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Study of Over-Consuming Household Cold Appliances

Literature review

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1 Introduction

In 2010 the Energy Saving Trust (EST) in combination with the Department of Energy and Climate Change (DECC), and the Department for Environment, Food and Rural Affairs (Defra), undertook a study which involved monitoring the electrical consumption of a range of appliances in over 250 owner-occupier households throughout England (Energy Savings Trust, 2012). The results from this study found that 16.2 per cent of a household's electrical consumption (excluding electric heating) was being used to operate cold appliances (primarily fridges, freezers and fridge-freezers). Further analysis of this data set was compiled into a report and published by DECC in 2014 (Palmer et al, 2014). This report established that a significant proportion of the monitored cold appliances were actually over-consuming electricity. This has led to further work which is being carried out by BRE, on behalf of DECC, to identify the causes of over consumption.

The key aims of this project are to understand the reasons behind why certain cold appliances are over-consuming; to determine how much additional electricity is being required as a consequence of these appliances; and to ascertain whether householders are actually aware of this over-consumption, as well as their level of understanding on how to prevent this. These questions are being investigated via focus groups and surveys with refrigeration engineers and other experts and a large field study of households and their cold appliances. Ahead of the field study, a literature review has been carried out to assist in the survey design and structure.

The review analyses the relevant literature on energy consumed by refrigerated appliances to help gain an understanding on what work has already been undertaken. This allows the identification of any gaps in the existing understanding, establish where future research is required, as well as highlighting any lessons learnt from any similar studies undertaken. The review was conducted between October and November 2014.

2 Methodology

The material for this review was sourced from a wide variety of literature including peer-reviewed scientific journals, grey literature sources, and other published material. Research partners undertook systematic searches relating to each of the key subject areas covered in this review. Databases used for searches were the Construction Information Service, Google Scholar and Elsevier Science Direct. Sources of grey literature included Lothian and Edinburgh Environmental Partnership (LEEP), Domestic Equipment and Carbon Dioxide Emissions (DECADE), Enertech, WRAP, Which?, BRE, and the Energy Saving Trust.

3 Findings

3.1 What is an over-consuming appliance?

Overall, household cold appliances are believed to consume 16.2% of the total household electricity usage (excludes electric heating) (Palmer and Terry, 2014). It is therefore of interest for a number of Government policies which aim to reduce energy use from the housing stock to try and determine appliances which may be over-consuming, and the reasons for this overconsumption. For the purposes of this study it is important to define what an over-consuming appliance is. Research suggests that normally a cold-appliance would use significant power for no more than 50 per cent of the time (Palmer *et al.,* 2014). This is due to the compressor cycling on and off when the desired temperature has been reached. By analysing data from monitored cold appliances, Palmer *et al.* (2014) defined over-consuming cold appliances as those which drew high power[1] for 90 per cent of the time (Figure 1). Figure 1 shows the daily electricity consumption profile of a normal and malfunctioning chest freezer; the normal appliance shows a cyclical pattern while the malfunctioning appliance shows an almost constant level of consumption. It should be noted however, that the definition by Palmer et al. (2014) was created in 2014, and subsequently any research undertaken before this date may have used an alternative definition. Furthermore, this definition was based on a sample of only 21 over-consuming goods.

[1] 'High power' usage was considered to be at half of the 90% quantile of energy consumption.

