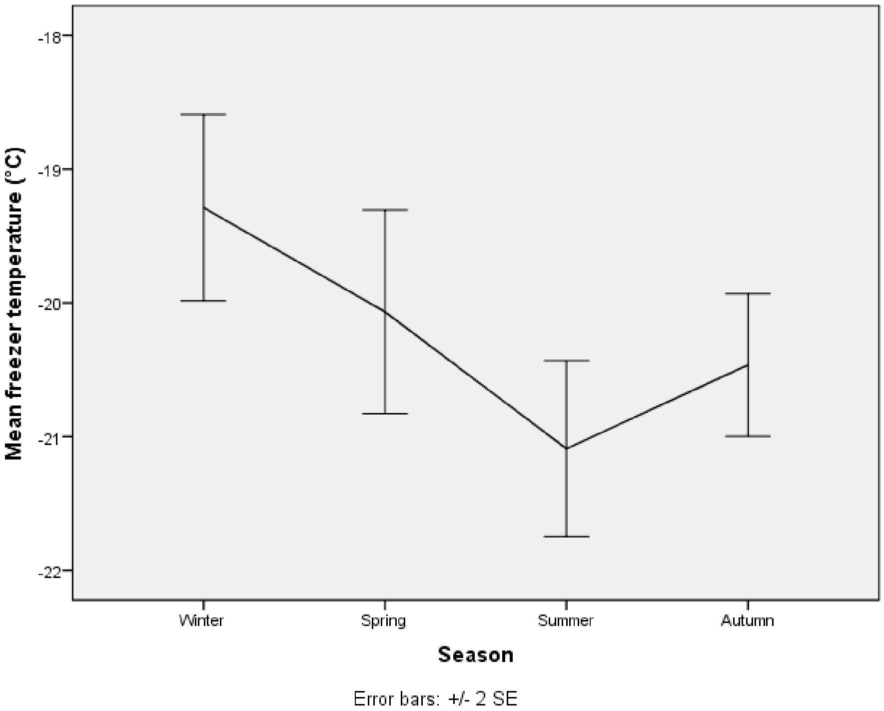


Figure 12. Mean freezer temperature by data collection wave (season)

3.4.4 Freezer temperature within fridge-freezers

Finally, for fridge-freezers, how full the appliance is kept (according to the occupant) was significant in affecting the internal temperature of the freezer compartment (Kruskal-Wallis, X^2=8.59, DF=3, N=463, p=0.035), with freezer compartments kept 76-100% full (mean = -20.1°C +/- 0.48°C) found to be operating at higher temperatures than those only 26-75% full (mean 26-50% = -20.9°C +/- 0.85°C, mean 51-75% = -21.1°C +/- 0.75°C). The greater variation (Figure 13) when least full is likely due to the freezers operating more efficiently when loaded with products, however, when full to capacity, air circulation may be restricted, therefore affecting the temperature observed within the appliance.

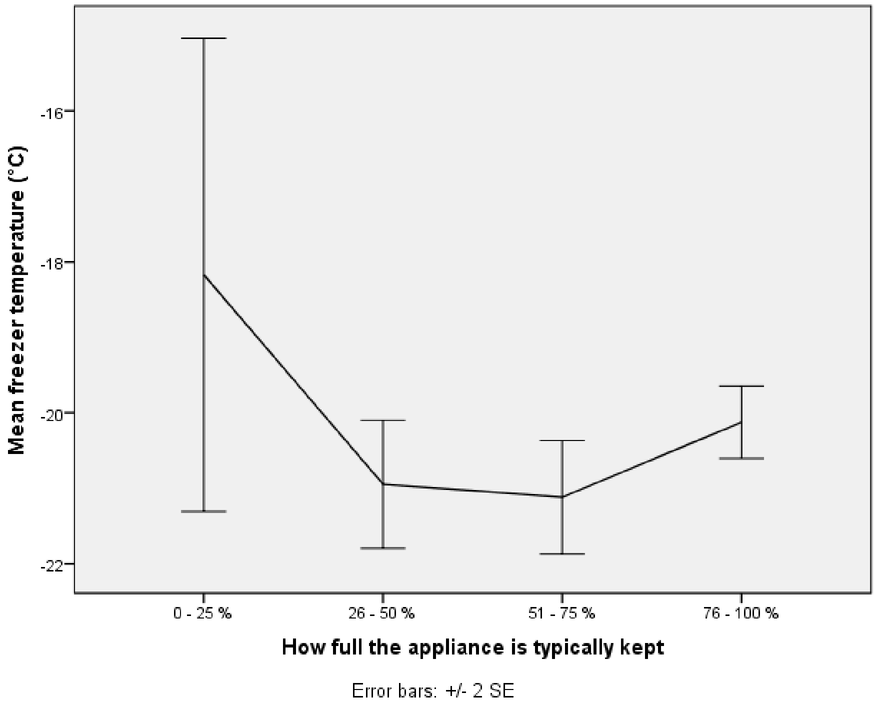


Figure 13. Mean freezer temperature by how full the appliance is kept

The significance of behavioural factors, when observing a single appliance type, suggests that further work analysing appliances of different types could yield interesting results related to behaviour and maintenance habits. Analysis of different appliance types is restricted in this study due to relatively small sample sizes.

3.5 Electricity consumption

Electricity consumption data was collected from 665 appliances. The annual consumption for a cold appliance was estimated to be, on average, 354 +/- 16.4 kWh/year, based on the entire monitored period. The average consumption was found to vary significantly according to the type of appliance (Table 6).

Table 6. Mean electricity consumption (kWh/year) of different cold appliances

Appliance type	Electricity consumption (kWh/year)

Fridge with ice-box	274 +/- 54
Larder fridge	201 +/- 36
Upright freezer	342 +/- 43
Fridge-freezer	390 +/- 20
Chest freezer	420 +/- 67

Figure 14 illustrates the greater electricity consumption from freezer appliances, with the lowest consumption from fridges without an ice-box (see Table 6), higher consumption from fridges with an ice-box, and the highest consumption from fridge-freezers, chest freezers and upright freezers. The greatest difference was observed between a standalone fridge without an ice-box freezer and a fridge-freezer.

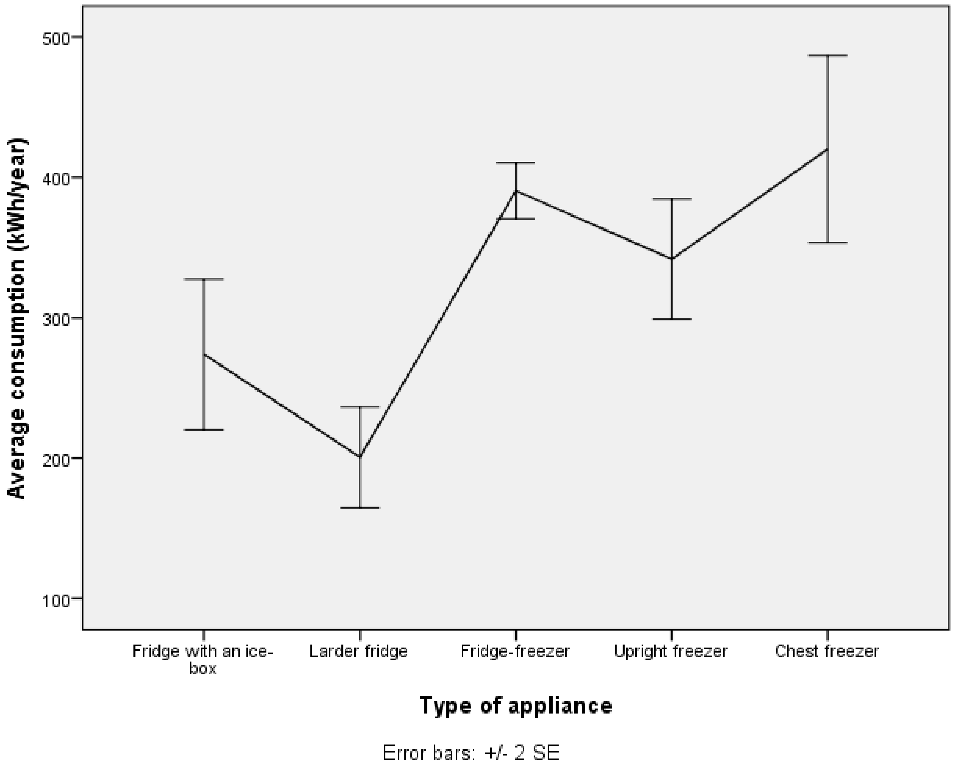


Figure 14. Mean annual electricity consumption by appliance type

In addition to the appliance type, the age and season, as well as how often warm food is added, were all found to be significant factors in determining the electricity consumption of monitored cold appliances, together explaining 30% of the variance within the data (ANOVA, R^2=0.30, N=611, appliance type (DF=4, p<0.001, 62% of model), age (DF=4, p<0.001, 26% of model), season (DF=3, p<0.001, 8% of model), how often warm food is added (DF=2, p=0.011, 4% of model)).

Figure 15 illustrates the increase in electricity consumption for appliances as the age of the appliance increases over 11 years. There is a clear difference observed in the electricity consumption between all appliances over 11 years (mean = 460 +/- 49 kWh/year, and any younger than 11 years (mean of all = 328 +/- 17 kWh/year). In research from WRAP (Knight et al, 2013), customers expected fridges to last on average 9 years, however 50% were found to not last as long as this.

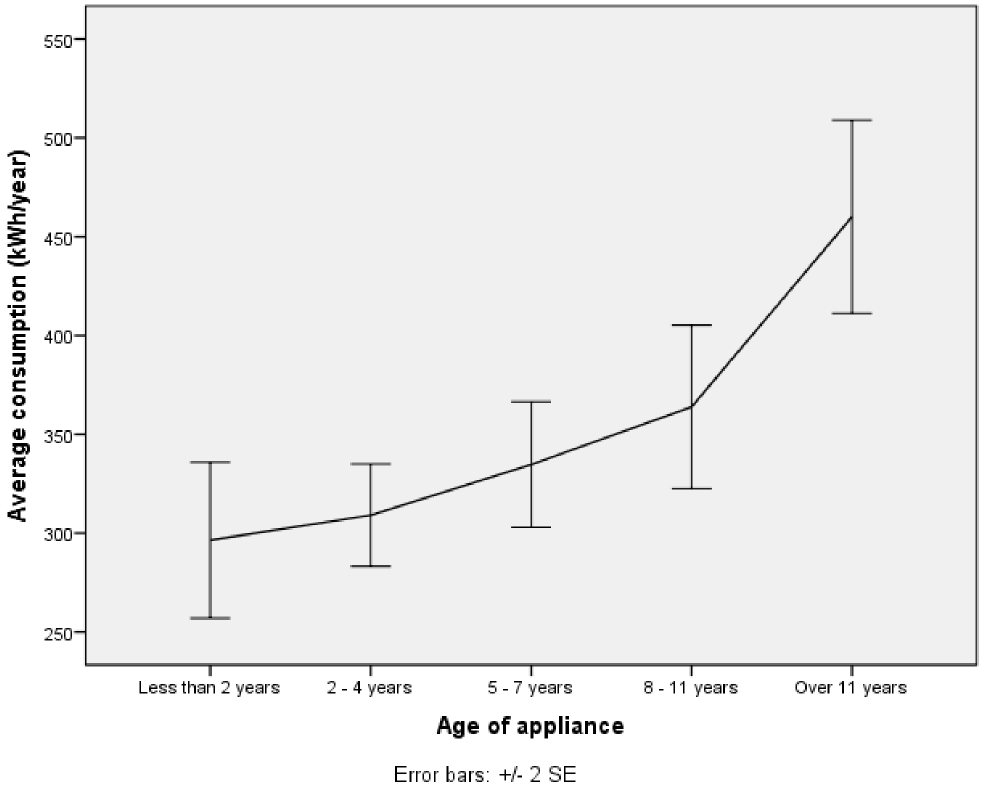


Figure 15. Mean annual electricity consumption by appliance age

Figure 16 illustrates that the electricity consumption in the winter, spring and autumn (mean = 338 +/- 18 kWh/year) was significantly less than the electricity consumption in the summer (mean = 403 +/- 34 kWh/year). Warmer temperatures at the end of the summer months may explain the increased consumption in this time period, with higher levels of electricity consumption matching colder freezer temperatures (Figure 12).

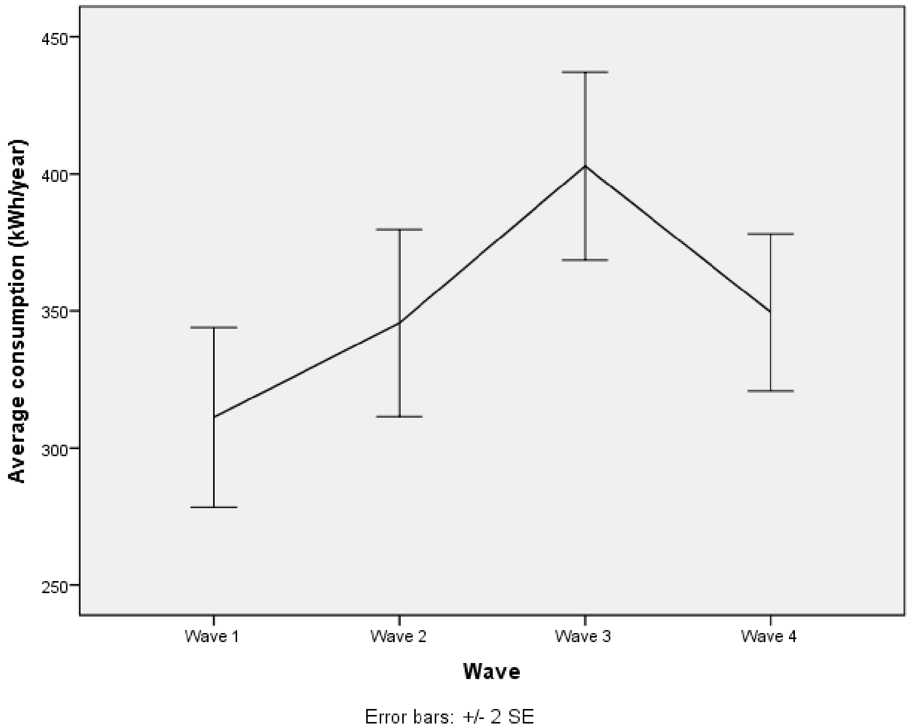


Figure 16. Mean annual electricity consumption by data collection wave (season)

An increase in average annual electricity consumption was observed when warm food is ‘often’ added to the cold appliance (mean = 494 +/- 147 kWh/year), compared to ‘never’ being added (mean = 351 +/- 17 kWh/year), yet 91% reported never adding warm food resulting in small sample sizes for those who report ‘occasionally’ or ‘often’ and therefore larger errors in the estimate of the mean average consumption.

An alternative way of explaining the observed differences in electricity consumption, is by including the maintenance of the appliance by unblocking the drains (ANOVA, R^2=0.28, N=575, appliance type (DF=4, p<0.001, 64% of model), age (DF=4, p<0.001, 29%), how often warm food is added (DF=2, p=0.027, 4%), how often clean drains (DF=2, p=0.011, 3%)).

Figure 17 shows the average annual consumption decreased, when moving from ‘never unblocking drains’ (mean = 379 +/- 26 kWh/year) to ‘regularly unblocking drains’ (mean = 318 +/- 35 kWh/year), indicating that this factor could be important in reducing electricity consumption, and may be more effective than regularly defrosting the appliance, cleaning the door seals, and removing dust from the back, in reducing electricity consumption.

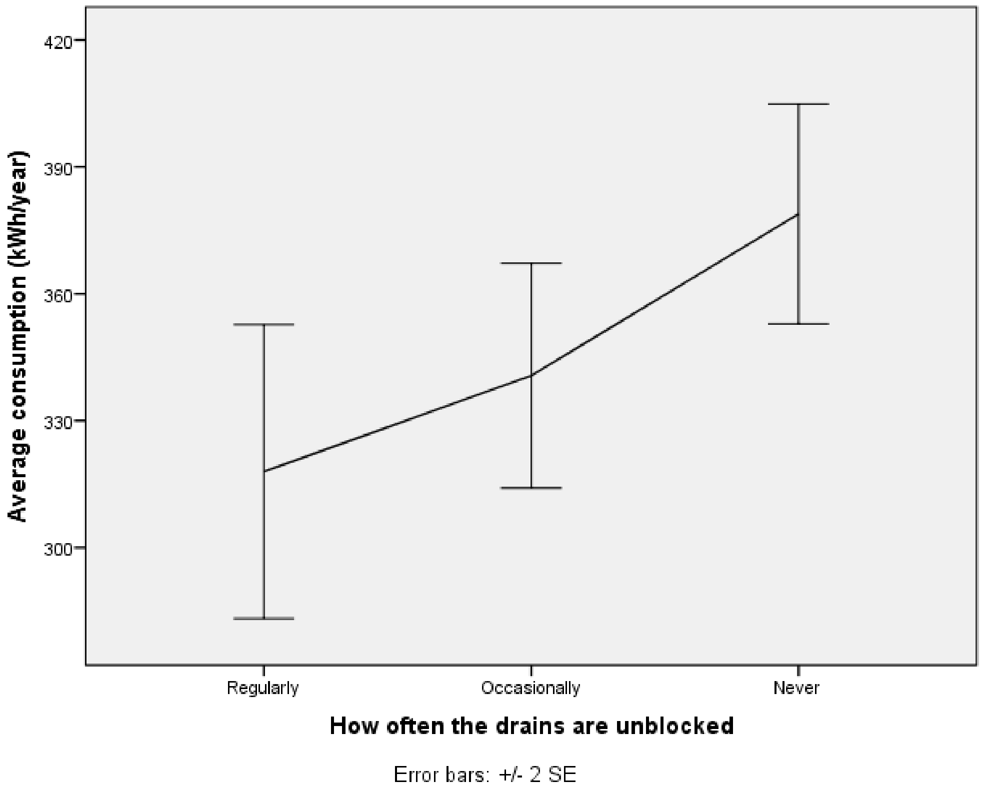


Figure 17. Mean annual electricity consumption by how often the drains are unblocked

Overall, appliance type has the largest effect on electricity consumption (>60%), followed by the appliance age (>25%). Lesser effects on electricity consumption includes; the wave, unblocking the drains, and adding warm food. These smaller effects are likely to become more significant when analysed for separate appliances, which is the dominant factor in determining how consumption varies within the sample.

3.6 Electricity consumption and internal temperature

The temperature within the appliance (mean fridge and freezer temperature) was found to correlate negatively with the annual electricity consumption, for all appliances. This means that when the consumption increases, the temperature in the appliance is decreasing (the appliance is working harder to achieve the lower temperatures). However, when investigating those with ‘high/over’-consuming classifications, the electricity consumption was found to *increase* as the temperature within the appliance also increased. This indicates that for ‘high’ and ‘over’-consuming appliances, a greater proportion are likely to be faulty, and despite working very hard, the appliance was not able to be cooled sufficiently. Table 7 shows the Pearson correlation (R) for ‘normal’ and ‘high/over’-consuming appliances, with corresponding correlation figures provided in Appendix F for those that are significant.

Table 7. Mean annual electricity consumption by mean internal fridge and freezer temperature, for ‘normal’ and ‘high/over’-consuming appliances

Cases	Mean fridge temperature	Mean freezer temperature

	N	P-value	Correlation (R)	N	P-value	Correlation (R)
All appliances	436	<0.001	-0.177	496	<0.001	-0.181
Normal appliances	304	0.018	-0.135	321	0.034	-0.118
High/over-consuming appliances	132	0.051	(Not sig at 0.05 level)	175	0.017	0.181

3.7 Classification of over-consuming cold appliances

Cold appliances were classified as ‘normal’, ‘high’ and ‘over’-consuming based on the run-time of the compressor. When power consumption was greater than 20W for more than 90% of the time, appliances were classified as ‘over’-consuming. When power consumption was greater than 20W for more than 50% of the time (but less than 90%), appliances were classified as ‘high’ consuming, otherwise appliances were classified as ‘normal’. The proportion of ‘normal’, ‘high’ and ‘over’-consuming appliances, is illustrated in Table 8 and Figure 18.

Table 8. Proportion of appliances classified as ‘normal’, ‘high’ and ‘over’-consuming

Classification	Run-time > 20W	Frequency	Percentage
Normal	>0%	455	68%
High	>50%	157	24%
Over-consuming	>90%	53	8%

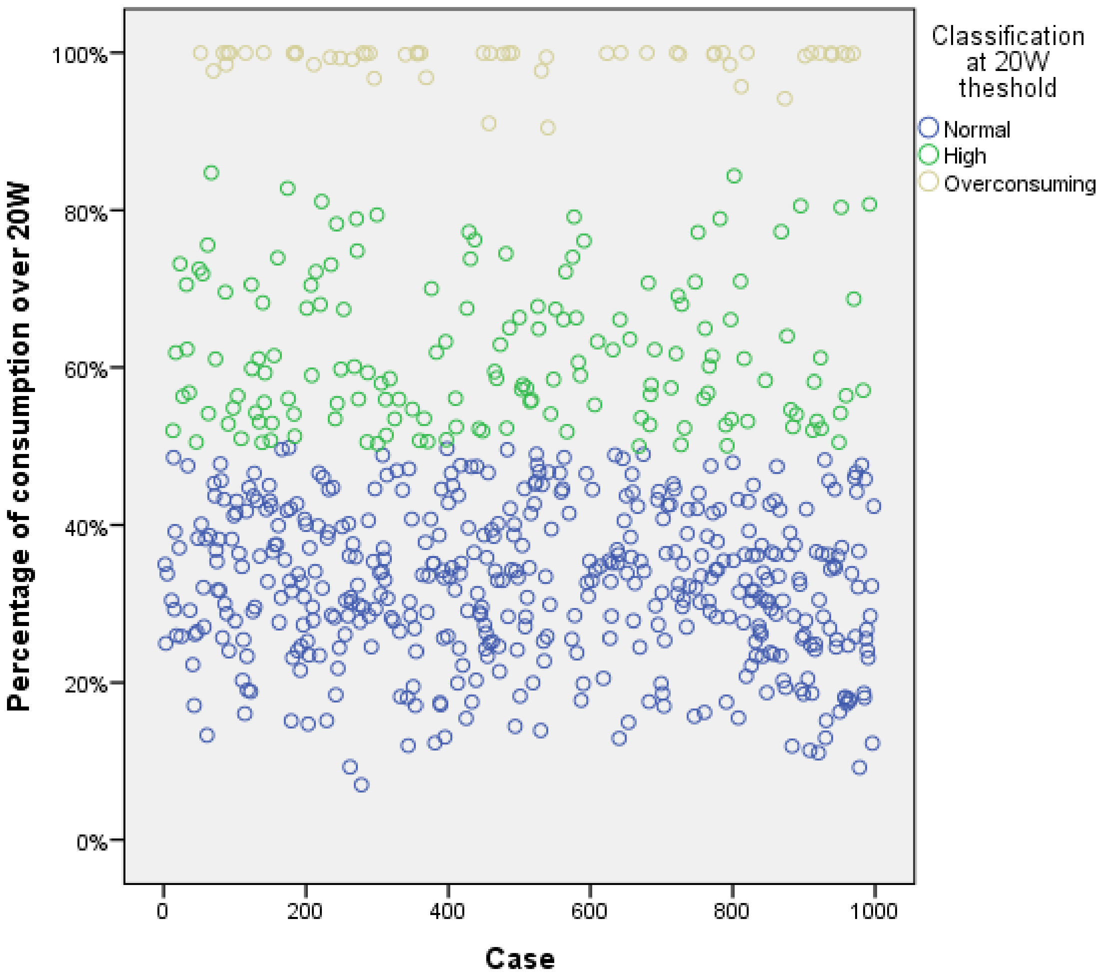


Figure 18. Run-time for ‘normal’, ‘high’ and ‘over’-consuming appliances

A positive correlation was observed between the consumption and the run-time of the appliance (R = 0.803, p<0.001). Greater variation in the average consumption was observed when the run-time increased, for example when the run-time was less than 20%, the average consumption varied from 6 - 23 W, whereas when the run-time was greater than 95%, the average consumption varied from 39 - 182 W (Figure 19).

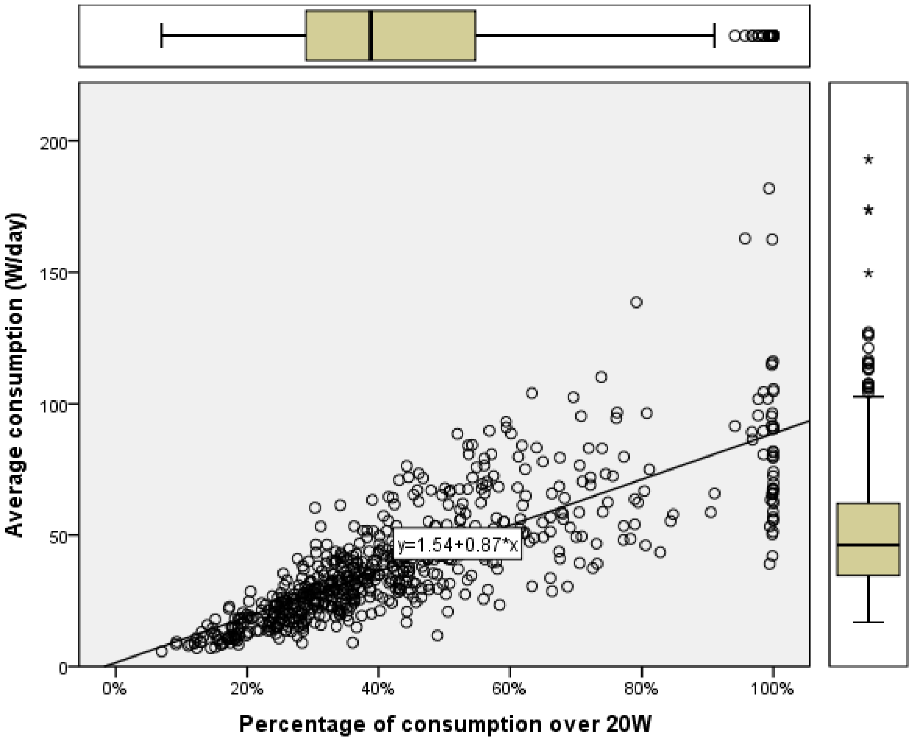


Figure 19. Mean consumption by run-time

A negative correlation was observed between the internal fridge/freezer temperature and the run-time (stronger than the correlation of internal appliance temperatures and electricity consumption). Greater correlation was observed for the freezer temperatures (fridge temperature = - 0.245, $p<0.001$, freezer temperature = -0.356, $p<0.001$).

3.7.1 'Normal', 'high' and 'over'-consuming cold appliances

In line with results from the correlation between consumption and run-time, the classification of whether 'normal', 'high' or 'over'-consuming was found to be have a large effect on the average electricity consumption (Kruskal-Wallis, X^2=324, DF=2, N=665, $p<0.001$), as shown in Table 9 and Figure 20. For those classified as 'normal' or 'high', the mean electricity consumption was 322 +/- 14 kWh/year.

Table 9. Mean electricity consumption (kWh/year) of 'normal', 'high' and 'over'-consuming appliances

Appliance classification	Electricity consumption (kWh/year)
Normal	256 +/- 11
High	512 +/- 27
Over-consuming	730 +/- 69

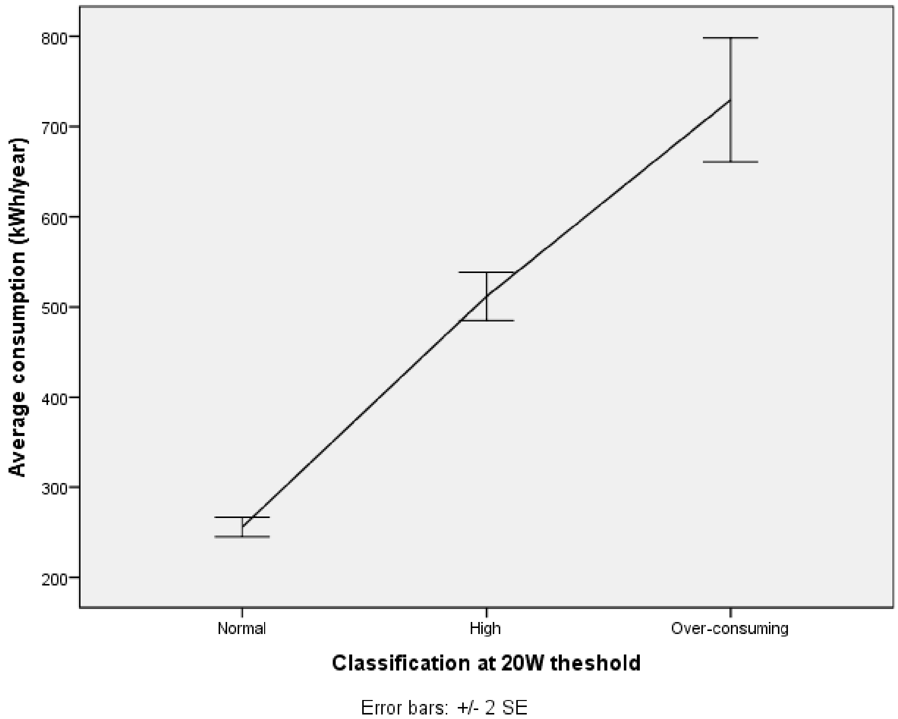


Figure 20. Mean annual electricity consumption by classification of run-time

The fridge internal temperatures differed significantly between classification groups (Kruskal-Wallis, X^2=41.26, DF=2, N=436, p<0.001). The fridge temperatures were significantly higher for 'normal' consuming appliances (mean = 5.4°C +/- 0.25°C), compared with 'high' consuming appliances (mean = 3.7°C +/- 0.45°C), that may be related to the lower consumption in these groups. Similarly, the freezer internal temperatures also differed significantly between classification groups (Kruskal-Wallis, X^2=65.19, DF=2, N=496, p<0.001). The freezer temperatures were significantly higher for 'normal' consuming appliances (mean = -19.3°C +/- 0.42°C), compared with 'high' consuming appliances (mean = -22.1°C +/- 0.75°C) or 'over'-consuming appliances (mean = -23.4°C +/- 2.16°C).

The larger error around the mean of over-consuming appliances suggests that, as well as cold temperatures caused by high compressor rates, there are also appliances with faults that consume a lot of electricity, but are not able to maintain a cold temperature within the appliance. This is discussed in more detail in Section 3.11 which uses case studies to explain some of the causes of over-consumption and Figure 23 highlights the large proportion of over-consuming appliances with cold (<-25°C) freezer temperatures.

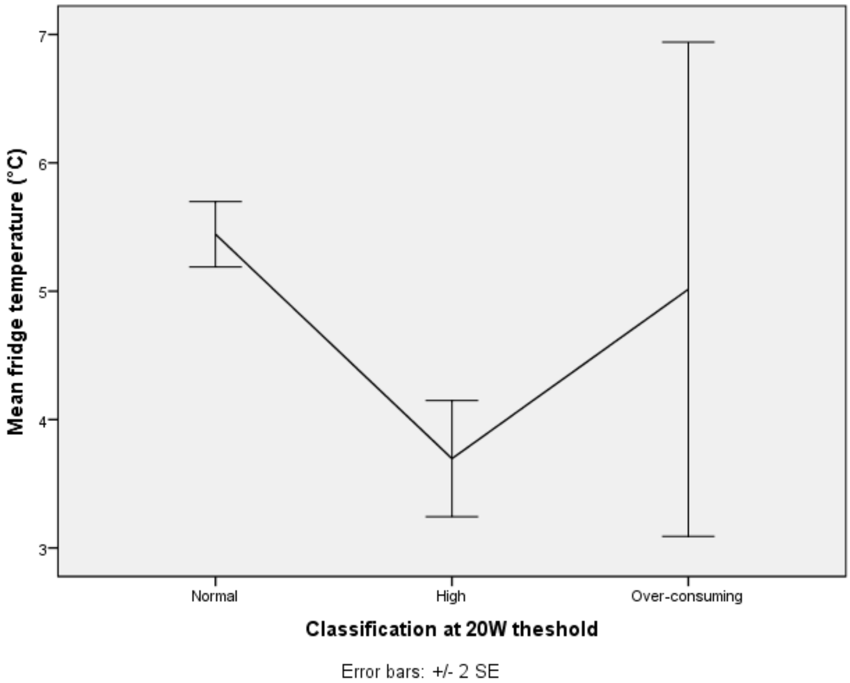


Figure 21. Mean fridge temperature by classification of run-time

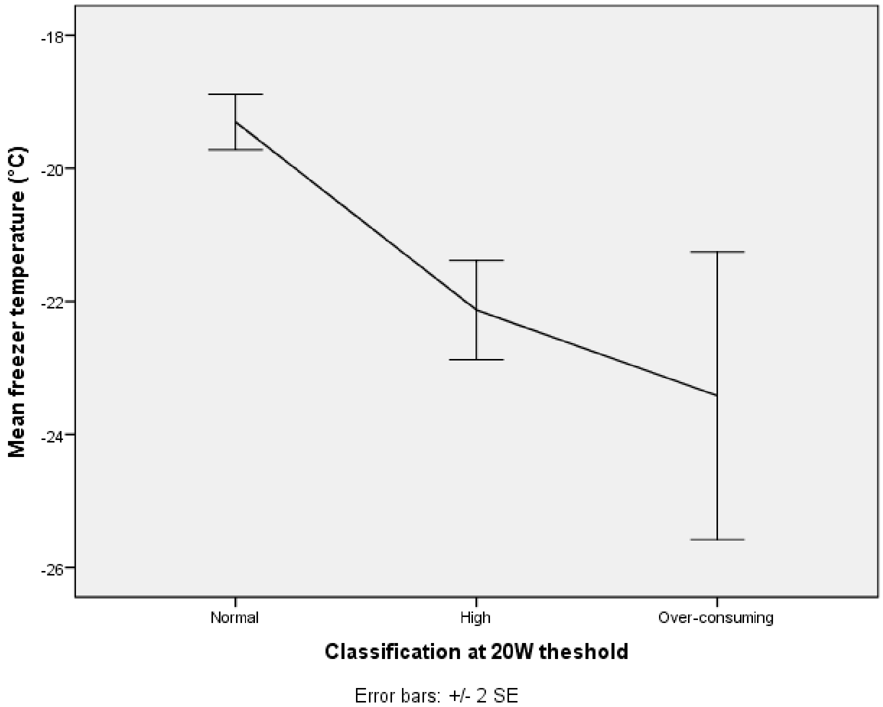


Figure 22. Mean freezer temperature by classification of run-time

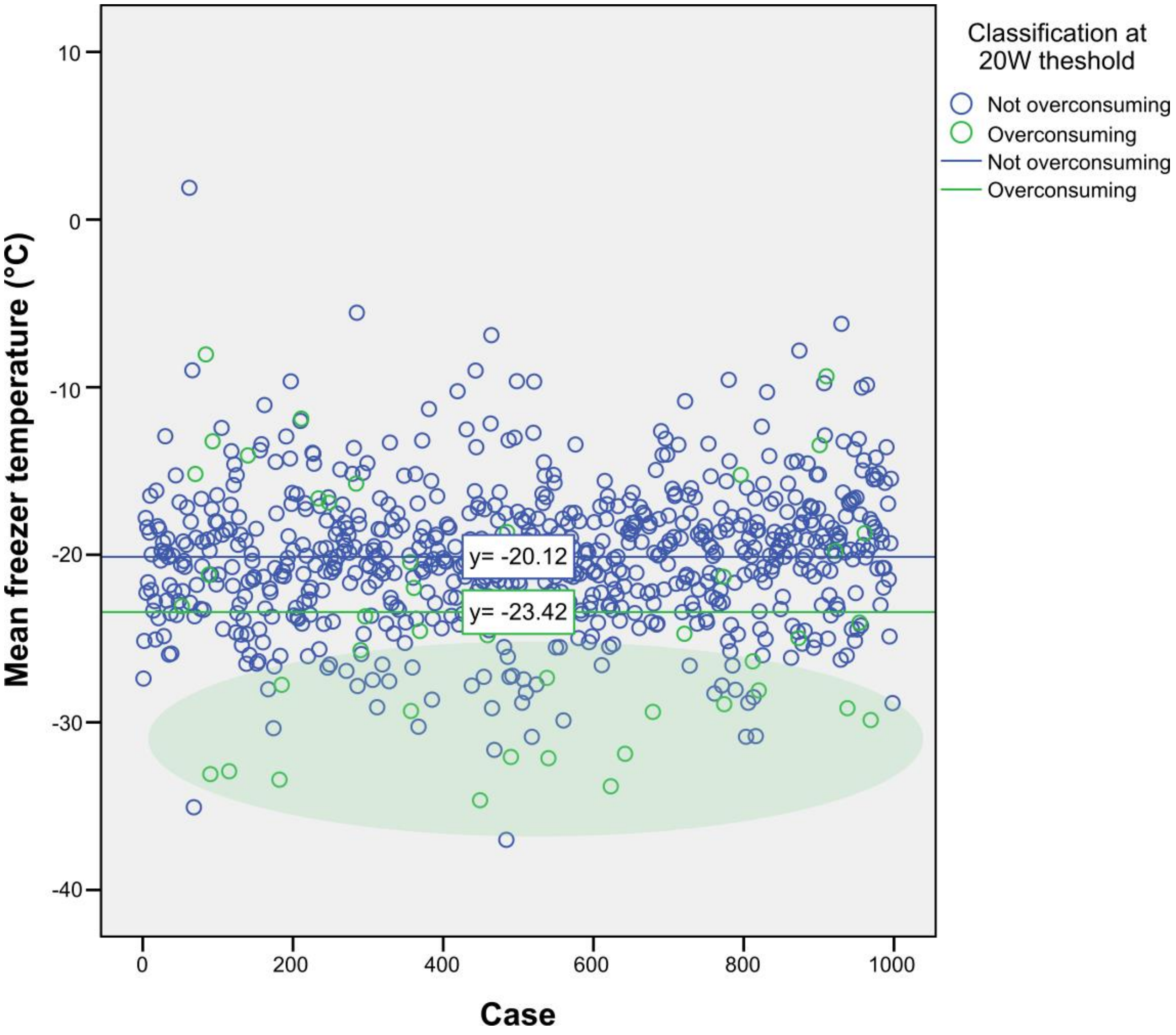


Figure 23. Mean freezer temperature for over-consuming (green) and non-over-consuming (blue) appliances. It can be seen that large numbers of the over-consuming freezers have very low internal temperatures (highlighted in dark ellipse).

3.8 Proportion of 'high' and 'over'-consuming cold appliances

The proportion of 'normal', 'high' and 'over'-consuming appliances was calculated for each factor using chi-squared tests. The results are displayed for significant factors only.

3.8.1 Appliance type

The proportion of appliances classified as 'normal', 'high' and 'over'-consuming, was found to significantly vary according to the type of appliance (Chi-squared, X^2=64.74, DF=8, N=665, p<0.001, medium effect), see Figure 24. The largest proportion of 'normal' consuming appliances were found to be fridges with or without ice-box freezers, with >86% in this group. There was a significantly higher proportion of 'high' consuming fridge-freezer appliances, potentially due to larger appliance sizes in this group (in particular American style side-by-side fridge-freezers). Freezers were the appliances most likely to 'over'-consume: 12% of upright freezers and 25% of chest freezers in the sample were considered to be 'over'-consuming. In addition the smallest proportion of 'normal' appliances were found to be chest freezers, at less than half of the sampled group size (44%).

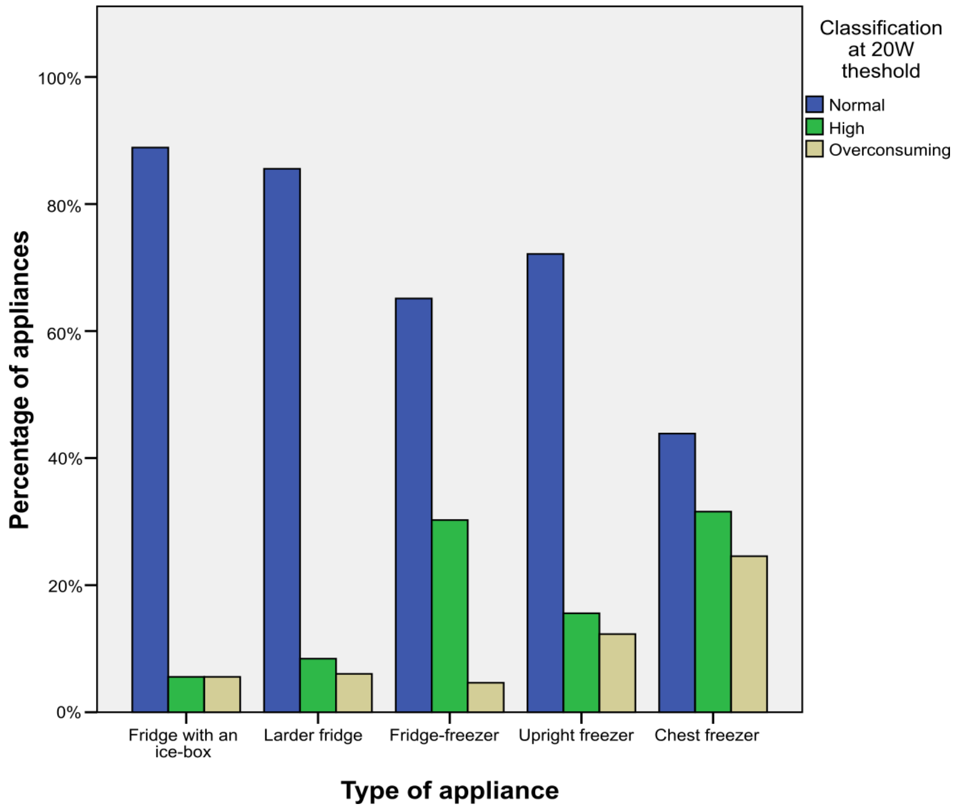


Figure 24. Appliance type by classification of run-time

3.8.2 Appliance age

The appliance age was only found to significantly affect the classification of the cold appliance, when appliances reached an age greater than 11 (Chi-squared, X^2=22.7, DF=8, N=611, p=0.004, small-medium effect). Figure 25 illustrates the increase in proportion of 'over'-consuming appliances in the oldest age group (17%), compared with newer appliances (4-8%).

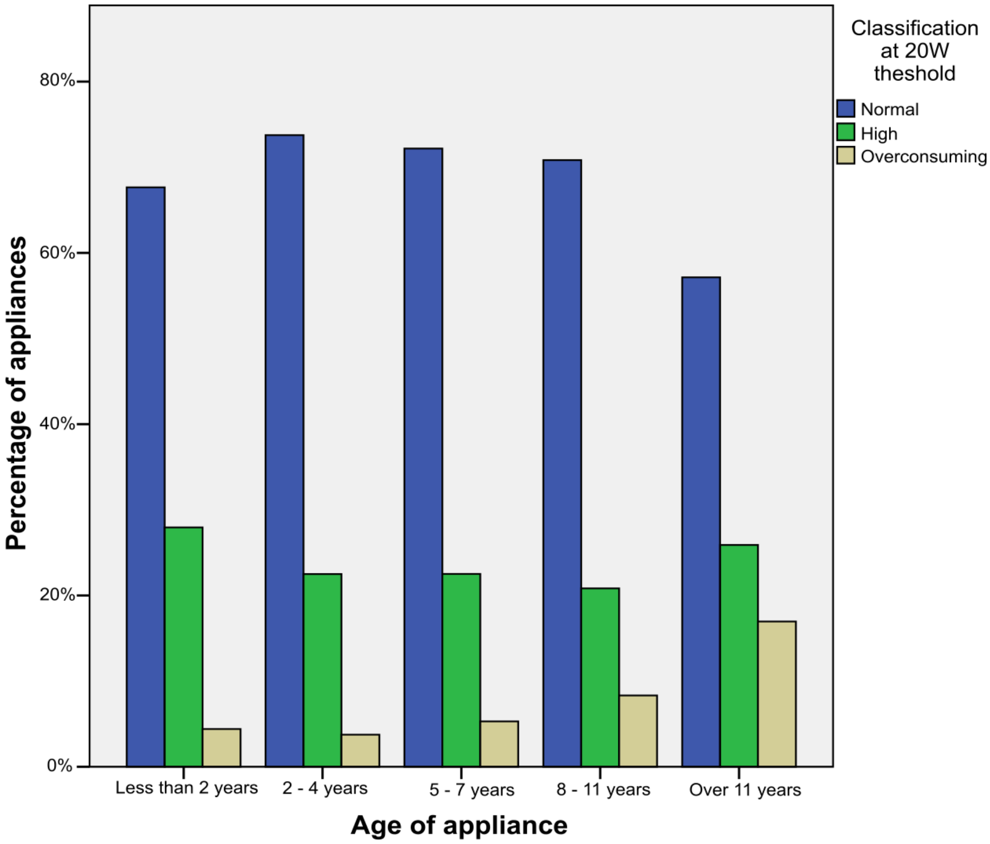


Figure 25. Appliance age by classification of run-time

3.8.3 Season (room temperature)

The season was a significant factor on the classification of the monitored appliance (Chi-squared, X^2=19.42, DF=6, N=665, p=0.004, small-medium effect), with the largest proportion of 'high' consuming appliances (35%) found in the summer data collection wave (when the room temperature was the highest), see Figure 26. However, no differences were observed in the proportion of 'over'-consuming appliances during this period (7-8% in all waves), suggesting that while consumption is affected by the ambient temperature, 'over'-consumption is not.

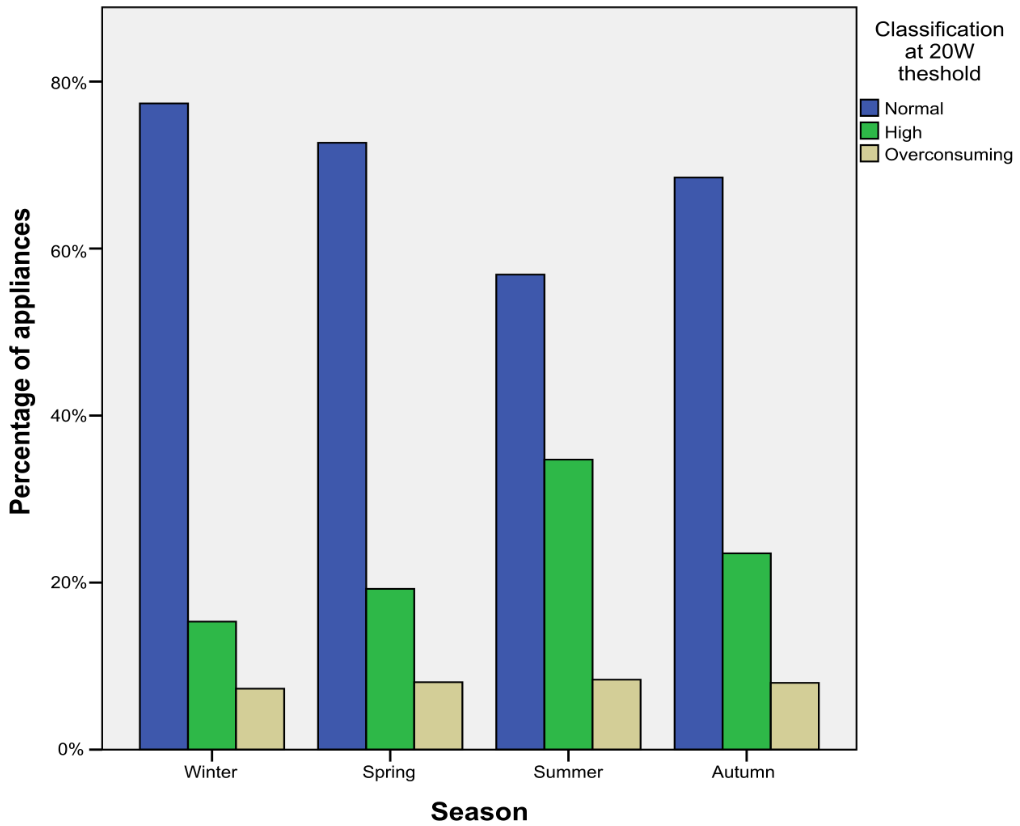


Figure 26. Data collection wave (season) by classification of run-time

3.8.4 Household income

The income of a household (basic income of the HRP and partner) was found to be a significant factor in determining whether an appliance is 'normal, 'high' or 'over'-consuming (Chi-squared, X^2=18.02, DF=8, N=587, p=0.021, small-medium effect). This effect was driven primarily by the lowest income quintile, with 15% of this group containing an 'over'-consuming appliance, compared to <10% of others (Figure 27). In addition a larger proportion of 'high' consuming appliances were found in quintile 4, suggesting that as household income increases, occupants own more energy intensive appliances (which could be attributed to larger or older appliances).