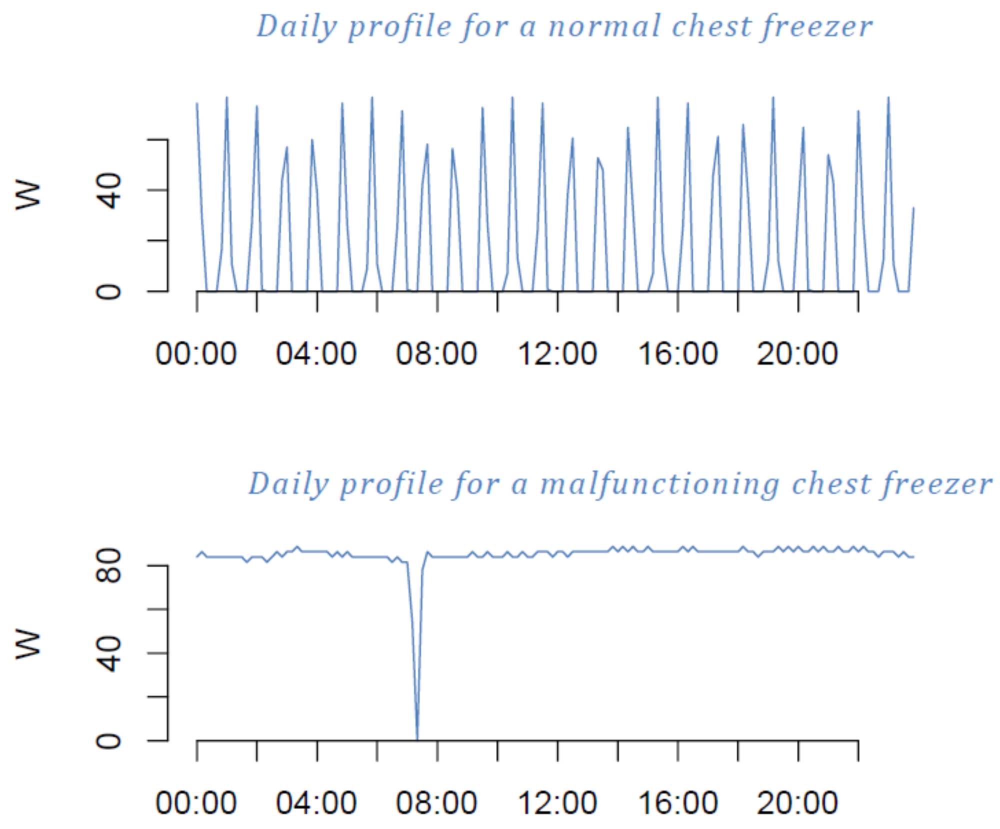

Figure 1. Daily electrical consumption profiles for normal and malfunctioning cold appliances (Palmer et al., 2014).

3.2 What factors cause over-consumption?

Issues may occur when trying to differentiate the additional electrical consumption as these may arise from a range of different factors. One possible factor influencing electrical consumption is the age of the appliance. A study produced by Enertech (2002), commissioned by the European Communities, demonstrates that older appliances are likely to consume more energy when compared to newer models. This is supported by the work undertaken by Palmer and Terry (2014) which suggested that around 20 per cent of cold appliances purchased before 1995 were faulty, while only 3 per cent of newer appliances were declared likewise, although again this was only based on 21 over-consuming appliances. With this in mind, if the proposed field study is attempting to maximise the amount of inefficient appliances it monitors it should target households containing older models.

Although Enertech (2002) demonstrates the link between the energy label of a cold appliance, and the amount of the energy it consumes, a recent study seems to provide contrasting views. A UK study monitoring households' electricity usage was unable to find a definitive link between energy rating and the amount of energy a household consumes from appliances (including cold appliances). The UK study had a sample of 398 cold appliances and not all had an energy rating recorded. Of those with an energy rating recorded, majority (>64%) were A rated. Aside from the energy rating, there are other factors which contribute to the energy use of an appliance, for example how the appliance is used, the size and the location of the cold appliance. The study concluded that these factors outweigh energy rating when determining energy use (Palmer and Terry, 2014).

There are a range of factors that influence the electrical consumption of a cold appliance. These include component faults; positioning; ambient temperature; maintenance; and the behaviour of the householder (Mennink and Berchowitz, 1998, cited in Haines *et al.*, 2010; Palmer and Terry, 2014; WRAP, 2013b, Palmer *et al,* 2014). With this in mind any study attempting to quantify the amount of additional electricity required to operate over-consuming cold appliances, should be cautious when using efficiency rating data alone. It should try to consider a wide range of factors.

Numerous components in a fridge can develop faults, and the most prominent of these have been outlined by WRAP (2013a). Of this list, there are six faults related to component failure, which when present can increase electrical consumption.

Compressor motor damage. Can cause compressor to operate excessively. **'**Burn out of windings can be due to overload caused by poor placement or high ambient temperature'. (WRAP, 2013a).**Thermostat failure.** Problems with the thermistor or control board (most likely due to poor design or manufacture) will lead to the compressor running constantly, leading to increased electrical consumption (WRAP, 2013a).