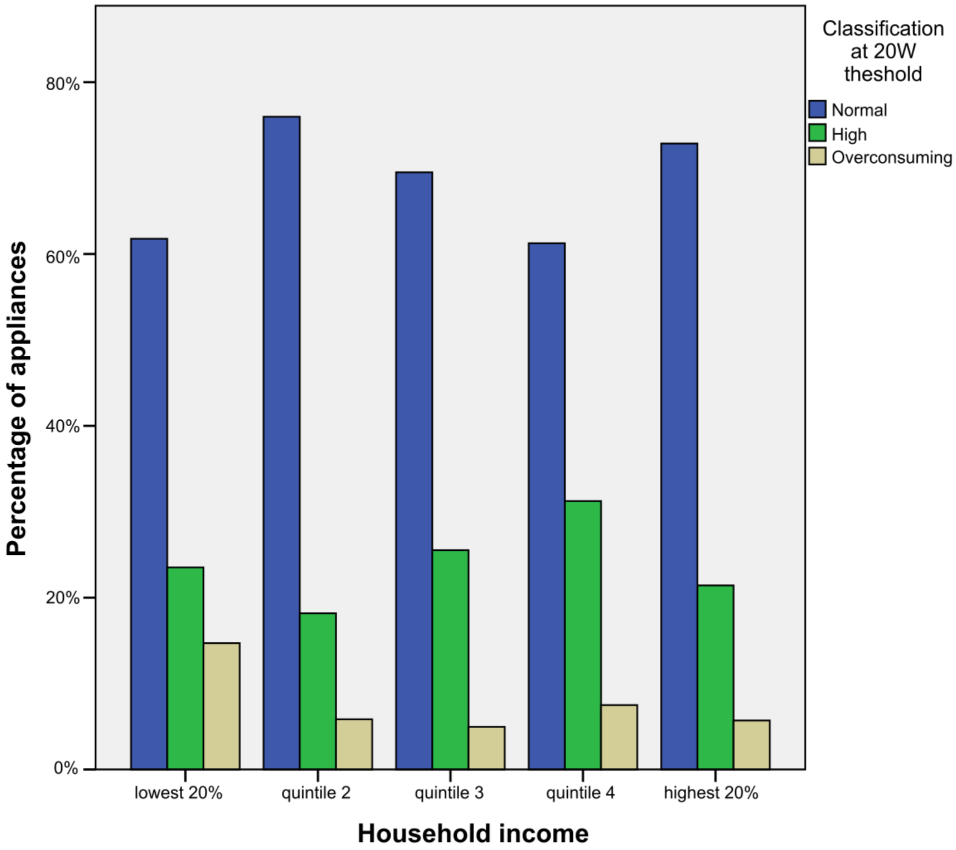


Figure 27. Household income by classification of run-time

3.8.5 How appliance was acquired

The effect on 'over'-consumption of purchasing second hand or from family/friends was observed in the sample (Figure 28), with <60% appliances classified as 'normal' in these two groups (Chi-squared, X^2=18.24, DF=6, N=660, p=0.006, small-medium effect). The largest proportion of 'over'-consuming appliances was observed in appliances that were from family/friends (17%), and the greatest proportion of 'high' consuming appliances was observed in those purchased second-hand (33%) or that came with the property (34%). No appliances were found to be ‘over’-consuming, of those that came with the property, however this group size was relatively small (32 appliances).

The household income, and information on how the occupant acquired the appliance, were seen to be closely linked. In the lowest income group, 25% of appliances were more than 11 years old. In addition 24% of those in the first income decile received their appliance second hand or from family/friends. This is compared with 8-15% in the higher income quintiles.

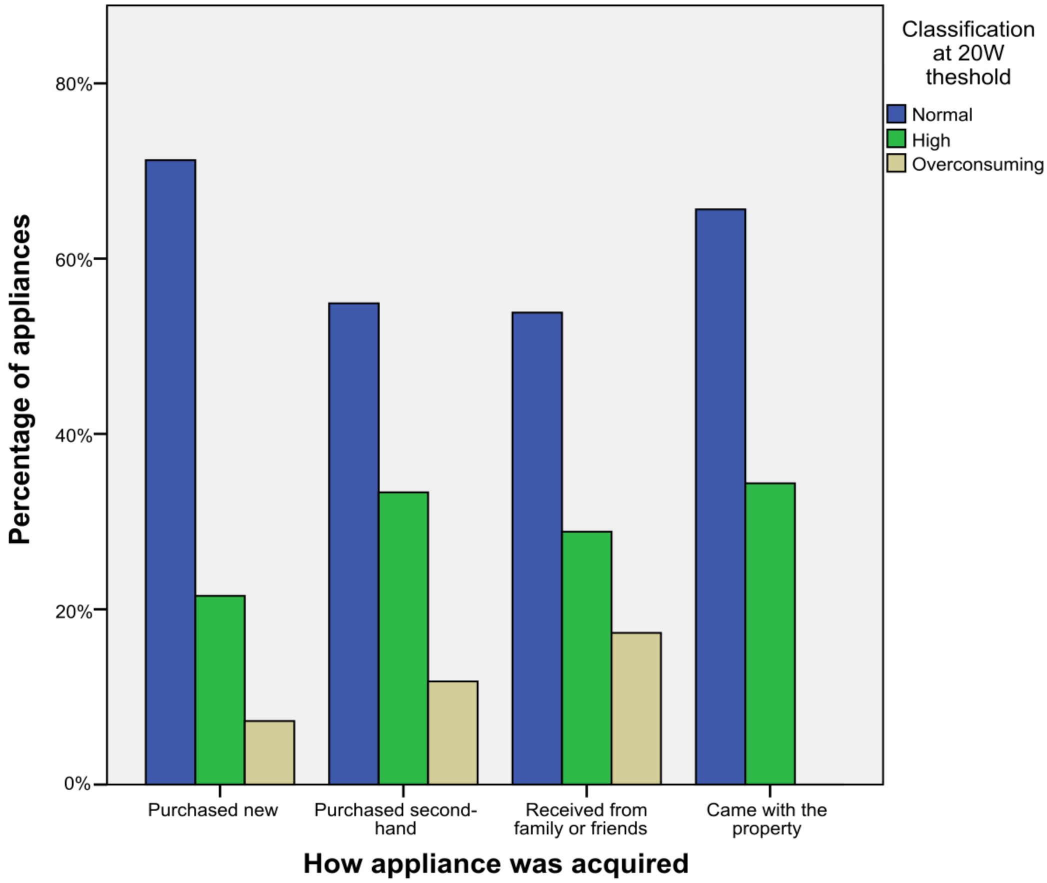


Figure 28. How the appliance was acquired by classification of run-time

3.9 Comparison with the manufacturer’s reported electricity consumption

A small sub-sample of the appliances surveyed was also matched with third party data on electricity consumption, allowing a comparison to be made with the electricity consumption calculated in this study. As indicated in Table 10, there was a positive correlation between average electricity consumption (y) and the manufacturer’s electricity consumption (x). When split into ‘normal’ and ‘high/over’-consuming appliances, ‘normal’ appliances showed that as electricity consumption increased, the manufacturer reported consumption also increased at the same rate, with electricity consumption in this study slightly lower than the manufacturer’s stated consumption (by >30 kWh). However, for ‘high/over’-consuming appliances the electricity consumption was typically >100 kWh higher than the manufacturer's reported consumption.

Table 10. Correlation of measured electricity consumption with the manufacturer reported consumption

Cases	p-value	Correlation	Relationship
All appliances (N=94)	<0.001	0.766	y = 1.4x - 90
Normal (N=68)	<0.001	0.798	y = x - 34
High/over-consuming (N=26)	<0.001	0.666	y = 1.2x + 120

The correlation between the measured electricity consumption and the manufacturer's reported electricity consumption can be seen in Figure 29, Figure 30, and Figure 31. The proportion of appliances with electricity consumption lower than the manufacturer's stated value was 51%, with only 1 case classified as 'high' consuming using the 20W threshold. All remaining 'high/over'-consuming cases had measured electricity consumption values greater than those specified by the manufacturer.

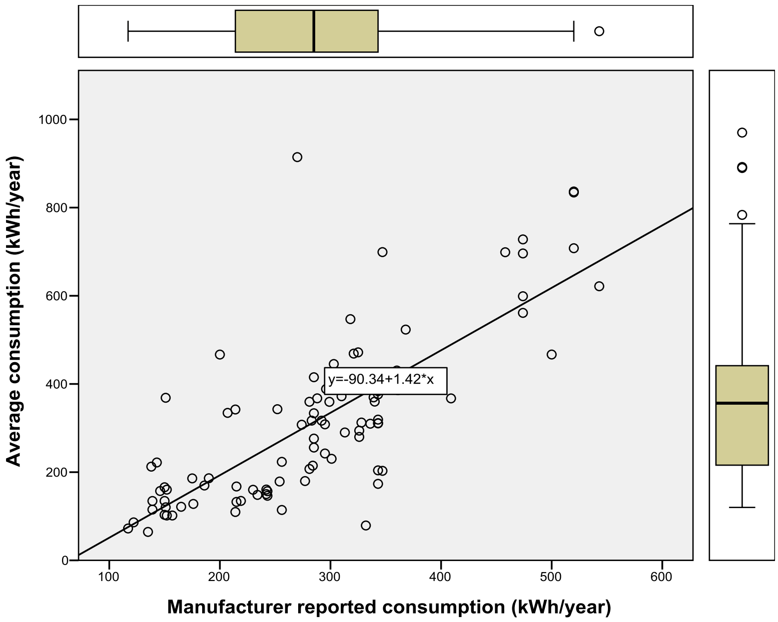


Figure 29. Correlation of annual electricity consumption with manufacturer reported electricity consumption, for all matched appliances

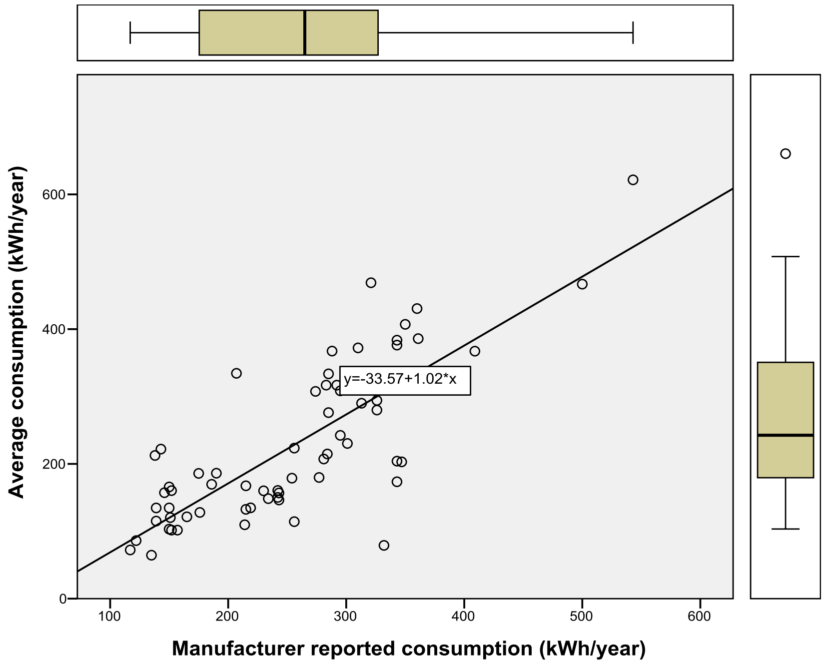


Figure 30. Correlation of annual electricity consumption with manufacturer reported electricity consumption, for all ‘normal’ matched appliances

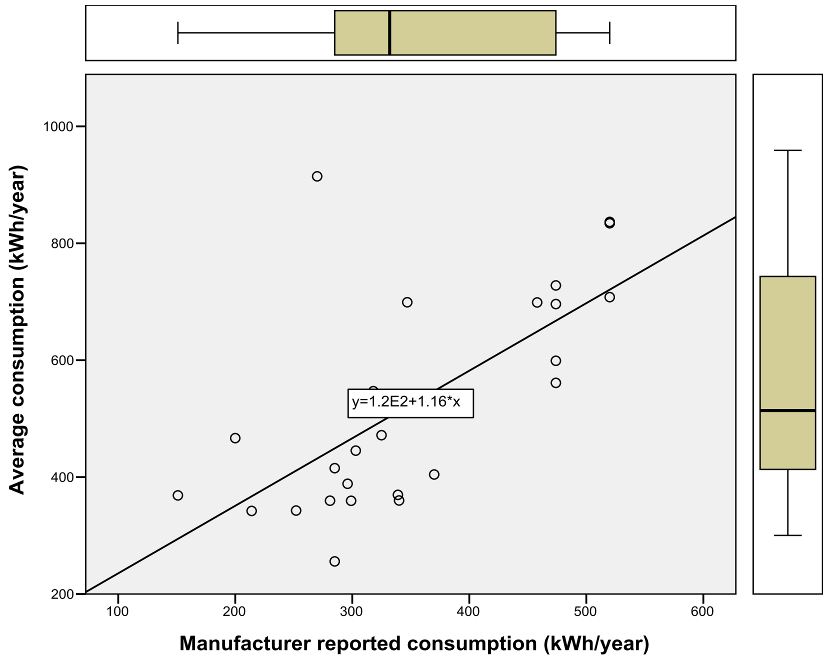


Figure 31. Correlation of annual electricity consumption with the manufacturer reported electricity consumption, for all ‘high’ and ‘over’-consuming matched appliances

3.10 Implications of over-consumption on electricity consumption, cost and carbon

The electricity consumption of over-consuming appliances, was compared with the electricity consumption from non-over-consuming appliances, and the following were estimated:

- The extra cost to the householder of owning an over-consuming cold appliance
- Average household electricity consumption for: all households; for households with no over-consuming appliances; and for households with 'normal' consuming appliances
- The extra electricity consumption from over-consuming appliances on the English housing stock
- The extra cost and CO_2 emissions from over-consuming appliances on the English housing stock

3.10.1 Cost of an over-consuming cold appliance

Based on data from all monitored appliances (665 cold appliances), 8% of appliances were found to be over-consuming, where the compressor was running at >20 W for >90% of the time. The average electricity consumption of an over-consuming cold appliance was 730 kWh/year (+/- 69 kWh/year), which was more than double that of all other appliances, where the average was 322 kWh/year (+/- 14 kWh/year). Based on an assumed household electricity consumption of 3,800 kWh/year, over-consuming appliances contribute to almost 20% of the electricity usage, compared to less than 10% of electricity usage for non-over-consuming appliances.

By replacing an 'over'-consuming appliance, with an appliance that operates 'normally' could represent an average saving of 408 kWh/year per appliance. This equates to £58/year, based on an electricity price of 14.21 p/kWh (DECC, 2016), and representing more than 10% of a typical household's electricity bill. This figure is likely to be conservative, as this is based on replacing an over-consuming appliance with a non-over-consuming appliance, which may include 'high' consumers (e.g. old or large appliances), but is representative of the appliances sampled in this study. In reality, replacement of an older appliance with a modern, more energy efficient model is likely, which would result in a greater saving than the average value assumed here.

3.10.2 Household electricity consumption from cold appliances

While the average consumption per cold appliance (based on all appliances monitored) is 354 kWh/year, the average household consumption from cold appliances is larger than this figure due to multiple ownership of cold appliances. Based on the average number of different types of appliance reported within a household (Table 11), the total household electricity consumption from cold appliances was calculated to be on average 513 kWh/year (+/- 24 kWh/year), and the difference in electricity consumption between all appliances, all non-over-consuming appliances, and all 'normal' appliances can be calculated.

Based on the results in Table 11, if over-consuming appliances were replaced with those that are not over-consuming, this could represent an average saving of 52 kWh/year (+/- 30.5 kWh/year) for each household, which scaled up to the English housing stock of 27 million households in 2015 (ONS, 2015) is 1.4 TWh/year (+/- 820 GWh/year). This figure represents >10% of total electricity estimated to be consumed by cold appliances in England in 2014 (10.5 TWh, scaled from DECC 2015, ECUK Data Tables, Table 3.10), and indicates potential savings of 0.648 mega tonnes of CO_2 (based on 0.46219 kg

CO_2 /kWh, (DEFRA, 2015)) and over £199 million in electricity costs. A much greater saving could be made by reducing the overall electricity consumption of cold appliances, and indeed replacing all 'high' or 'over'-consuming appliances with those operating at a lower rate of <50%, could represent a greater average saving of 137 kWh/year (+/- 28 kWh/year) for each household.

Table 11. Total household electricity consumption, based on the type of appliances owned

Appliance	Mean number per household	Mean annual consumption (kWh) for all appliances per household	Mean annual consumption (kWh) for all non-over-consuming appliances per household	Mean annual consumption (kWh) for all 'normal' appliances per household
Larder fridge	0.24 (16%)	52 +/- 9.4	45 +/- 7.3	38 +/- 4.2
Fridge, ice-box	0.08 (5%)	22 +/- 4.3	20 +/- 3.1	19 +/- 2.7
Fridge-freezer	0.72 (49%)	281 +/- 14.4	268 +/- 12.2	217 +/- 10.1
Upright freezer	0.29 (20%)	99 +/- 12.5	82 +/- 9.3	67 +/- 5.8
Chest freezer	0.14 (10%)	59 +/- 9.4	47 +/- 8.5	35 +/- 7.3
All	**1.47 (100%)**	**513 +/- 24**	**461 +/- 19**	**376 +/- 5**

3.10.3 Proportion of households with an over-consuming cold appliance

As 8% of all appliances monitored were found to be over-consuming, when extrapolated to 27 million households, with an average of 1.47 appliances per household, there could be as many as 3.2 million over-consuming appliances in households in England, which would represent almost 12% of households with at least one over-consuming appliance.

Using the interview and appliance datasets, total household electricity consumption from cold appliances was calculated for 416 households. Of these, 9.4% were reported to contain at least one over-consuming appliance. The mean power consumption and estimated annual electricity consumption of the two groups are shown in Table 12 below, as on average households with at least one over-consuming appliances were found to consume significantly more energy (more than double) than households with no over-consuming appliances (ANOVA, R^2=0.222, DF=1, N=416, p<0.001).

Table 12. Mean household electricity consumption, based on 1.23 appliances per household

	Mean power consumption (W)	Annual electricity use by cold appliances (kWh/year)

No over-consuming appliances	45 +/- 2.2	396 +/- 20
At least one over-consuming appliance	106 +/- 15.6	930 +/- 137

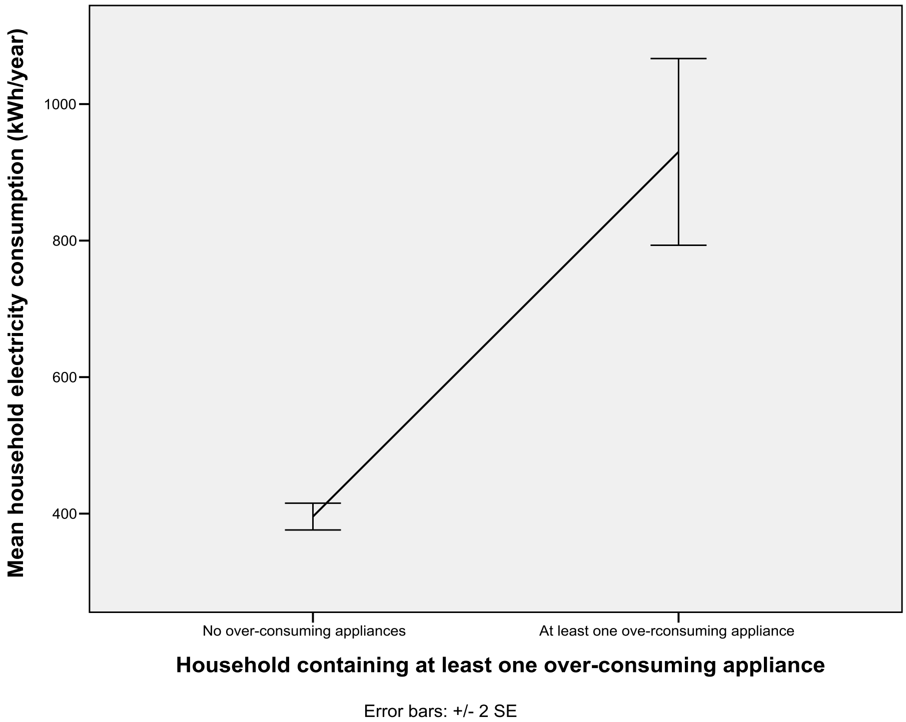


Figure 32. Mean annual electricity consumption per household, for households with or without an over-consuming appliance

Of the 416 households in this dataset, the average number of appliances was 1.23, which was less than the average number of appliances in households overall (1.47 appliances). Therefore, the average total household consumption was adjusted to account for this. The total household electricity consumption from cold appliances was calculated to be on average 533 +/- 32 kWh/year, within the error limits of the average total household electricity consumption from cold appliances calculated in Section 3.10.2. This was broken down into on average 473 +/- 23 kWh/year for households with no over-consuming appliances, and an average of 1111 +/- 163 kWh/year for households with at least one over-consuming appliance.

3.11 Example profiles

3.11.1 Typical profiles of ‘normal’, ‘high’ and ‘over’-consuming cold appliances

Figure 33 shows an example of an electricity consumption and temperature profile for a ‘normal’ consuming fridge-freezer appliance. For this 4 year old appliance, the compressor runtime was short at < 10 minutes, with longer periods of zero consumption (< 40 minute), with this pattern typical of an appliance working ‘normally’. As can be seen from the temperature graph this compressor runtime pattern results in stable internal temperatures that show little fluctuation. The average annual consumption of the appliance was 162 kWh/year, the average fridge temperature was 5.8°C, and freezer temperature was - 18.8°C.

In this example, and other profiles, sharp spikes were observed in the consumption profile. This is because when the compressor starts running, initially the electrical power drawn is momentarily very high (> 1000 W). Occasionally this is captured by the data logger, but as the data logger records the power every 30 seconds, often these high intensity peaks are missed.

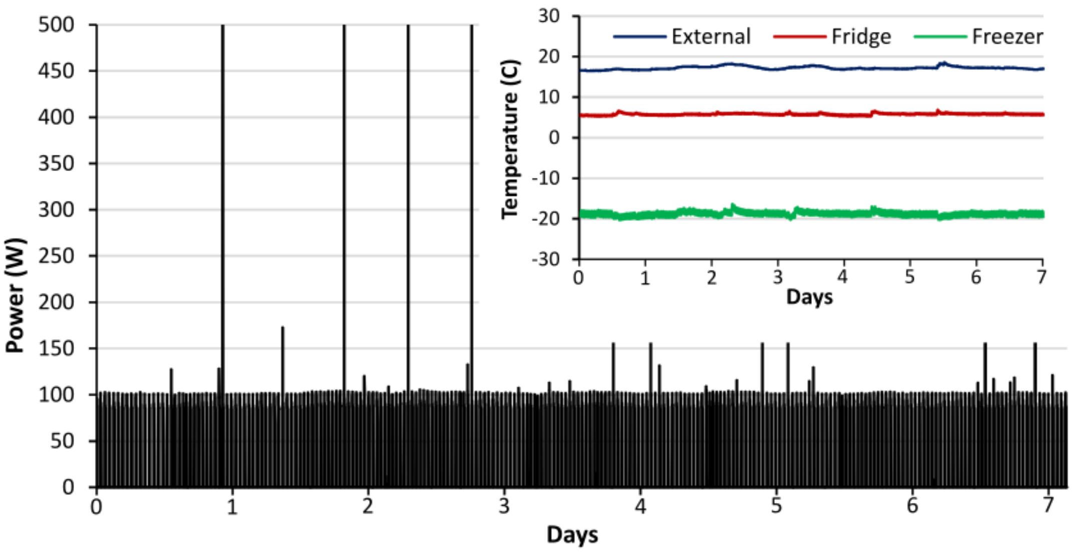


Figure 33. Electricity consumption and temperature, of a ‘normal’ appliance

Figure 34 gives an example of the electricity and temperature profile of a ‘high’ consuming appliance. This was a 10 year old chest freezer, with an average freezer temperature of -18.4°C and electricity consumption recorded at 419 kWh/year. In this example, compressor periods cycled on an off, for approximately an hour at each time. Longer compressor periods, of up to 2 hours, were also recorded every 24 hours which may be as a result of defrost cycles. As can be seen from the temperature graph this compressor runtime pattern results in a greater degree of fluctuation in the internal temperature.

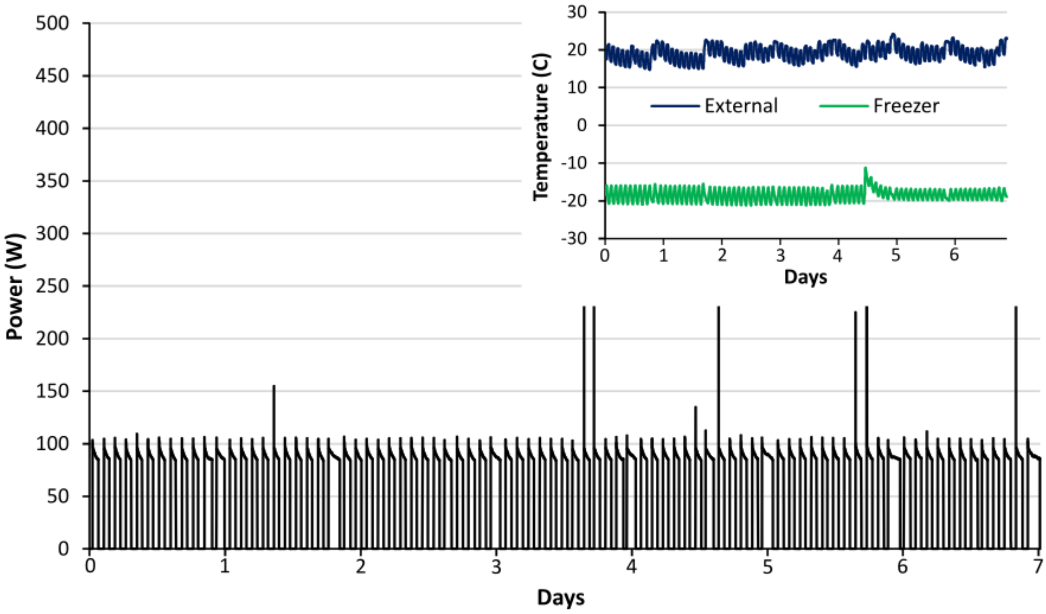


Figure 34. Electricity consumption and temperature, of a ‘high’ consuming appliance

The second example of a ‘high’ consuming appliance is illustrated in Figure 35. This profile is typically seen for large, American-style fridge-freezer. For this 5 year old appliance, the average temperature of the fridge was 4.5°C and the freezer temperature was -20.8°C.

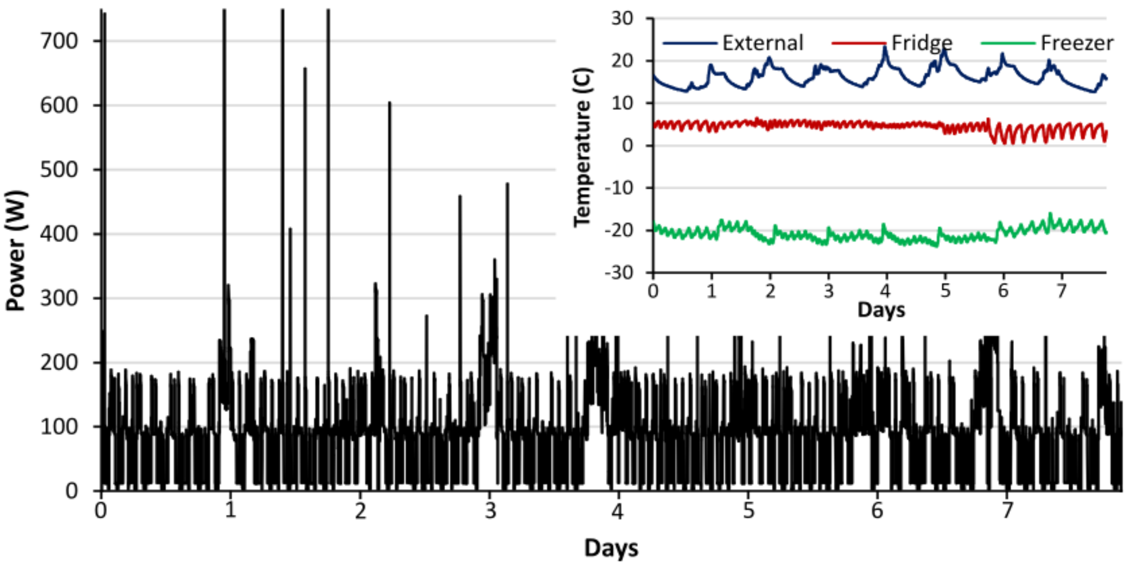


Figure 35. Electricity consumption and temperature, of a ‘high’ consuming, side-by-side appliance

The average electricity consumption was high in this appliance, at 730 kWh/year and the compressor run-time was 64%. Unlike other types of fridge-freezers the consumption pattern rarely dropped to 0 W, instead it fluctuated between high power (~ 100 W), very high (~200 W), and low (~ 10 W) power. This almost continuous consumption of electricity could be due to additional features such as water cooling and/or ice makers.

Figure 36 shows an example of an 'over'-consuming appliance, in this case being a 15 year old chest freezer. As can be seen in the electricity consumption profile, the compressor is constantly running, and in this case has resulted in very low temperatures in the freezer (average of -32.9°C). The average annual consumption was 498 kWh/year, as a result of the compressor constantly running.

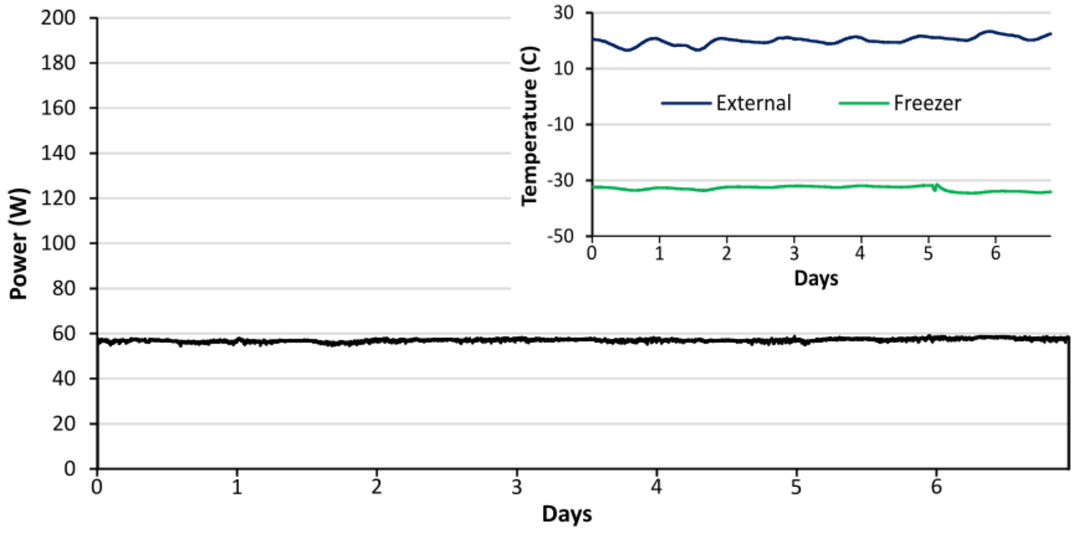


Figure 36. Electricity consumption and temperature, of an 'over'-consuming appliance

3.11.2 Case studies

As well as typical electricity and temperature profiles, case studies are provided to explain some of the reasons behind over-consumption and other issues observed during the engineer house visits. In particular, reasons for over-consumption can be varied and often multiple issues were found with an appliance that could explain the high compressor run-time. Some clear examples were chosen when the engineer reported with confidence the reason for over-consumption, and are illustrated by the use of temperature profiles (Figure 37).

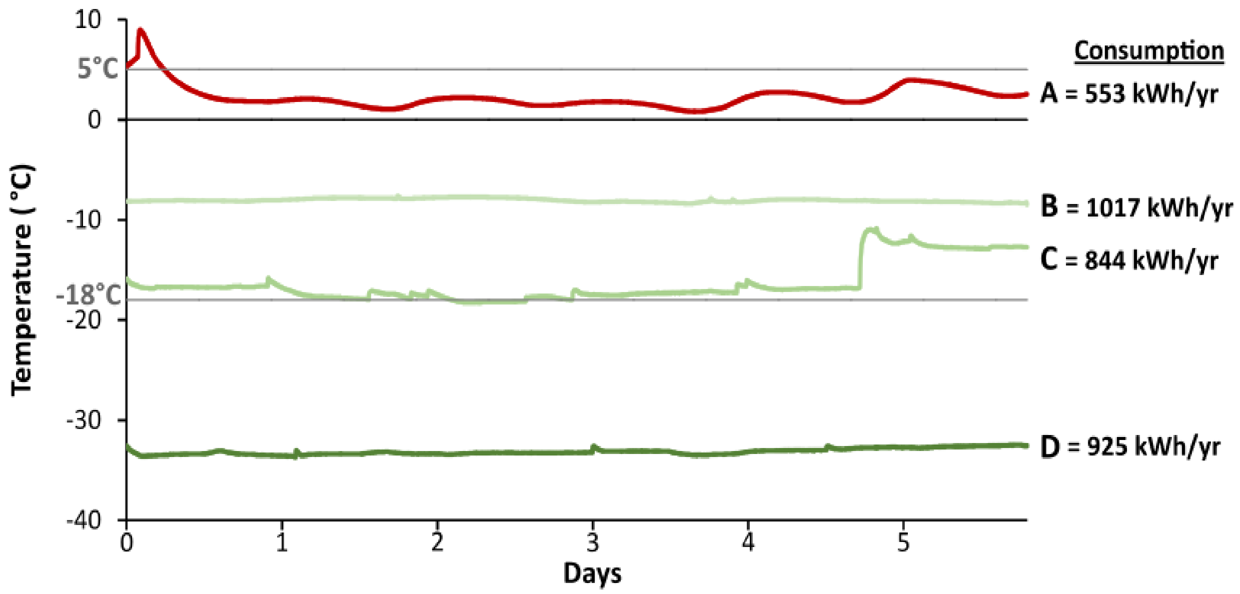


Figure 37. Temperature profiles of different over-consuming appliances (red = fridge, green = freezer), with reference lines showing recommended fridge and freezer temperature thresholds.

Fault – broken thermostat (Example A in Figure 37)

Problems with the thermostat within an appliance can lead to over-consumption. This is because if the thermostat is not accurately recording the temperature in the appliance, the compressor may run continuously to try and achieve cooler temperatures, despite having already reached them. Example A was a larder fridge achieving an average temperature of 2.4°C (> 2°C below the recommended threshold). It is an older appliance (14 years old), in an enclosed location, however the engineer reported with high confidence that a broken thermostat was the most likely reason for over-consumption.

Fault – breakdown of insulation (Example B in Figure 37)

Example B illustrates another appliance fault that can lead to over-consumption. Instead of the cold temperatures observed due to a broken thermostat in Example A, warmer temperatures were recorded in this example of a very old (20 years) chest freezer that had poor insulation. The average temperature was -8°C within the freezer, with the engineer reporting being able to smell food (indicating it is not fully frozen). Insulation at the rear of the appliance was found to be broken down, and the sides of the appliance were cold to touch (a sign of poor insulation). As a result, the appliance was considered to be over-working to try to achieve cold temperatures, but it failed to do so.

Similar examples of over-consumption with warm appliance temperatures were observed from appliances with damage to the refrigeration system, and also appliances with poor door seals (although the latter was often reported as a secondary cause of over-consumption, so it may have a similar but lesser effect than the breakdown of insulation).

User – Fast-freeze setting (Example D in Figure 37)

In Example D, extremely cold temperatures (average of -33.1°C) were reported in this 4-year old upright freezer, due to the appliance having the 'fast-freeze' setting selected. Similar temperature and over-consumption profiles can be observed by leaving the appliance on the maximum (coldest) setting. Of the 20 over-consuming appliances monitored during the engineer home visits, the use of fast-freeze or maximum settings were found to contribute to 53% of over-consuming cases, and was solely the reason in 32% of cases. Figure 23 (See Section 3.7.1) showed a large proportion of over-consuming appliances with colder freezer temperatures that could be a result of using the maximum setting of fast-freeze setting.

User – Maximum setting and poor ventilation (Example C in Figure 37)

In this example, freezer temperatures were found to be above the recommended threshold (average freezer temperature of -15.8°C), despite the compressor running constantly and the appliance set to the coldest temperature. Appliances with poor air flow and ventilation sometimes struggle to maintain cooler temperatures, as warm air dispelled from the appliance prevents cooling. In this case, the upright freezer was located within a pantry cupboard, and therefore could explain the warm ambient temperatures (average of 23.1°C).

Another example of an over-consuming appliance is shown in Figure 38; a larder fridge that also shows the compressor running continuously, with a few periods of zero consumption. During the periods that the compressor was running, the fridge achieved low temperatures (average of 1.5°C) as a high setting was used. However, when the compressor stopped running for short periods, the temperature within the fridge increased considerably (maximum of 7.2°C), with poor ventilation likely to contribute to the high temperatures.

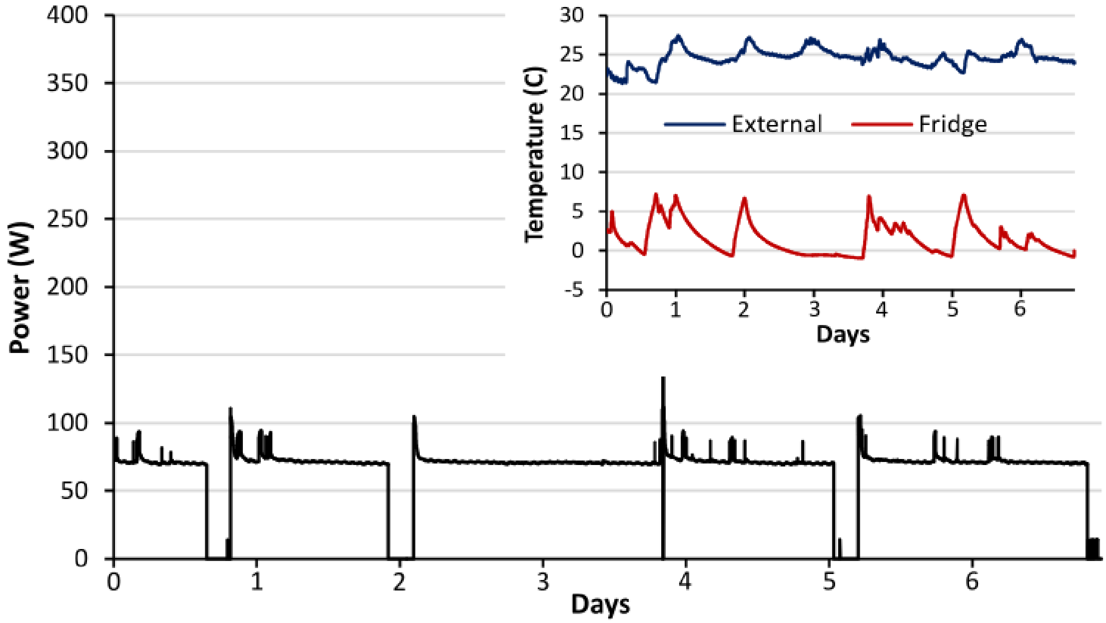


Figure 38. Electricity consumption and temperature, of an over-consuming appliance

These observations of over-consumption and poor ventilation suggest that this may play a part in why the compressor run-times can be so high. However, warmer appliance temperatures were also observed in appliances with ‘normal’ run-times, where a lack of air-flow was also reported. Often, the poor air-flow was a result of an appliance being built into the kitchen units when it may not be designed to be so. Further work is recommended in this area due to the small sample size in this study, and it is also likely that warm appliance temperatures are a result of low (warm) set-points, or faults within the appliance.

bre

3.12 Causes of over-consumption in cold appliances

The RD&T engineers inspected 90 appliances in the sample. This section refers to the results from these appliances only.

As described in the method section, for the purposes of this analysis, whether the appliances were classified as 'over'-consuming, 'high' consuming or 'normal' consuming was based on their run-time. As with the analysis of the complete field trial data set, 'over'-consuming was defined as running for ≥ 90% of the time, 'high' consuming defined as running for ≥ 50% and <90% of the time and 'normal' consuming defined as running for < 50% of the time. Overall 46 of the appliances (51%) were 'over' or 'high' consuming based on time spent >20 W (Figure 39).

The reasons for an appliance potentially using more electrical energy than it should were collected and categorised (Table 13). In many cases several issues were identified for each appliance. In these cases the reasons for potential over-consumption were ranked according to their importance (primary being the most important).

Table 13. Issues identified for appliances potentially using more energy than necessary.

	Issue	Assessment	Problem
Occupant operation	Fast-freeze on	Visual assessment	Compressor operates 100% of the time
	High usage	Obtained from interview with householder	Increased infiltration and product load. Included issues such as chilling/freezing large amounts of product, appliance door being left open regularly, large families where appliance door was opened regularly
	Maximum setting	Visual assessment	Likely to operate for long periods of time, potentially at temperatures lower than necessary
Appliance age, type, size and location	Inverter appliance	Visual assessment	Inverter driven appliances will operate for longer run times as the inverter driven compressor will modulate according to the appliance load. These appliances can be identified as 'high' or 'over'-consuming when in reality they do not have high electricity consumption. They have been included as a category to highlight the number of appliances with inverter drives that could be miscategorised
	Large appliance	Visual assessment	Appliances were selected on run time and total electricity use. Some appliances were high energy users due to their size

	Location	Visual assessment	Lack of air flow over condenser, appliance located near to warm items or in direct sunlight
	Old appliance	Visual assessment, information from householder of from appliance label	Older appliances (defined as being > 10 years old) may use more energy as energy usage has reduced since energy labelling was adopted in 1992 (Council Directive 92/75/EEC 1992)
Fault/ damage/ repair	Damage to refrigeration system	Visual and aural assessment, assessment of condensing temperature	Possible damage to the compressor, non-condensables in the refrigeration system or loss of refrigerant
	Damaged thermostat	Visual assessment	Thermostat damage may affect temperature control in appliance
	Door hinge damage	Visual assessment, test using 80 gsm paper	Increased infiltration
	Door seal damage	Visual assessment, test using 80 gsm paper	Increased infiltration
	Evaporator fan not working or damaged	Visual assessment	Lack of air distribution within appliance
	Iced evaporator	Visual assessment	May prevent temperature sensor from controlling correctly
	Insulation breakdown	Visual assessment	Additional transmission load
	Thermostat moved	Visual assessment	May result in poor temperature control. Refrigeration system may operate for longer periods.

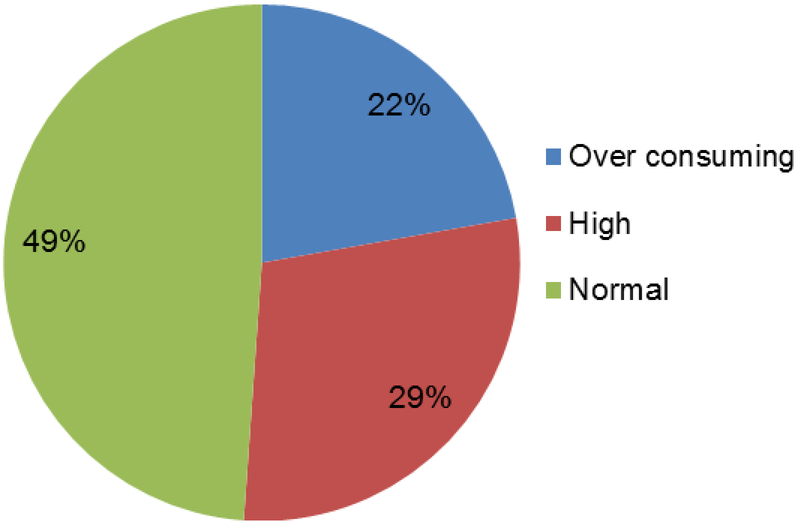


Figure 39. Number of appliances in each energy use category.

The appliances were divided into appliance types. This consisted of:

- 46 fridge-freezers
- 18 upright freezers
- 15 chest freezers
- 8 larder fridges
- 3 fridges with an ice-box

The division of each appliance type by energy use category is shown in Figure 40.

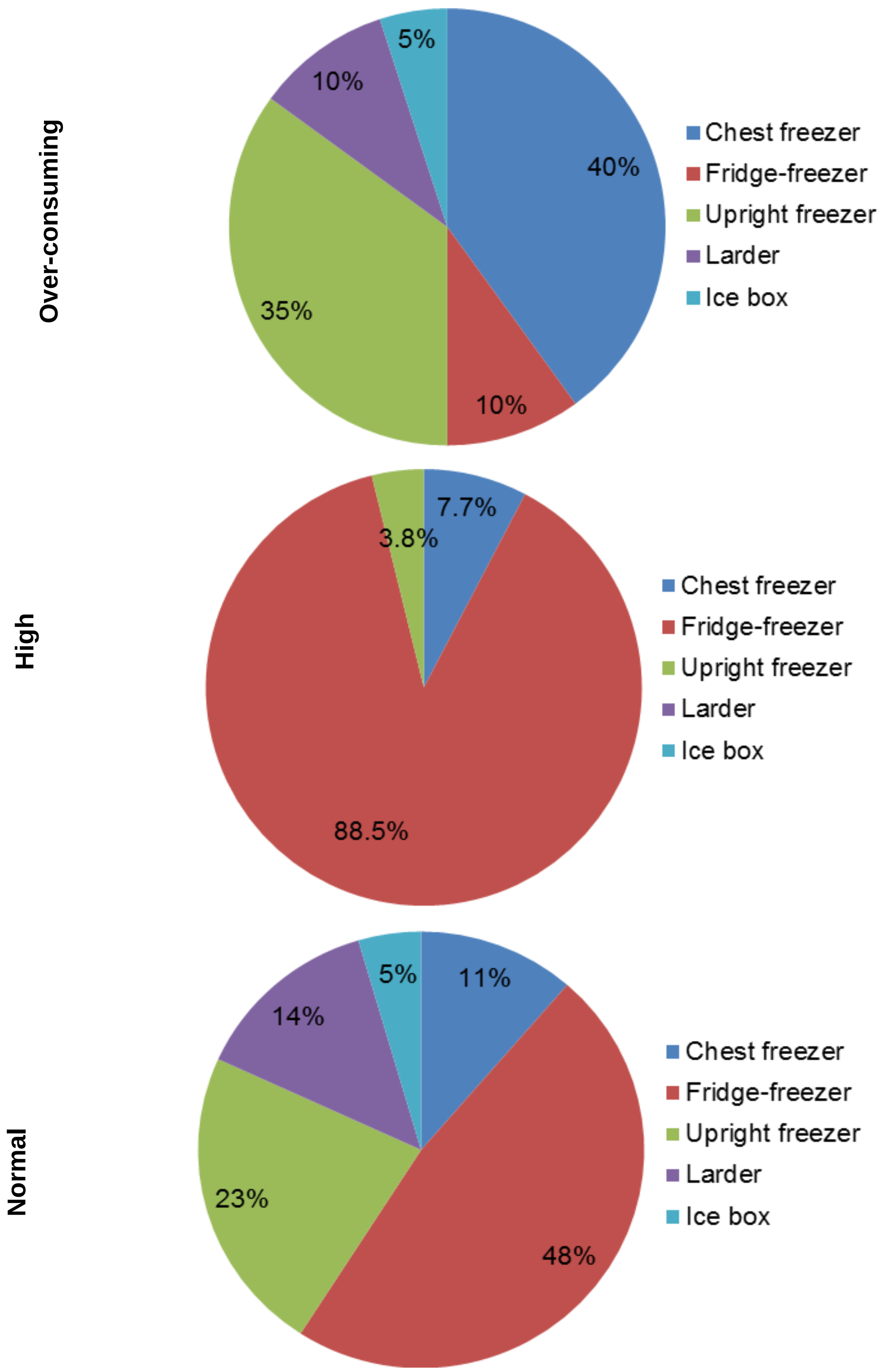
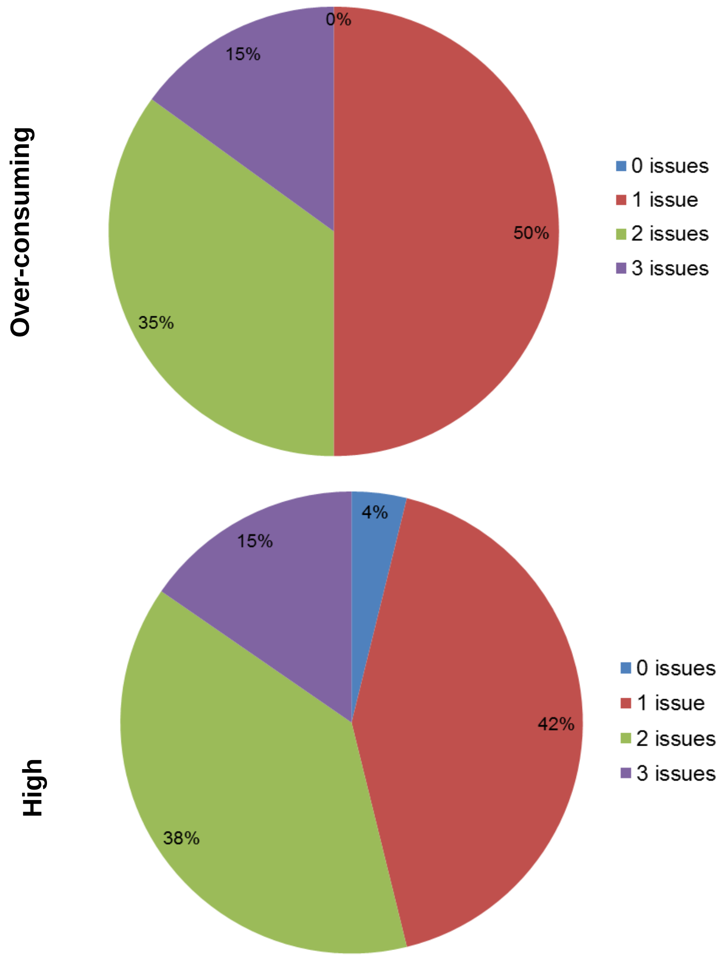


Figure 40. Types of appliances assessed according to classification

3.12.1 Issues identified

The level of confidence in the assessment of each appliance was recorded. Up to 3 issues per appliance were identified. Eight of the appliances were ranked as having low confidence (ranking of 1 or 2) in the assessment. These appliances were removed from the analysis of issues identified.