Deformation to the seal. This can lead to thermal bridging, again forcing the compressor to work for longer periods of time. One way to spot this is by finding a build-up of ice, due to moisture ingress through the seal (WRAP, 2013a). This fault is most likely due to poor maintenance by the householder, poor design and manufacture, or an inappropriate choice of material (DECADE, 1997).

Incorrectly hung door. Heavy objects being stored within the door can lead to the door hanging incorrectly. This prevents the seal from forming, subsequently leading to the same issues as a deformed seal (WRAP, 2013a).

Inadequate or uneven cooling. Frost-free cold appliances use a fan to circulate cold air around the appliance. A fault with this fan can lead to uneven or inadequate cooling, subsequently forcing the unit to work for longer periods of time (WRAP, 2013a). This is commonly caused by moisture ingress (originating from opening the door of the appliance for long periods, or alternatively a poor door seal), and can lead to ice building up around the fan resulting in slower operating speeds, or in some cases bringing it to a complete stop (White Goods Help, 2009).

Gas Leakage. Can cause compressor to operate excessively to try and maintain a cold temperature. 'Rare but could be down to manufacturing fault or damage of circuit in mishandling of unit or manual defrost, e.g. using a knife' (WRAP, 2013a).Although a list of prominent energy consuming faults have been established by WRAP (2013a), it would be sensible to see whether these factors are also identified by this research project.

While WRAP (2013a) explains various faults, they do not provide any information regarding how common each of these is. There appears to be limited literature regarding this subject area. This may be due to the fact that many research studies do not actually inspect appliances, and ultimately rely upon householders to provide information. This makes it difficult for projects to successfully assess this area, as it is thought that certain faults require technical knowledge, or even substantial monitoring to identify them (this is discussed further in section 4).

Although studies have struggled to quantify how common each individual fault is, several have estimated the proportion of fridges which are likely to be generally malfunctioning. By using the definition above (section 1) Palmer *et al.* (2014) found that 21 of the 380 cold appliances they monitored were likely to be malfunctioning, which equates to around 6 per cent. It should be noted, however, that this study was limited to a single tenure (owner occupied households) and no attempt was made to weight the data to correct any non-response bias. The consumer body Which? also undertook research in this areas, but used interviews to assess over 3000 households rather than actually monitor the appliances. Results demonstrated that the build-up of ice/frost is a problem in 15 per cent of freezers, 14 per cent of fridge-freezers, and 10 per cent of fridges (Which?, 2014a; Which?, 2014b; Which?, 2014c).

Although neither of these studies explains the actual fault, it does help to estimate the quantity of faulty cold appliances in operation in the UK. It is relatively unknown how common each particular fault is in cold appliances. Due to the lack of evidence in this area, it is recommended that the upcoming BRE study should utilise the upcoming focus group with industry experts to increase the available knowledge in this area, and ensure that the survey covers all tenures. There is a need for research into the additional consumption related to faulty cold appliances. The current available data in this area contains very small samples, and subsequently should be reviewed with caution.

3.3 How much additional energy does a faulty appliance consume?

The review of literature found limited evidence regarding the amount of additional energy consumed by cold appliances containing faulty components. The most detailed information was provided by a study undertaken by the Lothian and Edinburgh Environmental Partnership (LEEP, 1998), which analysed data from 200 households in Edinburgh to try and establish whether the electrical consumption from household appliances would differ depending on the income of the household. Faulty cold appliances found during this study, were sent to the UK Consumers' Association Research and Testing Centre (CARTC), where the units were placed under test conditions (EN 153) to establish how much energy they were consuming (DECADE, 1997). The results suggest that in some cases electrical consumption can more than double when compared to that of the UK average (Table 1). However, it must be stated the amount of additional energy can vary substantially, even when comparing appliances that are carrying the same faults. Due to the small number of appliances tested, these results are presented as case studies, rather than as representative of the stock and can only be seen as indicative of the type of faults in the stock.

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Table 1. Cold appliance component failure with respective over-consumption.

Appliance type and test ref number	Age when tested (years)	Fault	Measured Annual consumption (kWh)	Average annual consumption for appliances of a similar age (kWh)
Fridge Freezer (2103)	< 5	Broken thermostat	1420 (CA, 1995, cited in DECADE, 1997)	626 (DECADE, 1995, cited in DECADE, 1997)
Fridge Freezer* (1036)	5 – 10	Missing door seal	978 (CA, 1995, cited in DECADE, 1997)	744 (DECADE, 1997)
Fridge Freezer (1054)	5 – 10	Broken thermostat	858 (CA, 1995, cited in DECADE, 1997)	744 (DECADE, 1997)
Fridge Freezer* (1094)	5 – 10	Freezer door would not shut	1292 (CA, 1995, cited in DECADE, 1997)	744 (DECADE, 1997)
Fridge* (3037)	5 – 10	Icebox door would not close	767 (CA, 1995, cited in DECADE, 1997)	411 (DECADE, 1997)
Fridge Freezer (1001)	> 10	Deformed door seal	953 (CA, 1995, cited in DECADE, 1997)	659 (DECADE, 1995, cited in DECADE, 1997)
Fridge Freezer (2057)	> 10	Deformed door seal	825 (CA, 1995, cited in DECADE, 1997)	659 (DECADE, 1995, cited in DECADE, 1997)

Notes: *This appliance could not actually reach the target temperature during the test.

Another study which analysed this was Palmer *et al.* (2014). By using the previously mentioned definition for over-consuming appliances (section 1), the project found that on average the 12 freezers classified as over-consuming used an additional ~300 kWh/year more than the average of all other appliance. While it is to be expected that the definition used for this study should indicate higher than average levels of consumption (i.e. it is based on identifying high-consuming devices as a proxy for over-consuming devices) this does provide some initial quantification of the potential level of over consumption. However, there are considerations to be made when assessing both of these studies. Firstly, they both only managed to identify very small quantities of faulty appliances and therefore results cannot be considered in any way representative. Secondly, the research performed by CARTC (CA, 1995) is almost 20 years old, suggesting there is a need for up-to-date research in this area, as some of the older appliances tested by CARTC are unlikely to still be in circulation in the UK.

3.4 The impact of occupant behaviour

The BRE survey will include an interview with the household about their use of cold appliances. It is therefore important to ensure that this interview covers the most relevant aspects of behaviour. Previous studies have looked into the additional energy consumed due to different occupant behaviours. Behaviours such as opening the door of a cold appliance have been found to increase the total electrical consumption by around 8 per cent (Mennink and Berchowitz, 1998). A study by Saidur (2002) suggests that each time the appliance door is opened it can increase electrical consumption by up to 12.4 Wh/day, which would equate to around 45 kWh/year if the fridge is opened 10 times per day. These studies are supported by recent work undertaken by WRAP (2013b), who illustrate that keeping the freezer door open for 2 continuous minutes over a 24h period can increase electrical consumption by around 10 per cent, when compared to stable operation. While also adding warm food during the same 2 minute period mentioned above, increased consumption by 26.7% when compared to stable operation (Table 3).

Table 3. The influence of human behaviour on the electrical consumption of cold appliances (WRAP, 2013b).

Test periods in chronological order (each of 24h duration)	Compressor run time (%)	Average power (W)	Total consumption over 24h (kWh)
Stable operation before any food added[2]	30.0	24.0	0.576
Warm food added during 2 minute door opening[3]	38.2	30.4	0.730
Stable operation after food added	30.2	24.2	0.581
No food added but 2 minute door opening	33.3	26.6	0.638
Stable operation after door opening only	30.1	24.1	0.579

[2] Stable operation includes the freezer door being opened during 2 one-hour periods each day to simulate breakfast and evening meal periods. In each of these periods the door was opened for a duration of 15 seconds every 10 minutes to an open angle of greater than 60 degrees.

[3] Beef lasagne (enough for two people) in an air tight container, cooled to room temperature of approximately 20°C; beef cottage pie ready meal (approximately 400g two person portion) in original packaging of plastic tray with film lid and cardboard sleeve, cooled to room temperature of approximately 20°C; chicken breasts (two out of a pack of four) in a freezer bag, at fridge temperature of approximately 7°C; and half a loaf of white sliced bread in original packaging, at a temperature of approximately 7°C.