Figure 41 shows the number of issues split into electricity consumption classification. It can be seen that all over-consuming appliances had at least one issue that potentially could cause over-consumption. Just under half (48%) of the 'normal' energy use appliances had no obvious electricity consumption issues.



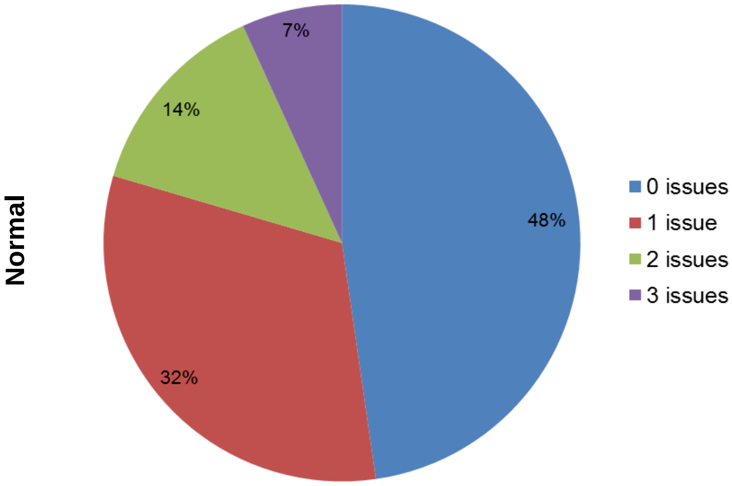


Figure 41. Number of issues identified for each appliance examined split into electricity consumption categories

3.12.2 Categorisation of issues

The issues identified were then broken down into 3 categories (as described in Table 13).

1. Issues caused by the way the occupants operate the appliance
2. Issues related to age, type, size or location of the appliance
3. Issues caused by faults, damage, or previous repairs

Up to three reasons for high electricity consumption were identified per appliance. These were ranked as the primary, secondary and tertiary issue by level of importance (primary being of greatest importance). Table 14 considers all reasons for high consumption (primary, secondary and tertiary) and shows the number of each type of issue observed when assessing ‘normal’, ‘high’ and ‘over’-consuming appliances.

Table 14. All issues identified that may cause high electricity usage, broken down into three categories

	Over-consuming		High		Normal		All	
	Freq	**%**	**Freq**	**%**	**Freq**	**%**	**Freq**	**%**
Occupant operation	12	38%	10	28%	8	25%	30	30%
Appliance age, type, size and location	5	16%	19	53%	18	56%	42	42%
Fault/damage/repair	15	47%	7	19%	6	19%	28	28%
TOTAL	32		36		32		100	

Table 15 shows the primary issues identified, broken down into the three main issue categories defined above. The results show that most primary issues associated with ‘over’-consuming appliances were related to the occupant operation of the appliances, whereas for ‘normal’ or ‘high’ consuming appliances the appliance characteristics were dominant reasons for higher electricity consumption. It should however, be noted that the analysis was based on a small sample.

Table 15. Primary issues identified that may cause high electricity use, broken down into three categories

	Over-consuming		High		Normal		All	
	Freq	**%**	**Freq**	**%**	**Freq**	**%**	**Freq**	**%**
Occupant operation	10	53%	6	30%	4	19%	20	33%
Appliance age, type, size and location	3	16%	10	50%	15	71%	28	47%
Fault/damage/repair	6	32%	4	20%	2	10%	12	20%
TOTAL	19		20		21		60	

All reasons for high electricity consumption (combining the primary, secondary and tertiary level issues) are presented in Table 16. The primary reasons for high consumption alone are presented in Table 17.

Table 16. All issues identified that may cause high electricity usage (note percentage values are rounded to nearest integer and results with confidence of 2 or less are removed)

		Over-consuming		High		Normal		All	
		Freq	**%**	**Freq**	**%**	**Freq**	**%**	**Freq**	**%**
Occupant operation	Fast-freeze on	6	19%	0	0%	0	0%	6	6%
	High usage	2	6%	8	22%	6	19%	16	16%
	Maximum setting	4	13%	2	6%	2	6%	8	8%
	Inverter appliance	0	0%	3	8%	0	0%	3	3%
Appliance age, type, size and location	Large appliance	0	0%	9	25%	4	13%	13	13%
	Location	4	13%	2	6%	10	31%	16	16%
	Old appliance	1	3%	5	14%	4	13%	10	10%
Fault/ damage/ repair	Damage to refrigeration system	2	6%	2	6%	1	3%	5	5%
	Damaged thermostat	3	9%	0	0%	0	0%	3	3%
	Door hinge	1	3%	0	0%	0	0%	1	1%
	Door seal	3	9%	4	11%	2	6%	9	9%
	Evaporator fan	1	3%	0	0%	0	0%	1	1%
	Iced evaporator	1	3%	0	0%	0	0%	1	1%
	Insulation breakdown	4	13%	1	3%	3	9%	8	8%
	Thermostat moved	0	0%	0	0%	0	0%	0	0%
	TOTAL	**32**		**36**		**32**		**100**	

1st rank	2nd rank	3rd rank

Table 17. Primary (first ranking) issues identified that may cause high electricity usage (note percentage values are rounded to nearest integer and results with confidence of 2 or less are removed)

		Over-consuming		High		Normal		All	
		Freq	**%**	**Freq**	**%**	**Freq**	**%**	**Freq**	**%**
Occupant operation	Fast-freeze on	6	32%	0	0%	0	0%	6	10%
	High usage	1	5%	4	20%	3	14%	8	13%
	Maximum setting	3	16%	2	10%	1	5%	6	10%
	Inverter appliance	0	0%	3	15%	0	0%	3	5%
Appliance age, type, size and location	Large appliance	0	0%	4	20%	3	14%	7	12%
	Location	2	11%	0	0%	8	38%	10	17%
	Old appliance	1	5%	3	15%	4	19%	8	13%
Fault/ damage/ repair	Damage to refrigeration system	1	5%	2	10%	1	5%	4	7%
	Damaged thermostat	2	11%	0	0%	0	0%	2	3%
	Door hinge	0	0%	0	0%	0	0%	0	0%
	Door seal	0	0%	2	10%	1	5%	3	5%
	Evaporator fan	0	0%	0	0%	0	0%	0	0%
	Iced evaporator	1	5%	0	0%	0	0%	1	2%
	Insulation breakdown	2	11%	0	0%	0	0%	2	3%
	Thermostat moved	0	0%	0	0%	0	0%	0	0%
	TOTAL	**19**		**20**		**21**		**60**	

1st rank	2nd rank	3rd rank

Appendix G shows the issues broken down by appliance type. This should be interpreted with caution given the relatively small sample size (19 over-consuming appliances).

3.12.3 Electricity use and Specific Electricity Consumption

In the assessment of appliances, it appeared that several appliances had high electricity consumption due to larger appliance size. Logically energy usage should be assessed as specific energy consumption (SEC) which is the energy usage per net volume or area, as the main heat load on a domestic appliance is most likely to be the transmission through the insulation, and despite not being recorded in the initial survey were recorded in the household re-visits. Data are presented as energy use per day (kWh/day) and SEC per year (kWh/litre/year) in Figure 42 and Figure 43. In the graphs, the data are divided into appliances that are freezers (chest and upright freezers), chillers (larder fridges) and fridge-freezers (conventional fridge-freezers and ice-box appliances).

In both graphs there is an overlap between the energy used by the different appliance categories (i.e. a normal appliance can use the same energy per day or per volume as an over-consuming appliance). This suggests that dividing appliances into electricity consumption categories (‘over’-consuming, ‘high’ consuming, and ‘normal’ consuming) based solely on run-time has some limitations. Assessing appliances by their SEC is a more robust approach as this is based on actual energy used and not run-time which is not directly correlated with power consumption. The advantage of using run-time is that appliances can be directly compared and it is a simple metric for consumers to assess. As stated in the Household Electricity Survey (Palmer et al. 2014) run-time is a simple method for consumers as they can listen for the compressor running excessively and identify that their appliance may be faulty. In addition it is extremely unlikely that an appliance would be manufactured to operate excessively and so run-time may be a good indicator of an issue with the appliance operation.

If the appliances examined were assessed based on their SEC the following would apply:

- SEC ≥1 kWh/litre/year = 71 appliances (78.9%)
- SEC ≥2 kWh/litre/year = 39 appliances (43.3%)
- SEC ≥3 kWh/litre/year = 22 appliances (24.4%)
- SEC ≥4 kWh/litre/year = 11 appliances (12.2%)
- SEC ≥5 kWh/litre/year = 7 appliances (7.8%)
- SEC ≥6 kWh/litre/year = 6 appliances (6.7%)

Whilst being a good indicator of electricity consumption, run-time is not an accurate measure of electricity consumption, as shown in Figure 44 where there is still large overlap between the different use categories and total daily electricity consumption.

If the appliances were divided into generic categories (freezers, fridge-freezers and chillers as described above) it is clear from Figure 45 that a greater proportion of freezers compared to other appliance types have a higher SEC. It is also clear from Figure 43 that some freezers can have an SEC of less than 1 kWh/litre/year whereas others have an SEC that can be up to 10 times greater.

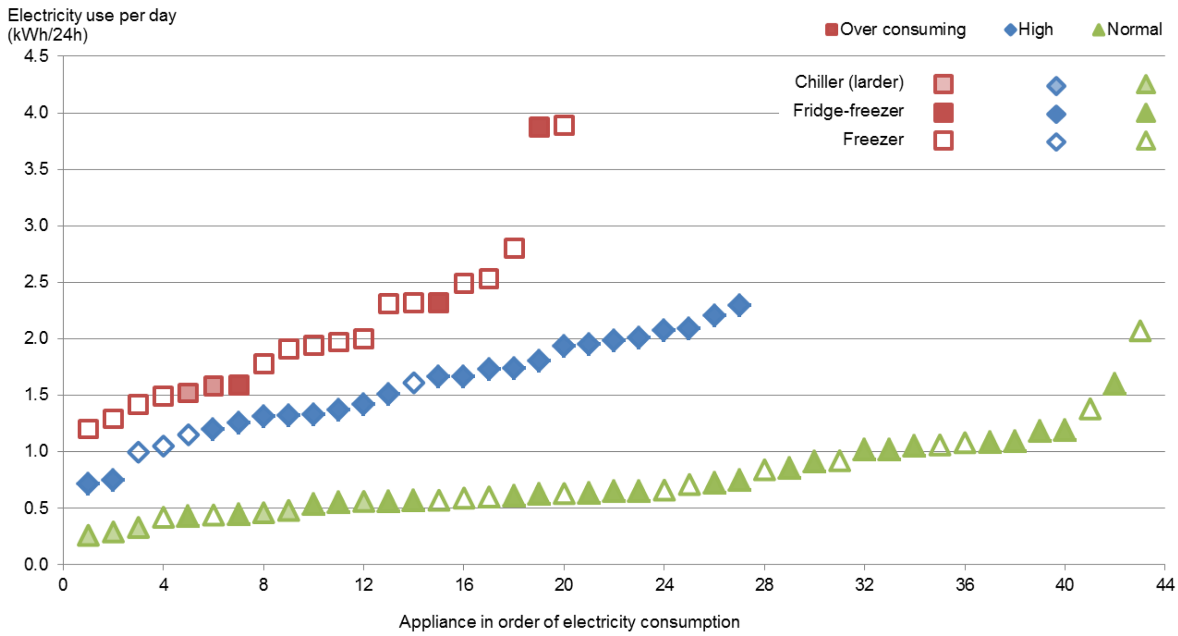


Figure 42. Actual electricity use (kWh/day) of appliances (separated into chillers, fridge-freezers and freezers) in consumption categories based on their run-times ranked according to electricity consumption.

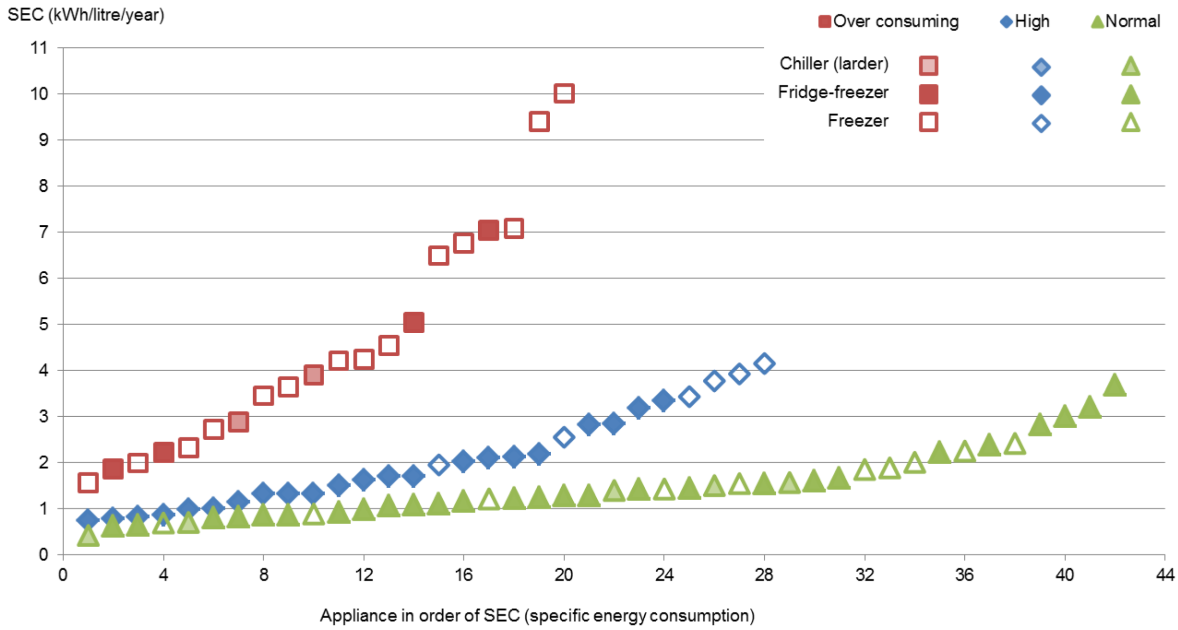
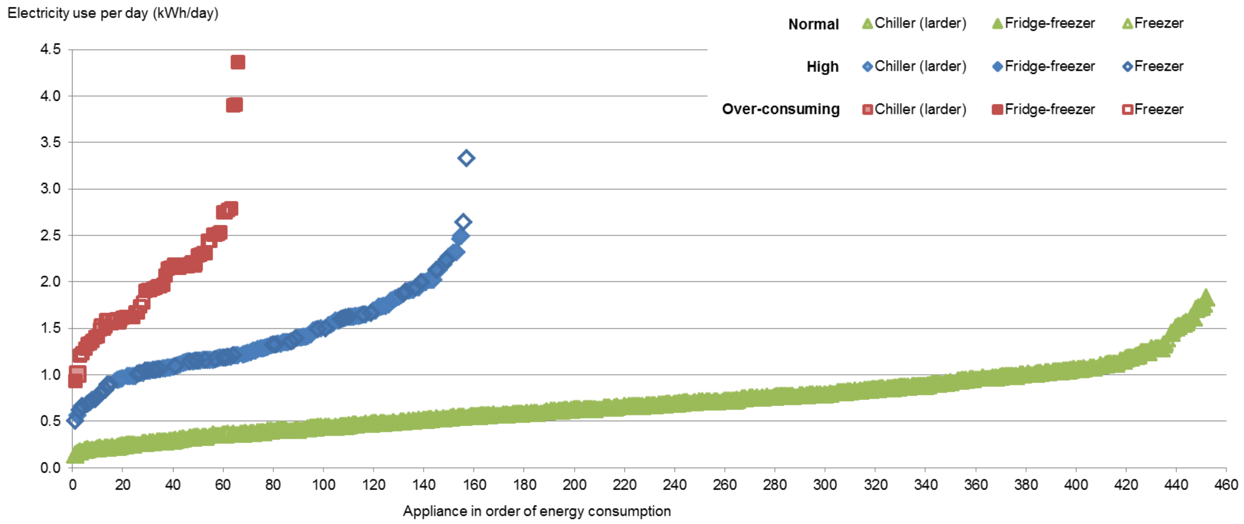


Figure 43. Actual SEC (kWh/litre/year) of appliances (separated into chillers, fridge-freezers and freezers) in consumption categories based on their run-times ranked according to electricity consumption.



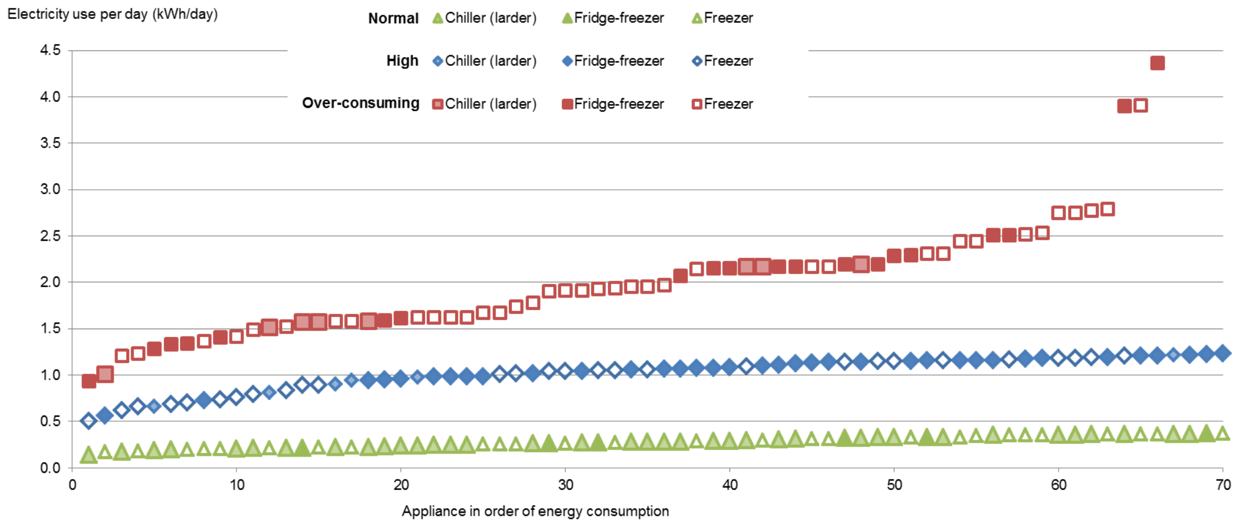


Figure 44. Actual electricity use (kWh/day) of appliances from complete data set in consumption categories based on their run-times ranked according to electricity consumption. Upper graph shows all data set, lower graph shows the same graph expanded to show appliances ranked 1-70.

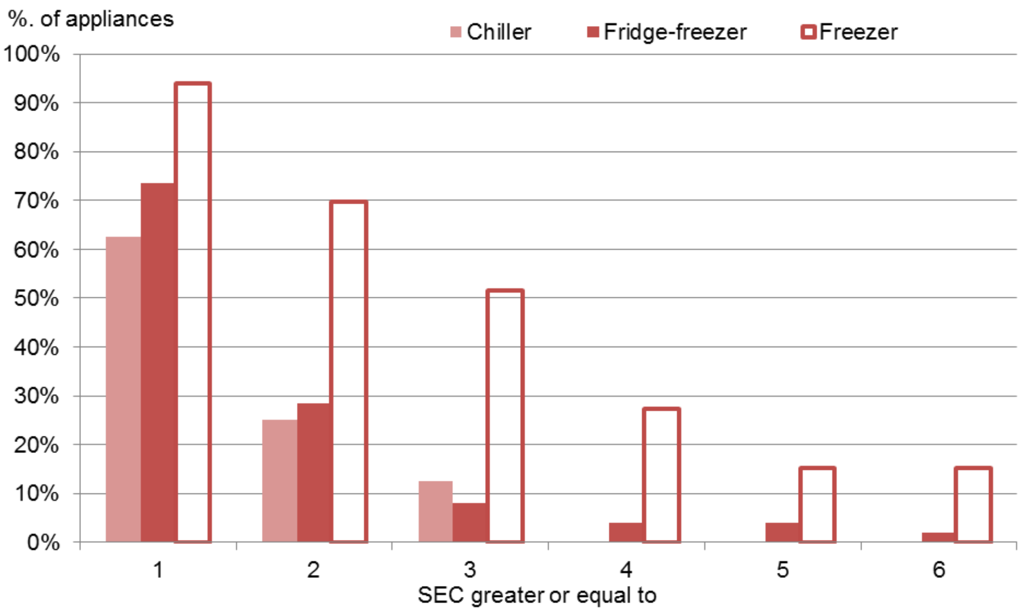


Figure 45. Percentage of appliances in each type category with an SEC above the value on the 'x axis'

3.12.4 Electricity consumption levels

A number of comparisons were run to see the difference in energy use per day, run-time and SEC based on the key appliance factors listed in Table 18. Note: the sample sizes were too small to conduct parametric tests of significance.

Table 18. Key factors assessed when comparing electricity consumption, run-time and SEC

Factor	Groups	Notes
Energy label	A+, A, B, C	
Appliance type	Chest freezer, Fridge-freezer, Ice-box, Larder, Upright freezer	
Free-standing or built-in	Built-in, Free-standing	
Frost free/non frost free	Frost free, Non frost free	
Refrigerant	R12, R134a, R600a	
Door seal condition -fridge	Excellent, Fair, Good, Poor	Based on test with 80 gsm paper
Door seal condition - freezer	Excellent, Fair, Good, Poor	Based on test with 80 gsm paper
Condenser cleanliness	Clean, Dirty	Visual assessment
Fast-freeze on	Yes, No	

The results indicated that more efficient energy label cabinets actually ran for longer periods. The average run time for an A+ appliance was 58%, compared with 48% for an A rated and 28% for a B rated appliance. Fridge-freezers had lower SEC values than other appliance types (Table 19), yet had large overall consumption, indicating the importance of volume on overall electricity consumption. Results must be interpreted with caution due to large error caused by small sample sizes, and further work is necessary to determine SEC between appliance types.

Table 19. Impact of appliance type on run-time and SEC

	Engineer re-visits			Monitored appliances		
Appliance type	**Freq**	**Run-time (%)**	**SEC (kWh/litre/year)**	**Freq**	**Run-time (%)**	**Consumption (kWh/year)**
Larder fridge	8	42 +/- 23.5	1.65 +/- 0.84	83	32 +/- 4.9	201 +/- 36
Fridge with ice-box	3	54 +/- 45	3.69 +/- 3.5	36	36 +/- 6.3	274 +/- 54
Fridge-freezer	46	53 +/- 6.2	1.59 +/- 0.26	367	46 +/- 2	390 +/- 20
Upright freezer	18	63 +/- 14.8	3.61 +/- 1.1	122	44 +/- 4.5	342 +/- 43
Chest freezer	14	75 +/- 16.5	3.28 +/- 1.22	57	59 +/- 7.4	420 +/- 67

No clear differences were found between free standing and built-in appliances. This may be due to the low number of built-in appliances (7) in the sample. Frost-free appliances had a lower SEC (1.7) than non-frost free appliances (2.9). In the sample there were 43 frost free and 47 non frost free appliances. A difference was found when comparing different refrigerant types. The results suggest that the R134a appliances used more energy (1.7) and also had a higher SEC (3.4) than the R600a (daily energy use 1.0, SEC 1.66) and R12 (1.1 energy use 1.0, SEC 2.23 (based on only 1 case)).

No clear differences were found by door seal condition, however, the results indicate that a dirty condenser resulted in high daily electricity use, longer compressor run-times and higher SEC values (Table 20). Appliances with the ‘fast-freeze’ setting turned on operated at 100% of the time (as designed to) and have a higher SEC (4.65) than those without (run time 59%, SEC 2.4).