Further research has established that leaving food to reduce in temperature from 50°C to 20°C before placing it in the fridge will reduce the amount of additional electricity consumed by two thirds (Lepthien, 2000).

General maintenance of a cold appliance can also be important in helping to reduce consumption. Research undertaken by Bos (1993) found that efficiencies can be reduced by up to 6 per cent when owners fail to remove dust from the condenser. The results suggest that the influence an occupant has on the energy consumption of a cold appliance is too large to disregard. Subsequently, during the BRE survey householders should be asked a range of questions allowing researchers to understand how each household uses their cold appliances.

With an estimated 50 per cent of all food poisoning cases originating in the home, it is important to ensure that goods are correctly stored (Perry, 1994). Current advice from the NHS (2014) illustrates that refrigerators should be kept below 5°C in order to prevent food spoiling, and subsequently reducing the risk of food poisoning. However, while monitoring 48 domestic refrigerators, WRAP (2010) found that 71 per cent were operating at temperatures exceeding this recommended level. This is surprising considering that the same study established that 79 per cent of people could correctly identify the recommended temperature of a fridge, without being prompted (WRAP, 2010). Understanding this is very important as operating temperatures can have an effect on energy use.

A recent study by WRAP (2013b) measured the additional electrical consumption required to reduce the temperature in a fridge from 7°C to 4°C. Results demonstrate that this increase could be as much as 19.1%, although on average the increase was found to be 13%. Subsequently, it has been estimated that it could require an additional 0.6 TWh per annum to ensure that all of the domestic cold appliances in the UK are set to the correct temperature (WRAP, 2013b). This increase in electricity would result in an additional 321,000 tonnes of CO_{2e} being released per year in the UK, while conversely the same reduction in temperature was only estimated to save 70,000 tonnes of food, which equated to 270,000 tonnes CO_{2e} (WRAP, 2013b). It must be noted, like many other studies regarding cold appliances this estimate was based upon a very small sample, and subsequently the results should be taken with caution. Nevertheless, if the government introduced policies capable of reducing the temperature in cold appliances to the recommended level, it is important for this study to take into account the potential increase in energy consumption. Furthermore this study will use data loggers in each of the monitored appliances to help researchers factor in the influence that temperature settings have upon the energy consumption of a cold appliance.

A further consideration is positioning. Any increase in ambient temperature will force the appliance to work harder, and subsequently can be significant in determining the electrical consumption of cold appliances. The ambient temperature can be influenced by a range of factors. One of these factors is the season, as the external temperature will alter. Two separate studies have found households where the electrical consumption of cold appliances has increased by over 50 per cent from winter to summer periods (LEEP 1998, Palmer *et al.,* 2013). It was suggested that this seasonality was most likely to occur in low-income households, where they may not be able to afford to heat their building sufficiently in the winter period, allowing refrigerators to operate more efficiently during colder months (LEEP, 1998). It is therefore recommended that the BRE field trial monitors homes during both the coldest and warmest times of the year.

Changes in ambient temperature can also arise from positioning cold appliances next to an oven; boiler; in a location receiving solar gain; or placed too close to the wall subsequently preventing any ventilation to the condenser (DECADE, 1997). Research in Germany has demonstrated that a change in ambient temperature can have substantially large impacts on electrical consumption (Table 4, (HMWVL, 2005)). This has also been seen in a Malaysian study which found that for every 1°C increase in ambient air temperature, a fridge-freezer will consume an additional 47-53 Wh/day (Saidur, 2002). In a follow-up to this study Saidur (2005) concluded that when comparing the effect that ambient temperature, freezer loading, and door openings have on energy consumption; ambient temperature had the largest influence, followed by loading. In a similar study Geppert and Stamminger (2013) found that the ambient temperature was far more important in dictating electrical consumption when compared to thermistor temperature settings and the additional heat load from storing warm food.

Table 4. Change in the electrical consumption of cold appliances due to a change in ambient temperature (HMWVL, 2005).

Start ambient temperature	New ambient temperature	Decrease in electrical consumption
25°C	21-23°C	16 %
25°C	17-21°C	32 %
25°C	13-17°C	53 %

The evidence suggests that ambient temperature is extremely important in dictating energy usage, and subsequently should be monitored simultaneously with the electrical energy consumption. With regards to loading, when and how people shop has the potential to influence the amount of food in the fridge at any one time. Subsequently it would be beneficial to ask occupants to record when they have shopped during the monitoring period, and whether they undertake one large shop a week, or several smaller ones. The interviewer can then report this when returning to the household to remove the monitoring equipment.