Table 20. Impact of condenser cleanliness on electricity consumption, run-time and SEC

Groups	**Frequency**	**Consumption (kWh/day)**	**Run-time (%)**	**SEC (kWh/litre/year)**
Dirty	13	1.9 +/- 0.42	79+/- 13	4.21 +/- 1.5
Clean	31	1.1 +/- 0.26	48 +/- 9.5	2.03 +/- 0.62

3.12.5 Comparing and consolidating results with WRAP's findings and recommendations

In 2013 the Waste and Resources Action Programme (WRAP), formed the Electrical Product Pathfinder Group (EPPG). The purpose of the group was to help the electrical and electronic product sector to cut costs, reduce resource use, and build a reputation for corporate responsibility. The EPPG aimed to:

- Identify the most significant changes in the supply and sale of electrical and electronic products in the UK that would use less material resources, reduce costs and reduce business risk, while improving profit;
- Implement changes on key products, measure the benefits and distil good practice;
- Share insight on consumers understanding and attitudes to product lifetime.

WRAP worked with a consortium of specialists to develop targeted research and engagement with industry and other bodies. The key outputs from this work are a series of e-product technical guides which provide specification and guidance for improving the durability and lifespan of electrical appliances including cold appliances, kettles, microwaves, LCD televisions, vacuum cleaners and washing machines. WRAP (2014) examined the critical components of domestic fridges and freezers prone to early failure and how these failures can be addressed.

The causes of early failure identified by WRAP largely overlap with the causes of over-consumption identified in the current study. Table 21 highlights the issues that both cause appliances to consume more electricity than they were designed to and reduce the lifespan of the appliances. As highlighted in the table, with the exception of 'Insulation breakdown', 'Fast-freeze on constantly' and 'Appliance set on maximum cold setting' all the issues/causes included were highlighted in both the WRAP research and this study. Also included in the table are recommendations for how the occurrence of these issues could be reduced and how householders can identify if their appliance may have a fault.

In addition to the faults and issues outlined in Table 21, WRAP also identified that issues with bulb failure, broken shelves, drawers and trays can also reduce the lifespan of appliances. As these issues do not directly cause appliances to consume more electricity than they were designed to, they were not included in the table.

Table 21. Issues identified to have an effect on the electricity consumption and lifespan of cold appliances

	Issue/fault	Driver/cause	Effect on consumption rate	Effect on appliance lifespan	How householders can identify the problem	How to reduce the risk
Fault/damage/ repair	Damaged thermostat	Poor design; poor connectors; no surge protection; no humidity or vibration protection	Can cause compressor to operate excessively	Temperature variation and poor cooling of contents can result in householders scrapping the appliance and buying a new one	Compressor running all the time or not running at all	Specification and testing for longer life of components, PCBs and connectors and accessibility for easy replacement
	Door hinge damage	Poor quality hinges and mounts Occupants overfilling appliance doors Lack of interchangeable/reversible doors	Poor seal between door and appliance body allows ambient air to infiltrate the appliance which adds an extra heat load on the appliance, leading to the compressor being on more	Hinges and mounts can weaken preventing the door from operating and sealing properly	Visual check Place strip of paper between appliance body and door seal. Paper should be clamped between door seal and appliance body and should show resistance when removed.	Door, hinges and mounts designed to support at least 30kg of door load on the door shelves (evenly distributed) with the door open Encourage householders not to overload the doors
	Door seal damage	Poor quality seals can crack or come away from the door altogether creating a poor seal They can also be difficult to clean, leading to mould growth	Allows ambient air to infiltrate the appliance which adds an extra heat load on the appliance, leading to the compressor being on more	As well as the effect on the performance of the appliance, householders may find the seals hard to clean and impossible to replace and therefor scrap the appliance early	Visual check Use paper test described above Look for evidence of dirt and mould build up	Anti-bacterial seal coating and removable seals will allow effective cleaning and replacement Encourage householders to clean the door seal regularly to make sure it seals properly
	Damaged, malfunctioning or iced up evaporator fan	Inadequate space at back of unit for condenser and circulation fan	Temperature stratification within appliance and so householder may reduce appliance set point to compensate , leading to the compressor being on more	Uneven or inadequate cooling Ice can build up on the evaporator and prevent the appliance storage area being cooled adequately	Noticeable temperature increase in appliance, food not keeping as long as normal	Better quality components and construction Fix spacers/ surround at back to ensure adequate ventilation; Better quality fan

Fault/damage/ repair	Damage to refrigeration system	Gas leakage Compressor motor failure Poor compressor quality Refrigeration circuit pipework and joints faults	Can cause compressor to operate excessively	Some newer fridge-freezers use relatively cheap compressors that are prone to premature failure Repair or replacement of the compressor is often not cost-effective, resulting in the whole unit being returned or discarded	Listen for compressor running for long periods Listen for noisy compressor or unusual noise from refrigeration system Appliance may be unable to maintain food temperature and householder may notice food deteriorating faster than normal	Better quality components and construction, with appropriate testing Improve quality of windings; improve surge suppression; fit resetting thermal overload switch Specify compressors to last 7, 9 or 11 years Use of 'Linear' compressor with fewer moving parts
	Insulation breakdown	Cheap insulation can deteriorate over time Insulation not properly bonded to doors, walls, compartment liners Thin outer skin that can easily be damaged	Greater heat gain across insulation and greater heat loss through appliance walls, leading to the compressor being on more to maintain the temperature set point	This was not specifically identified as an issue/failure in the WRAP reports, however, insulation breakdown leads to uneven or inadequate cooling and premature component failure	Visual check to determine whether any areas of the insulation are wet or damp or if outer skin is damaged Feel outer casing to identify if there are patches where the walls feel significantly colder	High levels (>95% by area) of bonding between door/compartment liner moulding and foam insulation
Location	Lack of ventilation around the appliance	Location of the appliance in poorly ventilated spaces Lack of rear spacers which keep the appliance the required distance from the wall	Preventing air flow over the condenser will prevent heat from being removed. This will increase condensing temperature and result in the appliance operating outside of its design condition. The compressor may operate excessively using more electricity	Excessive compressor run time results in premature failure of this component Repair or replacement of the compressor is often not cost-effective, resulting in the whole unit being returned or discarded	Visual check of whether there is a gap behind the appliance and whether air can flow over condenser Check for build-up of dust or debris on condenser Check built-in appliances are designed to be built-in	Clear instructions on location and spacing. Built-in solid and strong spacers at back of fridge Fridge heat exchange radiator recessed / covered Clean/dust if dirt is visible
Occupant operation	Fast-freeze on constantly	Occupants not aware of the fast-freeze setting, what the function does and why it should be generally turned off	Compressor will operate 100% of the time using more electricity than necessary. Temperature within freezer will be lower than required	This was not specifically identified as an issues/failure in the WRAP reports, however, excessive compressor run-time results in premature failure of this component	Check whether fast-freeze switch on control panel is on Listen for compressor running all the time Check for food such as ice cream in freezer being very hard and difficult to scoop	Inform householders about the function, what it does and how to turn it off when not needed Build in an automatic reset system which turns off the

				(indicates that the freezer temperature may be lower than necessary)	fast-freeze after a certain period of time
Appliance set on maximum cold setting	If there is a fault with the appliance such as a malfunctioning evaporator fan or thermostat occupants may set the thermostat to its lowest setting to try and kept the food cold/frozen	Compressor will operate for a very high proportion of the time using more electricity than necessary	This issue was not specifically identified as an issue/failure in the WRAP reports, however, excessive compressor run time results in premature failure of this component	Listen for compressor running all the time Check for food such as ice cream in freezer being very hard and difficult to scoop (indicates that the freezer temperature may be lower than necessary)	Inform households about the thermostat control, the optimum temperatures to keep frozen and chilled food at and other faults that can result in their appliance not keeping cool enough
Blocked defrost drain hole	The drain hole can gradually block with debris and ice, causing flooding inside the unit and/or icing of the evaporator and stopping of the fan	May lead to icing of the evaporator/preventing the fan from working, which in turn leads to higher compressor run rate	A simple blocked drain can lead to flooding and appliance malfunction and failure resulting in early disposal of the appliance	Check of defrost drain hole (if visible)	Better design of drain channels/drain hole as well as an external drain pipe that will not freeze. Clean the water drain hole on a regular basis Instructions should include a removable sticker clearly indicating where the drain is
High usage	Keeping appliance door(s) open or adding warm food to the appliance	Causes the refrigeration system to run excessively and use more electricity than necessary	Causes the refrigeration system to work harder and shortens the life of the components	Provide householders with guidance on how to use their appliance most efficiently	Check to make sure doors are kept closed. Use child lock if relevant

The findings from both the WRAP studies and our field study indicate that improving user guidance is critical to both prevent early failure and avoid over-consumption. WRAP recommends providing a single "Quick Start" instruction sheet on all products. This should be located at the top of the packaging so that the customer sees it immediately (using brightly-coloured paper can help). WRAP recommend for fridge-freezers the Quick Start Guide should:

- Emphasise the need to locate the product in a well-ventilated place to prevent overheating (this is better if it includes diagrams for non-English-speaking customers, for example with ticks and crosses for good and poor locations)
- Emphasise using the product correctly, e.g. in ambient temperature range, minimising door opening etc.
- Emphasise the need for regular cleaning, i.e. how and when to do this

In addition WRAP recommend:

- A removable sticker to be placed inside at the back of the fridge compartment to clearly indicate where the drain hole is (e.g. a large coloured arrow)
- A small plastic cleaning plunger to be provided to facilitate drain hole cleaning
- An 'easy-peel' sticker to be placed on the rear of the fridge to indicate that removal of the spacers could prevent the unit from cooling adequately and result in early failure of the unit

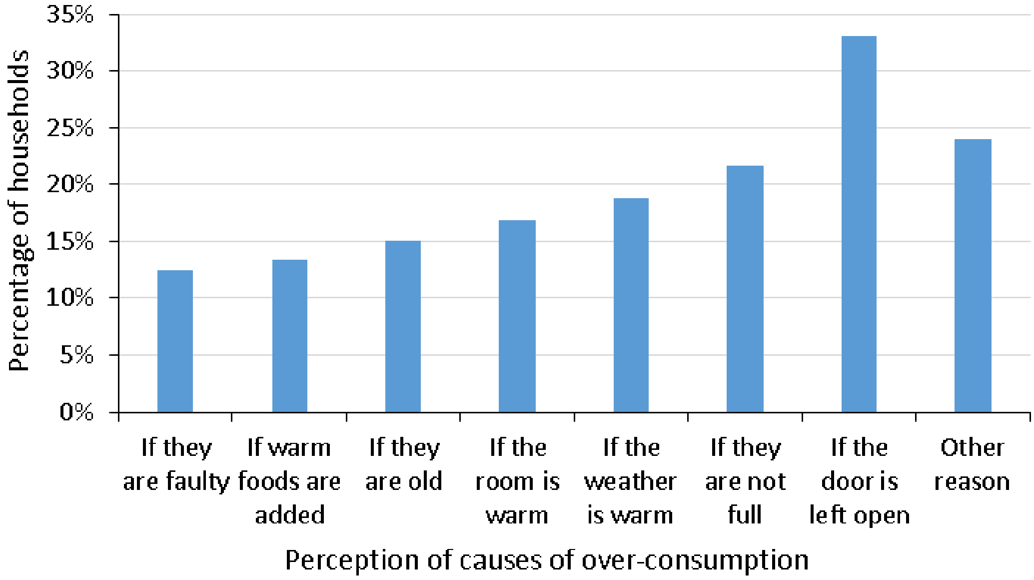
The findings of this field study support many of these suggestions as being beneficial to reducing the consumption of the appliances. In addition, our study indicates that information on the fast-freeze feature should also be included, specifically explaining what the feature is for, how and when it should and should not be used and, importantly, the cost implications of leaving it on. The user guides could also include information to help householders identify the tell-tail signs of a fault/issue developing and what they can do to avoid it getting worse (e.g. clean the drains, clean seals, re-hang the door, defrost the appliance, turn off fast-freeze, ensure there is sufficient ventilation around the appliance etc).

As well as providing better information to the users, WRAP (2014) provides detailed and comprehensive recommendations and specifications for manufacturers on how the risk of the issues and failures developing can be avoided/reduced.

It is worth noting that the fundamental aims of the WRAP work and the current study are different and, therefore, what is best in terms of maximising the lifespan of cold appliances may not be best in terms of reducing the amount of electricity used by cold appliances across the population. In particular, extending the life of old, inefficient, appliances may result in more electricity being consumed and carbon produced than if householders switched to new low energy appliances. Further research is needed to explore, from an energy/carbon perspective, at what point it becomes better to encourage householders to scrap old appliances and switch to new low energy ones. Given the energy and carbon associated with building new appliances and disposing of old ones, this becomes a difficult calculation to make.

3.13 Householder perceptions of over-consumption and how best to alert them to the issue

Householders were asked what they thought the likely causes might be for an increase in electricity consumption. The householders were not given a list of options or prompted. Only 12% of householders said a fault with the appliance would cause consumption to increase. The most popular answer was 'if the door was left open' (33%). Generally those households who have responded with 'other' stated the causes were thermostat set at too low a temperature, appliance kept too full or requires defrosting, warm weather, frequent opening of the appliance, or a fault to the door seal.



**Households could give more than one answer so the cumulative percentage will add up to over 100%*
Figure 46. Assumed causes of over-consumption

In terms of estimating the extra annual financial cost of using an over-consuming appliance (compared with an appliance performing normally). The results indicated that households generally do not have an appreciation of the potential cost of an over-consuming cold appliance. 63% of householders said they had no idea, 8% thought £0 - £20, 8% said £21 - £40, 10% said £41 - £60, and the remaining 10% thought it would be greater than £61. Based on the results in Section 3.10.1, the actual cost of an over-consuming appliance was calculated to be on average £58/year more than a non-over-consuming appliance.

Householders were asked a series of questions to understand what they would do if an appliance began to malfunction. The results are covered in Appendix H. Householders were also asked how interested they would be in receiving information that would help them to understand whether their appliance(s) are using more electricity than they should.

Figure 47 shows the breakdown of responses. The majority (64%) said they were interested in receiving information. No significant differences were found in the level of interest by tenure, household or type, age of HRP or household income group.

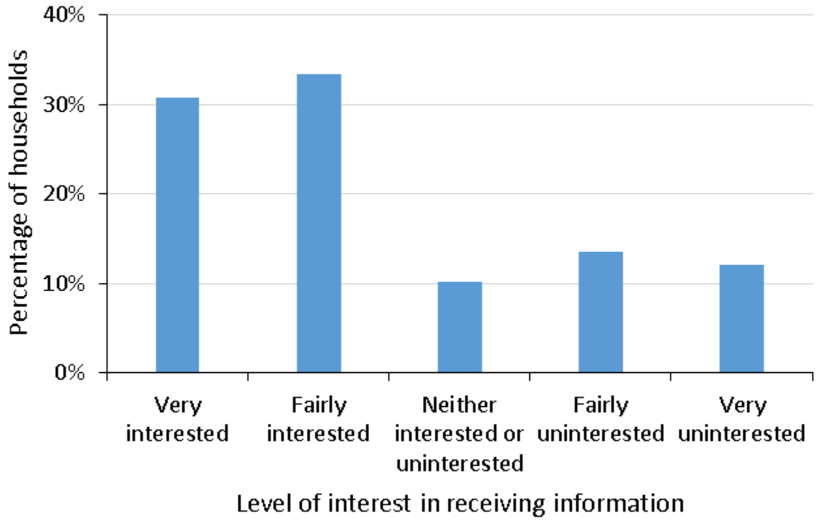


Figure 47. Level of interest in receiving information to help householders understand if their appliance(s) are using more electricity than they should

Next householders were asked which would be the best format for them to receive this information in. As shown in Figure 48 over half the householders (55%) said they would like the information to be included in the appliance manual or provided in a separate paper pamphlet, just over a third (55%) thought on line would be the best format for them to access the information. Only 7% said they would like an in-built warning device and 3% said they would like to access the information via an app.

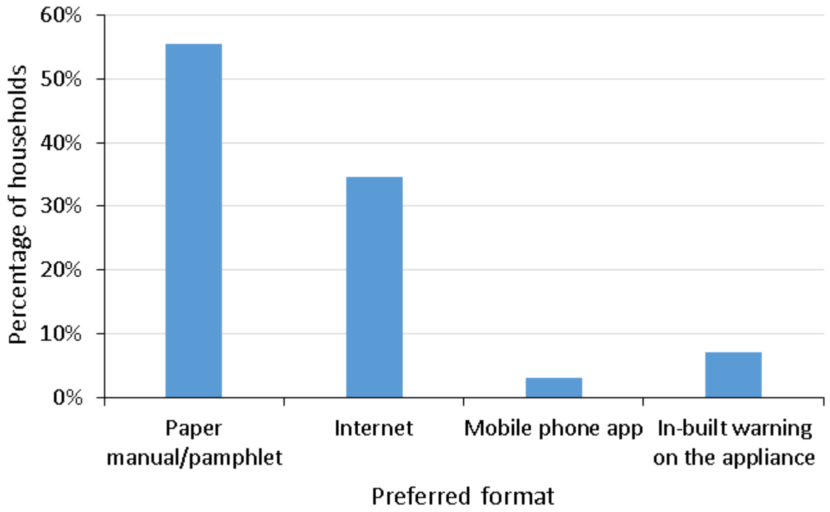


Figure 48. Householder's preference with regard to the format information should be provided in

In terms of the preferred format in which the information is provided, significant differences were found between different;

- Tenure groups (Pearson's $X^2 = 23.14$, DF = 9, $p = 0.004$)
- Household types (Pearson's $X^2 = 39.50$, DF = 15, $p = 0.001$)
- Age groups (Pearson's $X^2 = 40.56$, DF = 12, $p < 0.001$)
- Income bands (Pearson's $X^2 = 47.46$, DF = 12, $p < 0.001$)

The differences were largely attributable to differences in the proportions of households who felt on line or paper were the best formats for them. Typically owner occupiers and private renters were found to be more likely to prefer the online format and less likely to prefer a paper format than those in Local Authority or RSL properties (although the largest proportion of all the tenure groups said they would prefer the paper format).

Couples with dependent children were found to be more likely to prefer the online format than the other household types. In fact this was the only group for which the highest proportion of householders said online was the preferred format. One person households aged 60 or over were found to be significantly less likely to prefer the on-line format than the other household groups.

As age increased the preference for the online format decreased (48% of 16-34 year olds, 44% of 35-44 year olds, 39% of 45-54 year olds, 30% of 55-64 year olds, and 23% of those 65 or over would prefer the online format). It should be noted that the largest proportion of households from each age band said they would prefer the information in a paper format.

Those in the highest and lowest income quartiles were found to significantly differ from the other groups in terms of their preference for the online format. 55% of households in the highest 20% would prefer the on line format compared with just 17% of those in the lowest 20% income group.

4 Discussion of key findings

Headline Results

- A cold appliance was identified to be over-consuming when the compressor was running for more than 90% of the time
- In total 8% of all monitored appliances were over-consuming, and 9% of households owned at least one over-consuming appliance
- An over-consuming appliance could add >£50/year to a household's energy bill[2]
- Households in the lowest income band were the most likely to own an over-consuming appliance, but also the least equipped to remedy this
- The appliances found to be most likely to over-consume were freezers, and older appliances. The primary causes of over-consumption were identified to be:
    - Appliance faults
    - Use of maximum or fast-freeze settings
    - Poor ventilation

Over-consuming appliances

For the purposes of the analysis, appliances were classified as 'normal' (68%), 'high' (24%), or 'over'-consuming (8%), based on the amount of time the compressor was running above 20W. Lower internal freezer temperatures were reported in appliances with longer run-times. This is to be expected as longer run times should bring down the temperature in the appliance (to the level set at the thermostat). Yet within the 'high/over'-consuming group of appliances, increasing consumption did not correlate with decreasing temperatures, indicating that there were likely to be a higher proportion of faults within the 'high' and 'over'-consuming group. This was also supported by comparison with manufacturer data, with electricity consumption typically more than 120 kWh higher than manufacturer's values, for 'high' and 'over'-consuming appliances.

Whether an appliance was 'high' consuming or 'over'-consuming was extremely dependent on the appliance type, with upright and chest freezers most likely to be 'over'-consuming than any other appliance. However, fridges with or without ice-box freezers showed warmer internal temperatures overall, signifying that they may not be as suited to cooling food to the recommended levels. For future work, separate analysis of different appliances may yield more significant results when broken down by occupant behaviour.

The second most important factor on electricity consumption in this study, was the age of the appliance, however this had no effect on the internal temperatures within the appliance indicating that the reason for

[2] Based on an electricity price of 14.21 p/kWh (DECC, 2016) and an average saving of >400 kWh/year

higher electricity consumption and a higher proportion of 'over'-consuming appliances, was due to the compressors in older appliances having a much longer and higher run-time. The age of the appliances was found to be linked to household income. For households in the lowest income quintile, 25% of appliances were reported to be over 11 years old, and 24% were second-hand (either bought or inherited from family or friends).

Occupant behaviour was found to have an effect on electricity consumption. The addition of warm food for example caused the compressor to run more to stabilise the appliance temperature. In addition, the maintenance of the appliance had an effect on compressor run-time and electricity consumption. The results indicate that cleaning the drains regularly could increase the electricity efficiency of an appliance, more so than any other maintenance technique reported. Blocked drains (due to food blockages) can result in the freezing of the evaporator, and preventing the fan from working, which in turn leads to higher compressor run-time and overall electricity consumption.

Overall, the average electricity consumption of an 'over'-consuming appliance was found to be over 400 kWh/year higher than those classified as 'normal' or 'high', with a mean consumption of 730 kWh/year for 'over'-consuming appliances. For estimates of total electricity consumption, households with no 'over'-consuming appliances were calculated to consume ~470 kWh/year (just over 10% of annual electricity usage, based on an average household using 3,800 kWh/year), whereas households with at least one 'over'-consuming appliance were calculated to consume more than 1,000 kWh/year (~1,100 kWh/year, which is more than 25% of an average households electricity consumption). The proportion of households with at least one 'over'-consuming appliance was calculated to be 9%. Scaling the total electricity consumption up to 27 million households in the UK in 2015, and based on an average number of 1.47 appliances per household, the replacement or repair of over-consuming appliances from the household stock could result in a saving of 1.4 TWh/year of electricity.

Assessing and defining over-consumption

It was found that when comparing appliances based just on percentage run-time some 'normal' appliances used similar electricity per day to appliances categorised as 'high' or 'over'-consuming. Although compressor run time was found to be a reasonable metric of whether an appliance was 'over' or 'high' consuming it was found that SEC, or energy use per day, were potentially better metrics as they included total energy and in the case of SEC, appliance volume.

Using run-time as the metric to identify 'high' energy appliances may not always identify the appliances that use the most energy. If the overall aim of future projects is to examine energy used in householders' appliances a better metric would be energy use per day or SEC. If the aim is to identify appliances that are performing poorly or outside of design conditions then run-time is a good metric.

Causes of over-consumption

All appliances identified as 'high' or 'over'-consuming were found to have at least one fault or issue. Issues identified in the survey that can cause 'high' or 'over'-consumption can be broken down into three categories;

1. **Occupant operation** – this included the occupants setting the appliance on the maximum cold setting, chilling/freezing large amounts of product, having the fast-freeze setting on constantly.

2. **Appliance age, type, size and location** – larger and older appliances were found to be more likely to be 'high' or 'over'-consuming, in addition to appliances located near warm items, in direct sunlight or in a location with a lack of air flow over the condenser. Inverter driven appliances will, by design, operate for longer run-times.
3. **Faults or damage** – including damage to the refrigeration system, thermostat, evaporator fans and door hinges and seals, and condenser

The results showed that 'high' and 'over'-consuming appliances were observed to have considerably more faults/damage than 'normal' appliances. Almost half (47%) of 'over'-consuming appliances had at least one technical fault. However, the primary cause for 'over'-consumption in the majority of cases (53%) was occupant operation. The fast-freeze setting was found to be the primary cause in almost a third of cases (32%). The appliance being set to its coldest setting was the next most common primary cause (16% of cases).

This result indicates that when attempting to address over-consumption in cold appliances efforts should focus on educating the end users and influencing how they use their appliances as much as looking for ways to reduce faults within appliances.

Addressing over-consumption

WRAP (2014) have produced a detailed and comprehensive list of standards for manufacturers that would significantly reduce the risk of key technical failures. The issues/causes identified through the current project were consistent with those identified by the Electrical Product Pathfinder Group (EPPG) and the recommendations made by WRAP would not only extend the lifespan of cold appliances but would reduce the risk of over-consumption. The only exception was the identification of the 'fast-freeze' issue, which was not specifically addressed in the WRAP work.

The findings from both the WRAP studies and the current project indicate that improving user guidance is critical to both prevent early failure and avoid over-consumption. WRAP recommends providing a single "Quick Start" instruction sheet on all new products. However, in order to try and reduce over-consumption in the current cold appliance stock it would be necessary to provide householders with information related to their existing appliances aimed at reducing the occupant operation issues identified through this study.

This should include information on;

- Information about the fast-freeze feature, specifically explaining what the feature is for, how and when it should and should not be used and, importantly, the implications of leaving it on
- The importance of cleaning out drains and door seals
- Ensuring there is sufficient ventilation around the appliance
- The optimum temperatures to keep the appliances at.

The majority of householders said they would be interested in receiving information that would help them to understand whether their appliance(s) are using more electricity than they should. For most the best format to receive this information would be in the appliance manual or provided in a separate paper pamphlet. Surprisingly, only 7% said they would like an in-built warning device in their appliance to tell them when it was over-consuming.

Differences were found between different tenure groups, household types, age groups and household income bands in terms of the preferred format to receive the information. The differences were largely attributable to differences in the proportions of households who felt online or paper were the best formats for them. Typically owner occupiers and private renters were found to be more likely to prefer the online format and less likely to prefer a paper format than those in Local Authority or RSL properties (although the largest proportion of all the tenure groups said they would prefer the paper format).

Couples with dependent children were found to be more likely to prefer the online format and one person households aged 60 or over were found to be significantly less likely to prefer the on-line format than the other household types. Generally, as age increased the preference for the online format decreased. Finally, over half of households in the highest quintile would prefer the online format compared with less than 20% of those in the lowest quintile income group. In terms of preferences for online information, these differences were largely consistent with the sources of information householders would go to if a problem developed with their appliance.

The findings of this study indicate that those on the lowest household income were significantly more likely to have an over-consuming appliance. This group are also least likely to be able to afford to buy a new appliance if it began to malfunction or use more energy than it should. Therefore it is particularly important to educate this group about how to use their appliances most efficiently and reduce the risks of over-consumption and premature failure. The interview data shows that the vast majority of this particular group would prefer to receive this information in a paper format, less than 20% said they would go online. These results indicate that a targeted letter/leaflet campaign aimed at those in the lowest 20% income band may be the most efficient and effective way to tackle the occupant operation issues causing over-consumption in existing appliances.

Next steps and recommendations

The first recommendation is to encourage WRAP to include specifications and recommendations related to fast-freeze in their “Durable Fridge-Freezers” product technical guide. It is recommended that manufacturers look for ways to avoid the fast-freeze setting being used when it is not required. This could be by designing systems which automatically turn the fast-freeze setting off after a certain period of time, or when certain internal conditions are reached, or even developing appliances where the fast-freeze feature is not required at all.

The second is that DECC should look into the feasibility of developing an information/education campaign to raise awareness of the occupant operation issues that lead to ‘high’ or ‘over’-consumption. The data collected through the householder interviews provide DECC with useful information as to the best format to present this information in for different demographic groups. A ‘pre-post’ pilot study could be used to assess the effectiveness of such a campaign. This would involve conducting a period of monitoring before providing householders with information and then monitoring for a period after to observe any changes in the electricity consumption, internal temperatures and/or occupant behaviour.

Given that older appliances tend to be less efficient than new low energy appliances, further research is needed to explore, from an energy/carbon perspective, at what point in the life span of existing appliances it becomes preferable to scrap old appliances and switch to new low energy ones. Given the energy and carbon associated with building new appliances and disposing of old ones, cost benefit analysis is needed to calculate this. DECC could then assess whether a ‘scrappage scheme’ could be implemented to encourage householders to scrap their old inefficient appliances and buy new low energy ones.

Using the current field trial data it has not been possible to quantify the relative impact of a particular factor/cause on consumption given the number of variables affecting the electricity use measured in the field. In order to do this a laboratory study would be needed which could (as far as possible) control for other variables and assess the effect of each cause in turn. Combining the findings of such a lab study with the data from this study would enable the researchers to explain what proportion of the 1.4 TWh/year can be attributed to each of the factors/causes.

Finally, a vast amount of data has been collected through this field trial. The data will be incredibly useful for examining a range of issues not necessarily related specifically to over-consumption. For example, work that looks more generally at what kind of appliances households have and how do they use and maintain them.

- On average, how many appliances do different groups of households have?
- What types of appliances do different groups of households have?
- How old are the appliances and how do people acquire them?
- How efficient are they?
- Where are they kept?
- How are they used and maintained?
- Use and reference to manuals
- Behaviours that result in ‘high/over’-consumption

5 Conclusions

In total, 8% of the appliances monitored were found to be over-consuming. The average electricity consumption of a cold appliance was 730 kWh/year (+/- 69 kWh/year), which was more than double that of a 'normal' or 'high' consuming appliance, where the average was 322 kWh/year (+/- 14 kWh/year). Over-consuming appliances were estimated to contribute almost 20% of household electricity consumption, compared to less than 10% of electricity usage for non-over-consuming appliances.

Replacing over-consuming appliances with appliances that operate 'normally' could represent a saving of 408 kWh/year per appliance. This equates to £58/year, which is more than 10% of a household's electricity bill[3]. Scaled up to the English housing stock, the removal of over-consuming appliances from the household stock could result in a saving of 1.4 TWh/year, 0.65 mega tonnes[4] of CO_2 and over £199 million in domestic electricity costs nationally.

Freezers (standalone or chest) were found to be more likely to be over-consuming than other appliance types, however a significant proportion of fridge-freezers were found to be 'high' consumers. Older appliances, particularly those older than 11 years, were found to be more likely to be over-consuming but other factors such as the room temperature, occupant behaviour and maintenance of the appliance were also found to have an effect on overall appliance consumption.

In terms of the causes of over-consumption, appliances defined as 'high' or 'over'-consuming were found to have considerably more issues related to faults or damage than 'normal' consuming appliances. Almost half of over-consuming appliances had at least one technical fault. However, the primary cause for over-consumption in the majority of cases was occupant operation. The fast-freeze setting was found to be the primary cause in almost a third of cases, followed by the appliance being set to its coldest setting.

This result indicates that when attempting to address over-consumption in cold appliances, efforts should focus on educating the end users. This should include influencing how occupants use their appliances, as well as looking for ways to reduce faults with appliances.

The findings of this study indicate that those on the lowest household income were significantly more likely to have an over-consuming appliance. This group are also least likely to be able to afford to buy a new appliance if it began to malfunction or use more energy than it should. Therefore it is particularly important to educate this group about how to use their appliances most efficiently and reduce the risks of over-consumption and premature failure.

[3] Based on an electricity price of 14.21 p/kWh (DECC, 2016)

[4] Based on 0.46219 kg CO_2 /kWh (DEFRA, 2015)

References

ADEME (2000) Cold II The revision of energy labelling and minimum energy efficiency standards for domestic refrigeration appliances. Contract no: XVII/4.1031/Z/98-269, 2000

ATLETE Project Work Package 6: Evaluation, Outcome of the pan-EU compliance of refrigerators and freezers, Draft Report, July 2011

Council Directive 92/75/EEC of 22 September 1992 on the indication by labelling and standard product information of the consumption of energy and other resources by household appliances. Europa (web portal: http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:31992L0075 .

CSN EN 62552 (2013), Household refrigerating appliances - Characteristics and test methods. http://www.en-standard.eu/csn-en-62552-household-refrigerating-appliances-characteristics-and-test-methods/

DECC (2015), ECUK Data Tables, Table 3.10: Total electricity consumption by household domestic appliances 1970 to 2014. http://webarchive.nationalarchives.gov.uk/20160317154000/https://www.gov.uk/government/statistics/energy-consumption-in-the-uk

DECC (2016), Average annual domestic electricity bills by home and non-home supplier (QEP 2.2.1)

DEFRA (2015) DEFRA Carbon Factors, http://www.ukconversionfactorscarbonsmart.co.uk/ .

Hulme, Beaumont and Summers (2014). The Energy Follow-Up Survey (EFUS): 2011. https://www.gov.uk/government/statistics/energy-follow-up-survey-efus-2011

ONS (2015) Statistical Bulletin: Families and Households: 2015

Palmer, Terry, Armitage and Godoy-Shimizu (2014) Savings, beliefs and demographic change. Further analysis household electricity survey. London: DECC

Tim Knight, Geoff King, Sylviane Herren, Jayne Cox (2013), Electrical and electronic product design: product lifetime. WRAP http://www.wrap.org.uk/sites/files/wrap/WRAP%20longer%20product%20lifetimes.pdf

WRAP (2009). A performance assessment of domestic fridge thermometers. http://www.wrap.org.uk/sites/files/wrap/Final%20Report%20vSE%20141209.pdf

WRAP (2014), Specification and guidance for improving durability. http://eproducttechguide.wrap.org.uk/download/fridge_freezer_guidance_v2.0.pdf

Appendix A Sample demographics

The tables below show the breakdown of the sample by tenure, household type, age of household reference person and household income.

Table A1. Sample breakdown by tenure

Tenure	Frequency	Percent	Cumulative percent
Owner occupied	370	56.1	56.1
Private rented	53	8.0	64.1
Local authority	107	16.2	80.3
RSL	130	19.7	100.0
Total	660	100.0	

Table A2. Sample breakdown by household type

Household type	Frequency	Percent	Cumulative percent
Couple, no dependent child(ren)	228	34.5	34.5
Couple with dependent child(ren)	130	19.7	54.2
Lone parent with dependent child(ren)	57	8.6	62.9
Other multi-person households	60	9.1	72.0
One person under 60	70	10.6	82.6
One person aged 60 or over	115	17.4	100.0
Total	660	100.0	

Table A3. Sample breakdown by age of household reference person (HRP)

Age of HRP	Frequency	Percent	Cumulative percent
16-34	93	14.1	14.1
35-44	106	16.1	30.2
45-54	122	18.5	48.6
55-64	141	21.4	70.0
65 or over	198	30.0	100.0
Total	660	100.0	

Table A4. Sample breakdown by household income

Household income	Frequency	Percent	Cumulative percent
Lowest 20%	164	24.8	24.8
Quintile 2	177	26.8	51.7
Quintile 3	146	22.1	73.8
Quintile 4	98	14.8	88.6
Highest 20%	75	11.4	100.0
Total	660	100.0	

Appendix B Householder interview questions

Fridge/Freezer Energy Use Questionnaire

To start with I'd just like to collect some information about the household.

q01. Is it the same household living here that was interviewed as part of the EHS in 2013 /14?

Yes. No. Don't know

q02. How many people are there in each of these age groups in this household, including yourself? READ OUT

	Age	Enter no.
q02_1	0-4	
q02_2	5-10	
q02_3	11-15	
q02_4	16-24	
q02_5	25-34	
q02_6	35-44	
q02_7	45-54	
q02_8	55-64	
q02_9	65+	
	Refused	

q03. How many (*appliance name*) do you have at this property?

	Appliance	**Enter no.**
q03_1	Standalone fridge with small ice-box freezer	
q03_2	Standalone fridge without ice-box freezer	
q03_3	Fridge-Freezer	
q03_4	Standalone upright freezer	
q03_5	Chest Freezer	

bre

FOR EACH APPLIANCE ASK

q04 Where is the (*appliance name*)?

Kitchen

Kitchen/diner

Conservatory

Utility room

Garage

Under the stairs

Pantry

Sitting room/lounge

Dining room

Bedroom

Other (specify)

q05. How did you acquire your (appliance name)? READ OUT

(a) Purchased New
(b) Purchased second-hand
(c) Received from family or friends
(d) Came with the property
(e) Other (please write)

q06_h. Is there any heating in the room housing the (name of appliance)?

Q07. In some circumstances the amount of electricity fridges and freezers use can increase. What do you think the likely causes might be? DO NOT PROMPT

q0701	If warm foods are put into them
q0702	If they are not full
q0703	If the weather is warm
q0704	If the room the appliances are in is warm
q0705	If the door is left open
q0706	If they are old
q0707	If they are faulty
q0708	Other (specify)
q0709	Other (specify)
q0710	Other (specify)
q0711	Don't know

q0712	Not stated

q08. Roughly, on an average day, how often are you likely to open the (*appliance name*)?

Less than once a day

1-4 times

5-9 times

10-14 times

15-19 times

20+

q09. Apart from when you are defrosting or carrying out any other maintenance of the (*appliance name*), how often do you adjust the temperature setting

Never

Occasionally

Every 6 months

Monthly

Weekly

Daily

q10. Typically do you tend to do one big grocery shop a week or shop more regularly? PROBE FOR CODE

1. One big shop a week
2. One big shop and top up as required during the week
3. Several similar sized shops
4. Changes week to week
5. Not stated

IF (1) OR (2) ASK q11, OTHERS GO TO q12

q11. Which day of the week is your one big shop usually done?

1. Saturday

2. Sunday
3. Monday
4. Tuesday
5. Wednesday
6. Thursday
7. Friday
8. Varies
9. Not stated

q12. Typically how full do you keep the (*appliance name*); completely full, three quarters full, half full, quarter full or less?

1	0 – 25%
2	26 – 50%
3	51 – 75%
4	76 – 100%
5	Not stated

q13. How often do you put warm/hot food into your fridge(s) or freezer(s)?

1. Never
2. Occasionally
3. Often
4. Always
5. Not stated

q14. How often do you….?

		Regularly	Occasionally	Never	N/A
q14_1	Defrost your fridge(s)/freezer(s)				
q14_2	Unblock the drain in your fridge(s) /freezer(s)				
q14_3	Clean door seals				
q14_4	Remove dust from the back				

q15. If problems developed with the appliance(s) where would you go for information on what to do about it? DO NOT PROMPT

q151. Online

q152. Manual

q153. Call someone

q154. Fix it myself

q155. Other (specify)

q156. Don't know

q157. Not stated

q16. When you received your appliance(s) did you have a look at the manual(s)?

1. Yes
2. No

q17. If a problem developed with the appliance(s) would you know where to find the manual(s)?

1. Yes
2. No

q18. If you noticed a problem with your fridge or freezer, but it was still able to keep the food and drink cold, would you; READ OUT

1. Live with it until it started to get significantly worse,
2. Get it repaired,
3. Get a new appliance
4. Don't know
5. Not stated

q19. If your fridge or freezer stopped working, would you; READ OUT

1. Get it repaired
2. Get a new appliance
3. Other
4. Not stated

q20. How interested would you be in receiving information helping you to understand whether your appliances are using more energy than they should? READ OUT

1. Very interested
2. Fairly interested
3. Neither interested or uninterested
4. Fairly uninterested
5. Very uninterested

q21. If you were to receive this information, which format would be best for you? READ OUT

1. Paper manual/pamphlet
2. Internet
3. Mobile phone app
4. In-built warning on the appliance

5. Not stated

QUESTION ASKED ONLY FOR WAVES 3 AND 4

q23a. If a fridge or freezer is using more electricity than it should, how much extra do you think this would cost to run per year? DO NOT PROMPT

1. £0-£20
2. £21-£40
3. £41-£60
4. £61-£80
5. £81-£100
6. More than £100
7. Don't know
8. Not stated

q22. Thank you for completing this interview. When we have looked at all of the information collected we may wish for an engineer to visit your property to have a closer look at your fridge and or/freezers. They will inspect the appliance and try to identify any faults with the appliance. This would not cost anything and would be arranged at a time convenient for you.

Are you happy for an engineer to arrange a visit?

1. Yes
2. No
3. With qualifications
4. Not stated

q23. It would also be very useful for us to match the information you have given to us today with the previous information you gave as part of the English Housing Survey. Do we have your consent to do this?

1. Yes
2. No
3. With qualifications
4. Not stated

q24. Would it be acceptable for the Department for Energy and Climate Change (DECC) to add information they hold on energy use and efficiency at this address to your survey responses to help with their research? This matched information will be used for energy research and statistical purposes only.

1. Yes
2. No
3. With qualifications
4. Not stated

q25. Would it be acceptable for the Department for Energy and Climate Change (DECC) to obtain the reference numbers for your electricity and gas meters, known as the MPRN and MPAN numbers, from the agency that stores these to assist with their matching?

1. Yes
2. No
3. With qualifications
4. Not stated

q26. This survey is funded by the Department for Energy and Climate Change (DECC). If this department (or their contractors) needed help with any future research, would it be all right if they contacted you again? Any further research would be conducted by GfK NOP or another research organisation contracted to Government under confidentiality rules consistent with the Code of practice for Official Statistics. Data passed to that organisation would only be used for research purposes

1. Yes
2. No
3. Yes, with conditions
4. Not stated

IF EITHER ENGINEER VISIT IS YES, OR ANY RECONTACT QUESTIONS ARE A YES, RECOLLECT THE CONTACT DETAILS AND NAME

q27. Please may I have your contact telephone number?

Please collect a landline AND mobile number where possible. This will allow an engineer to get in touch (or recontact).

Code all that apply

Yes, landline number
Yes, mobile number
No, telephone number refused
No, has no telephone

q28. Please can I take a note of your name again?

ENTER NAME

Interviewer: now ask to be shown all the fridges and freezers identified above and for each record the following information

q29_make. Record the make and model of each cold appliance

q29_make	Make
q29_model	Model
qage	Age (if known)
qenergy	Energy Label (if accessible)
qtype	Type (built-in or free standing?)

q28a. If the there is a digital display allowing the householder to set a target temperature please enter the temperature this is set at, for example 2°C. Alternatively, if there is a manual dial please enter the current setting (to the nearest whole number), as well as the number this is out of, for example 5 out of 6.

Q28a_Fridge

Q28a_Freezer

q31. Is the cold appliance positioned within one metre (approx. 3 feet 3 inches) of any of the following?

q311 - An oven

q312 - A boiler

q313 - A heater or radiator

q314 - Any other source of heat (please state)

q315 – No

q316 – Not stated

Thank you for taking the time to complete this questionnaire.

Appendix C Analysis and reporting of data

The following variables were assessed to investigate their effect on the electricity consumption and internal temperatures of monitored appliances, over-consuming appliances, as well as on total household consumption:

- Appliance (type, age, energy label)
- Location (ambient temperature)
- Component faults
- Household behaviour (door opening, how full, warm food added, temp adjustment)
- Maintenance of the appliance (defrosting, cleaning seals, unblocking drain, removing dust from the back)
- Household characteristics
- Measures of 'How often do you open the appliance', 'How often do you adjust the temperature', and 'How full is the appliance' were separated for fridge-freezers (i.e. householders answered each of these questions for both the fridge and freezer part of the appliance separately). This resulted in smaller sample sizes for the analysis. Data related to different sections of fridge-freezers, were analysed separately as they could not be analysed alongside other factors without significantly reducing the sample size.

Statistical analysis was conducted on interview, temperature and electricity consumption data. The distributions for the fridge temperatures were found to be normal (using Kolmogorov-Smirnov test for normality), therefore statistical analysis using Analysis of Variance (ANOVA) was used. The freezer temperatures and external temperatures were non-normal, however analysis of the distributions and the robustness of ANOVA to violations of normality, allowed the data to be analysed statistically without transformations or use of non-parametric analysis.

Due to extreme high values, the distribution of the consumption data was found to be skewed. A log transformation was applied which resulted in a normal distribution. The LOG (Average consumption) was used in ANOVA (Analysis of variance) tests. Where the assumption for homogenous variances was violated, non-parametric analysis was used, in the form of Kruskal-Wallis tests. Post-hoc tests were conducted using Tukey tests for parametric analysis, and Mann-Whitney tests for non-parametric analysis. Pearson Chi Square tests were used when comparing groups, from variables with categorical data and the effect size was reported using Cramer's V test.

Significant results were reported ($p<0.05$), when $R^2>0.01$, and post-hoc tests show significant differences between factor groups. Throughout the text, the mean is reported (± 2 x standard error), showing the accuracy of the estimate of the mean for the population. Test results were illustrated with the use of main factor plots, using the mean of each group, with error bars illustrating the standard error. Differences between groups have been reported based on results from post-hoc tests. Pearson correlations (R) are reported throughout, when significant at the 0.05 level.

Appendix D Method for assessing selected cold appliances

Data collection template used during visits to householders.

From initial visit:

House number	
House address	
Householder name	
Appliance type	
Make	
Model	
Age of appliance	
Energy label	
Location of appliance	
Was it located close to heat source (where)?	
Day of week when most often go shopping	M / T / W / T / F / Sa / Su
Typical fill of appliance	0-25% / 26-50% / 51-75% / 76-100%
kWh/day recorded	
Run time (%)	
Mean temperature fridge (°C)	
Mean temperature freezer (°C)	
Mean ambient temperature (°C)	

Second visit:

Date of visit	
Appliance type: Is it FF?	
Free standing or built-in	
Manufacturer name	
Model (from name plate)	
Serial no.	
Appliance age (name plate)	
Refrigerant	
Refrigerant charge (grams)	
Size (internal) (litres) - Gross	

Size (internal) (litres) - Net[5]	
Testing class (T/SN/etc)	
Input power (kWh/24h or W)	
Compressor: Manufacturer + model Serial number	
Star rating if freezer	
Energy label?	
Control setting(s) (setting/max)	
Has setting been changed since initial visit?	Y/N
When did you last go shopping for food placed in appliance?	
How full is the appliance?	Fridge (%) Freezer (%)
Fast-freeze setting Is it switched on?	Yes / No Yes / No
Does cabinet have 'winter' setting?	Yes / No
Does cabinet have 'holiday' setting?	Yes / No
General condition (mark out of 10):	
Inside	
Outside	
If ice-box type, is tray under freezer damaged?	Yes / No
Condition of door seals (use A4 paper test)	
Fridge	excellent / good / fair / poor / awful
Freezer	excellent / good / fair / poor / awful
Condition of door hinges + info if damaged	OK / worn / damaged
Condenser condition	Clean / dirty / damaged
Has appliance undergone any remedial refrigeration or refurbishment work (list)?	Yes / No
Does appliance have light? Does it work?	Yes / No Yes / No
Does appliance have temperature alarm?	Yes / No
Does appliance have door alarm?	Yes / No
Does appliance have defrost drain?	Yes / No

[5] If the volume was not available from the manufacturer's name plate an estimate was made or data were obtained from the internet.

If so, is it blocked?	Yes / No
Comments on appliance, sound, vibration, condenser blockage, seal condition, usage, air flow around appliance, any additional comments on location (e.g. sunlight)	

Appendix E Total number of cold appliances split by key household characteristics

A significant difference was found in the total number of appliances in each house by tenure (Kruskal-Wallis test, X^2 =18.8, DF = 3, p<0.001). As shown in Figure E1, owner occupiers were found to have the highest number of appliances, with a mean of 1.56 per property. Households living in Housing Association (RSL) properties were found to have the least with a mean of 1.29 per property.

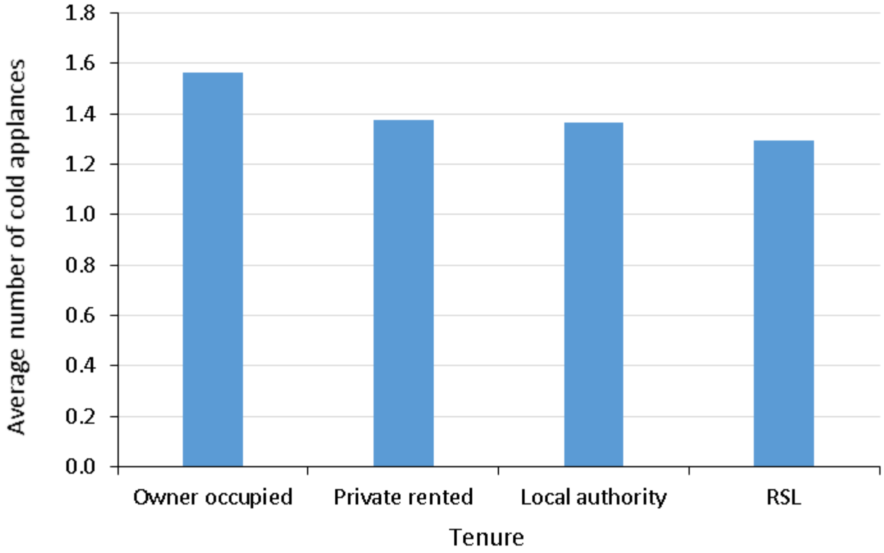


Figure E1. Average number of cold appliances per household by tenure.

A significant difference in the total number of appliances in each house was also found by household type (Kruskal-Wallis test, X^2 =16.5, DF = 5, p=0.005). Figure E2 shows that couples, both with and without dependent children, tended to have the highest average number of appliances (1.59 and 1.57 respectively). Single person households under the age of 60 tended to have the lowest number (on average 1.28 per household). The difference between the one person households aged under and over 60 is due to the types of appliances these two groups use. Those over 60 were found to be more likely to have separate fridges and freezers rather than a combined fridge-freezer. 76% of single person households aged under 60 had a fridge-freezer compared with just 59% of over 60's.

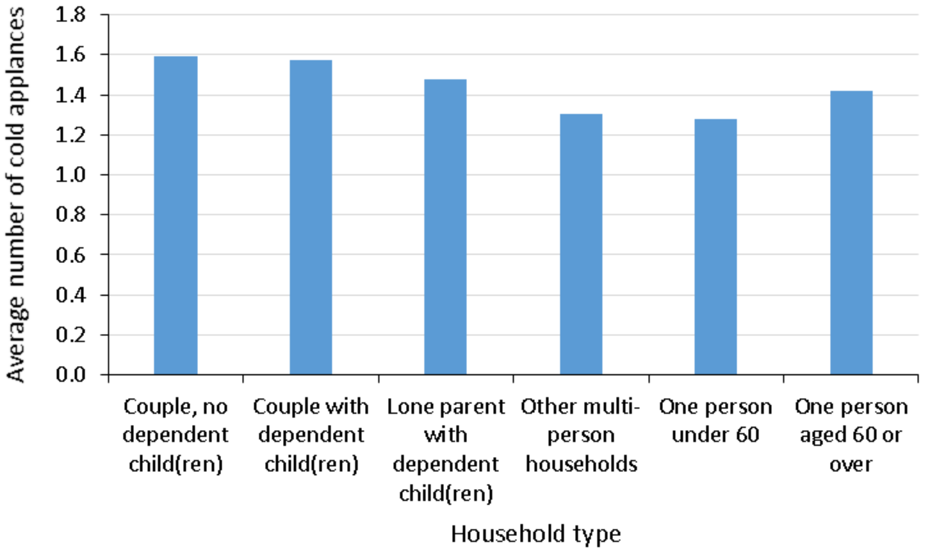


Figure E2. Average number of cold appliances by household type.

No significant different was found in terms of the average number of appliances by age of the household reference person (Kruskal-Wallis test, X^2 =6.91, DF = 4, p = 0.141). However, a significant difference was found between households with different numbers of occupants (Kruskal-Wallis test, X^2 =11.83, DF = 4, p = 0.019) the total number of occupants and number of appliances. Although, as can be seen in Figure E3, this difference was almost entirely driven by the difference between large households (5 or more people) and single person households. The average number of appliances for 2, 3 and 4 person households was almost the same (1.5).

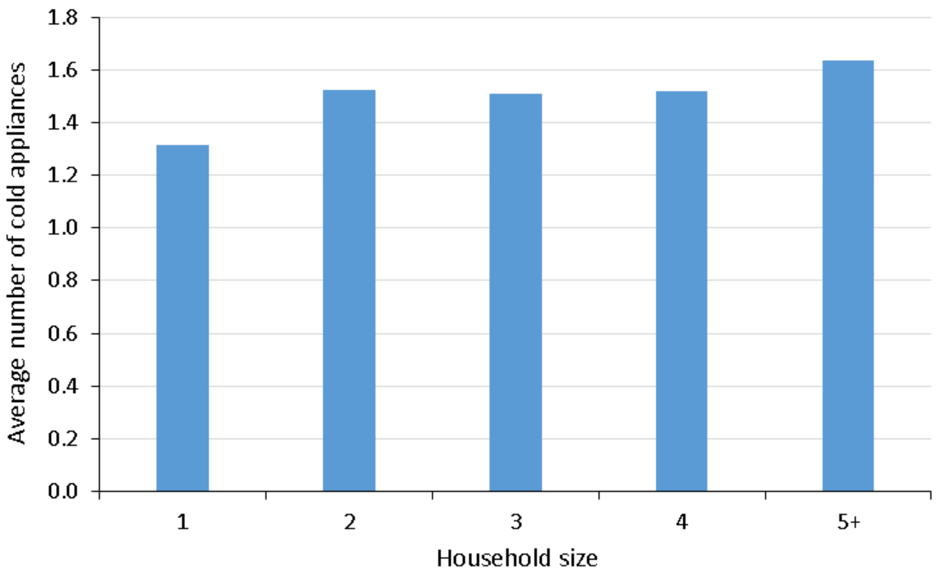


Figure E3. Average number of cold appliances by household size (number of occupants)

A significant difference was found in number of appliances by household income band (Kruskal-Wallis test, X^2 =17.98, DF = 4, p = 0.001). Figure E4 shows a gradual increase in the average number of appliances as income increases.

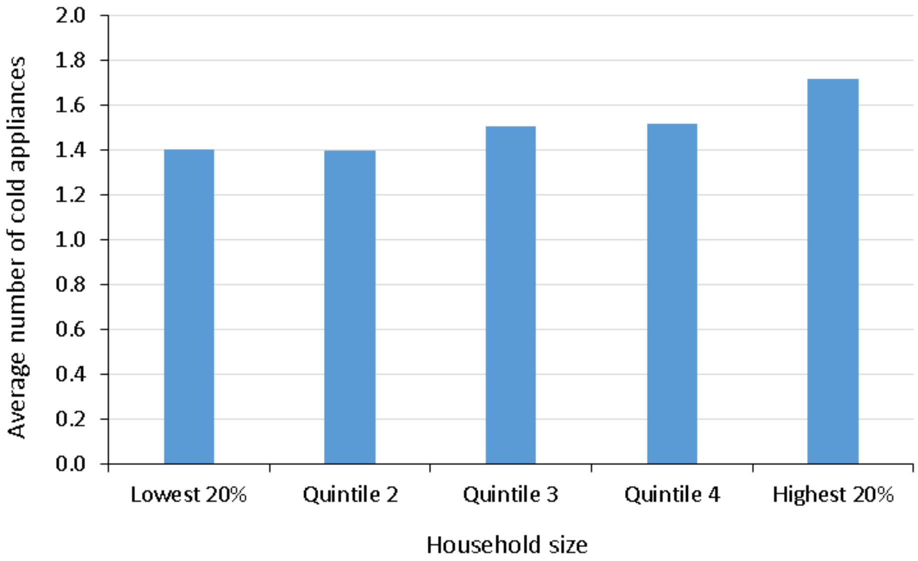


Figure E4. Average number of cold appliances by household income quintile

Appendix F Electricity consumption and internal appliance temperatures

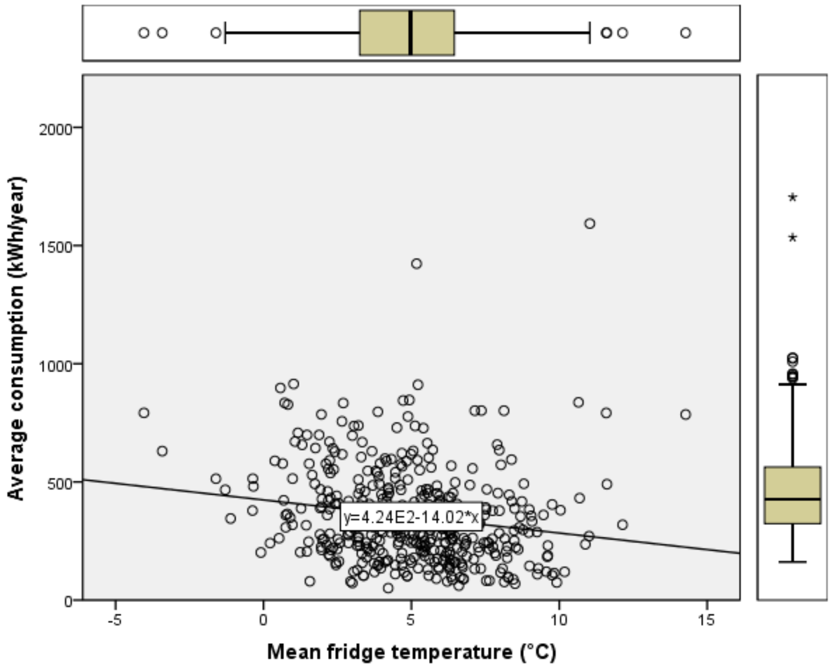


Figure F1. Correlation of mean annual electricity consumption with mean fridge temperature, for all appliances

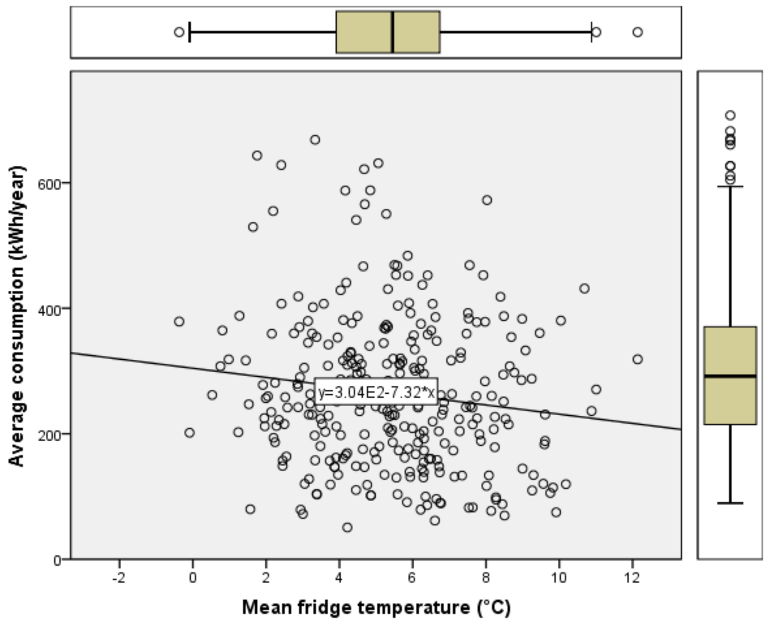


Figure F2. Correlation of mean annual electricity consumption with mean fridge temperature, for 'normal' appliances

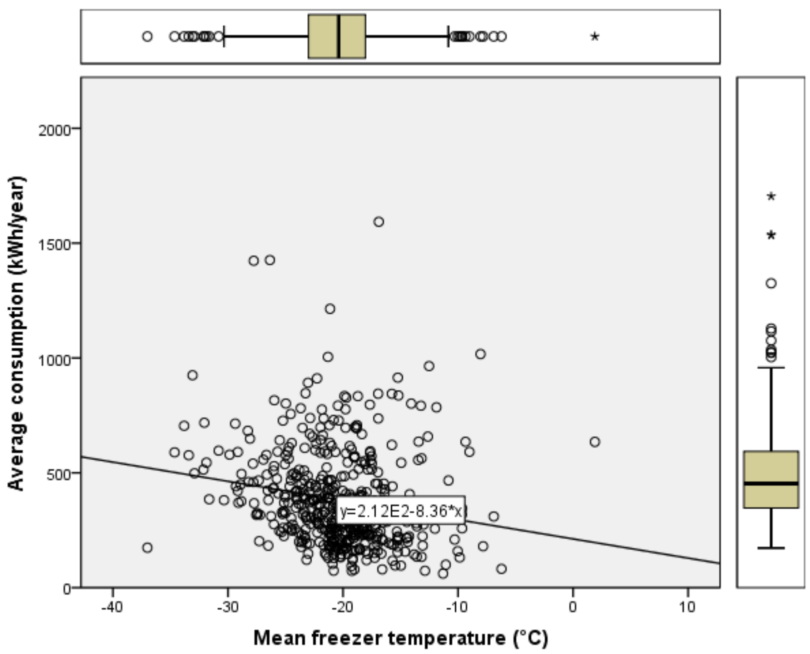


Figure F3. Correlation of mean electricity consumption with mean freezer temperature, for all appliances

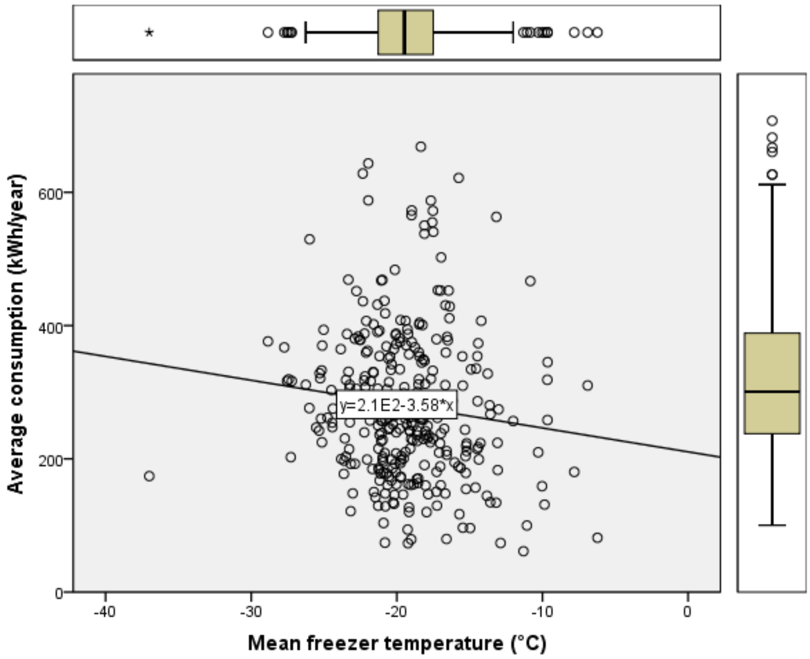


Figure F4. Correlation of mean electricity consumption with mean freezer temperature, for 'normal' appliances

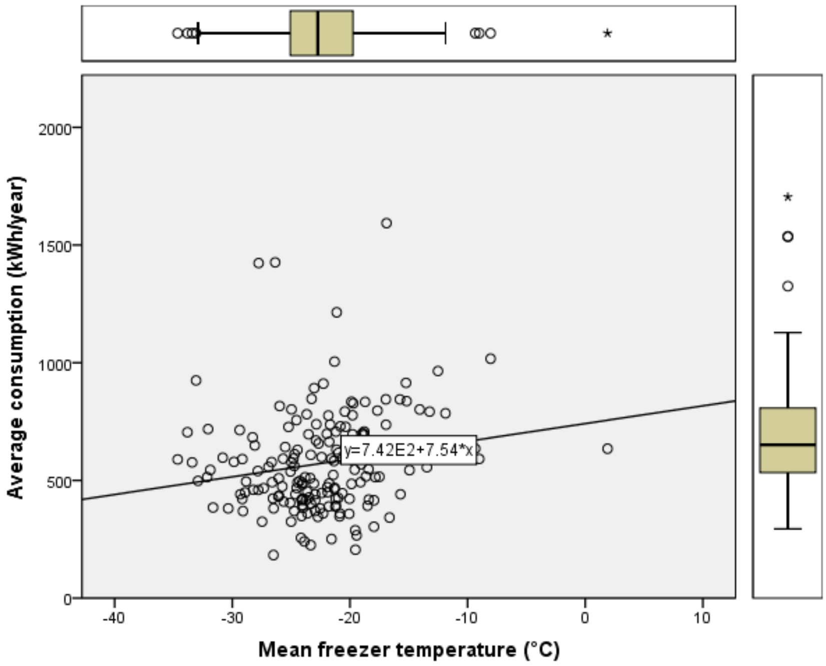


Figure F5. Correlation of mean electricity consumption with mean freezer temperature, for 'high/over'-consuming appliances

Appendix G All issues and primary issues divided by cold appliance type

		Chest freezer				Fridge-freezer				Upright freezer				Larder fridge				Fridge with ice-box			
		All		Primary		All		Primary		All		Primary		All		Primary		All		Primary	
		No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Occupant operation	Fast-freeze on	2	15%	2	29%	0	0%	0	0%	4	36%	4	57%	0	0%	0	0%	0	0%	0	0%
	High usage	0	0%	0	0%	0	0%	0	0%	1	9%	1	14%	1	25%	0	0%	0	0%	0	0%
	Maximum setting	2	15%	2	29%	0	0%	0	0%	2	18%	1	14%	0	0%	0	0%	0	0%	0	0%
Appliance age, type, size and location	Inverter appliance	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
	Large appliance	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
	Location	0	0%	0	0%	0	0%	0	0%	2	18%	1	14%	2	50%	1	50%	0	0%	0	0%
	Old appliance	1	8%	1	14%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
Fault/ damage/ repair	Damage to refrigeration system	0	0%	0	0%	0	0%	0	0%	1	9%	0	0%	0	0%	0	0%	1	100%	1	100%
	Damaged thermostat	1	8%	0	0%	1	33%	1	50%	0	0%	0	0%	1	25%	1	50%	0	0%	0	0%
	Door hinge	1	8%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
	Door seal	2	15%	0	0%	1	33%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
	Evaporator fan	0	0%	0	0%	0	0%	0	0%	1	9%	0	0%	0	0%	0	0%	0	0%	0	0%
	Iced evaporator	0	0%	0	0%	1	33%	1	50%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
	Insulation breakdown	4	31%	2	29%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
	Thermostat moved	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
	Total	**13**		**7**		**3**		**2**		**11**		**7**		**4**		**2**		**1**		**1**	

Appendix H Householder response to malfunction

Householders were asked “If problems developed with the appliance(s) where would you go for information on what to do about it?” Table H1 shows the breakdown of responses. The ‘other’ (18%) responses consisted mainly of contacting either the manufacturer, insurance company, the shop it was purchased or replacing the appliance.

Table H1. Where householders would go for information if problems developed with an appliance

	Number of households (000s)	Percent
Online	6,165	27.4
Manual	3,638	16.2
Call Someone	7,562	33.6
Fix it Myself	1,078	4.8
Other	4,012	17.8
Don’t know	1614.0	7.2

**Households can have more than one type of appliance so there is no cumulative percentage*

In terms of the proportion of households who said they would look online for information, no significant difference was found between tenure groups. A significant difference was found between different household types (Pearson’s $X^2 = 38.1$, DF = 5, $p < 0.001$). Couples with dependent children were found to be significantly more likely to look online than other groups and one person households aged 60 or over were found to be significantly less likely. This difference is likely to be driven by the age of the householders. A significant difference was found for the age of the HRP (Pearson’s $X^2 = 48.1$, DF = 4, $p < 0.001$). Households with a HRP aged 55-64 or 65 and over were found to be significantly less likely to look on-line than the other lower age bands (see Figure H1).

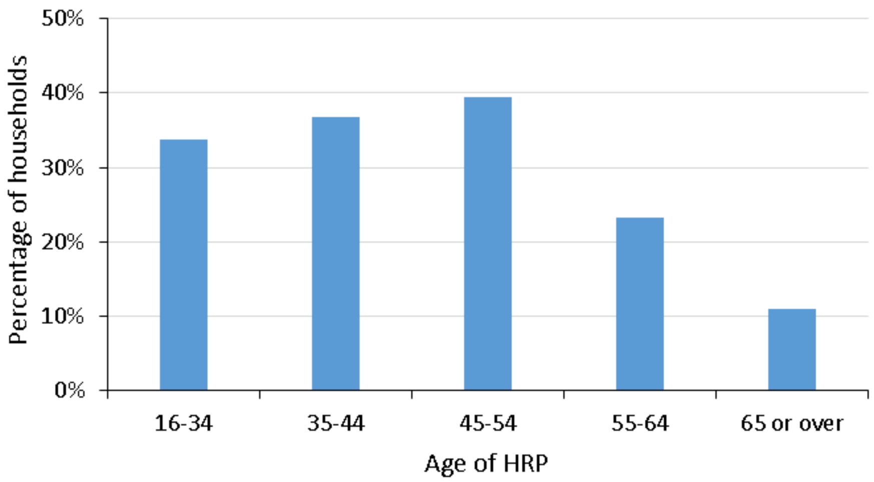


Figure H1. Percentage of each age group who said they would look online for information if their appliance developed a problem.

A difference was found by household income band (Pearson's $X^2 = 23.9$, DF = 4, $p < 0.001$). Those in the highest and lowest income quartiles were found to differ from the other groups. Those in the highest 20% were found to be more likely to look online and those in the lowest 20% were less likely. This difference was also found in terms of households who said they would look in the manual for information (Pearson's $X^2 = 13.0$, DF = 4, $p = 0.011$). Again those in the highest 20% were found to be more likely to look online and those in the lowest 20% were less likely.

In terms of households who said they would look in the manual for information, a difference was also found by tenure (Pearson's $X^2 = 12.67$, DF = 3, $p = 0.005$). Owner occupiers were found to be more likely to look in the manual than those renting, particularly those in social housing.

The results suggest those on the lowest income groups and those renting are less likely to look for information online or in the manual, instead they are more likely to call someone. A significant difference in the proportion of households who would call someone was found by both tenure (Pearson's X^2 11.90, DF = 3, $p = 0.008$) and income quintile (Pearson's $X^2 = 20.32$, DF = 4, $p < 0.001$). Owner occupiers were found to be less likely to call someone than renters, particularly those in RSL properties. Those in the in the two highest income quintiles were found to be less likely to call someone than those in the lower quintiles, particularly those in the lowest 20%. No significant differences were found between the groups in terms of the proportions of householders who said they would try and fix it themselves

Householders were asked if they looked at their manual when they first received the appliance and if a problem developed with the appliance(s) would they know where to find the manual(s)?

Figure H2 shows 34% of householders did not looked at their manual when they first received the appliance and 36% would not know where to find the manual(s) if a problem developed.

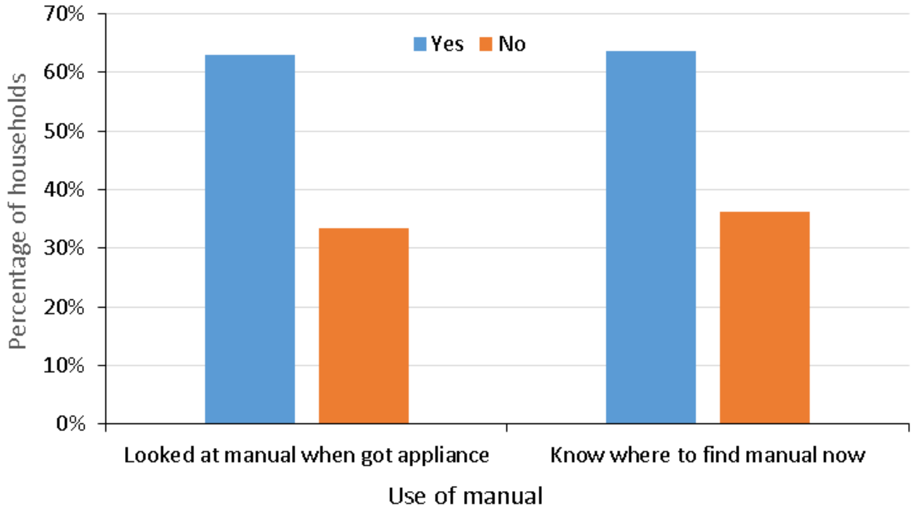


Figure H2. Proportion of householders who looked at their manual when they got the appliance and know where to find them now

Householders were also asked what they would do if they noticed a problem with their cold appliance but it was still able to keep food and drink cold. As shown in Figure H3 almost a third said they would live with it until it started to get significantly worse. A quarter said they would just buy a new appliance but almost 40% said they would try and get it repaired. If the appliance stopped working all together one third said they would get it repaired but 60% they would get a new one.

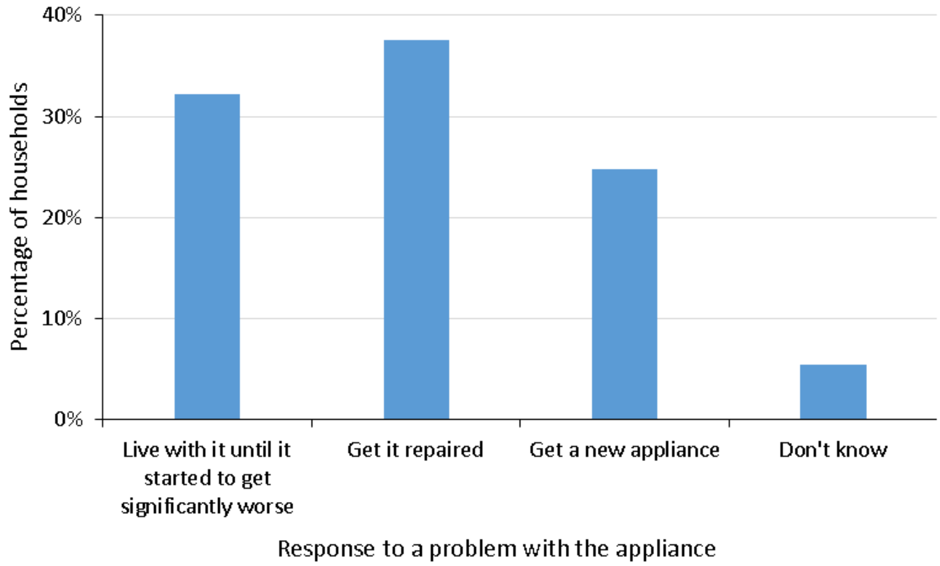


Figure H3. Householder's response if they noticed a problem with their cold appliance but it was still able to keep food and drink cold