Overall, the evidence to date illustrates that it could be a combination of various factors that lead to a cold appliance over consuming. However, there is a distinct lack of research into the quantifiable effect each particular component fault has on electrical consumption. One problem with this is being able to successfully remove all of the other factors mentioned above. A possible way to overcome this could involve monitoring a range of faulty appliances before and after an engineer has repaired the unit. Only then can households truly understand the amount of money and energy a particular fault is costing them.

3.5 Which kinds of households have over-consuming cold appliances?

Research has shown that certain social-demographic groups are more likely to own over-consuming appliances when compared with others. It has already been discussed that older appliances are more likely to be over-consuming (section 2). With this in mind, results from the study undertaken by LEEP (section 3) illustrated that low-income households would be over four times more likely to buy second-hand cold appliances, when compared to medium/high–income households, subsequently leading to low-income families being in possession of older appliances (LEEP, 1998). Another social-demographic group of interest is households containing multiple pensioners. Data obtained by Intertek (2012) shows that refrigerators, fridge-freezers, and chest freezers owned by multiple pensioner households consume more energy per year than any other household demographic. Furthermore, Palmer and Terry (2014) and BRE (2013), found that older people were likely to own significantly older cold appliances. This evidence demonstrates that in order to identify over-consuming cold appliances in the UK, both low-income households, and those occupied by multiple pensioners, should be initially targeted for monitoring.

3.6 Householder awareness of faults, and the likelihood of undertaking repairs

The identification of faults appears to be an issue. Some of the faults seen in cold appliances, such as a damaged door seal, can be identified by a simple visual check; however other faults, such as a broken thermostat, can require the appliance to be monitored over a period of time (DECADE, 1997). This has not been helped with more and more electronic devices being installed within certain modern fridges, as this can make faults increasingly difficult for even engineers to diagnose (UK White Goods, 2005). However, Palmer *et al.* (2014) suggest that there may be fast simple methods which householders can undertake (if provided with guidance), such as listening to the compressor, which enable them to identify more technical faults. Nevertheless, without any type of intervention householders may find it difficult to establish whether their cold appliance is consuming more electricity than it is supposed to. The BRE study should consider using the focus group to see whether current methods of diagnosis exploited by engineers can be adapted to help UK householders. With this information it may then be possible to ask occupants about their knowledge in this area, as this would allow the study to understand the current level of awareness.

The study undertaken by LEEP (1998) asked 200 householders whether they felt their cold appliance was working correctly (section 1). The study found that only 48 per cent of low-income households felt their appliance was working correctly, compared to 91 per cent in medium/high-income households. However, when asked whether they had undertaken repairs on their appliances, those from medium/high-income homes were more likely to do so (LEEP, 1998). Not only does this suggest that low-income families are more likely to own faulty appliances, but they also seem to be less inclined to undertake any repairs to them (table 5). It must be stated that the percentages related to faulty appliances were based on the householders' perception of the appliance, and not faults diagnosed by an engineer. Nevertheless, the evidence does show that there appears to be a barrier, most likely economic, preventing this social-demographic from undertaking repairs on faulty cold appliances. LEEP (1998) considered that the high running cost of the faulty appliance may prevent low-income householders from saving the money required to carry out necessary repairs.

Table 5. Lothian and Edinburgh Environmental Partnership Interview Results (LEEP, 1998)

LEEP Project Interview Results		
Householder's declared condition	Low-income households	Med/High-income households
Good	48 %	91 %
Faulty but working	52 %	9 %
Out of order	0 %	0 %
Repairs undertaken	Low-income households	Med/High-income households
Within the last year	0 %	4 %
Over a year ago	6 %	8 %
No repairs	94 %	88 %

There appears to be a limited amount of literature regarding the cost of repairing cold appliances. Which? (2014d) illustrates that certain repairs, such as changing a damaged door seal, can be undertaken by the householder, subsequently reducing the price. However the price of replacement parts can vary substantially depending on the appliance model. Evidence from a recent study suggests that a replacement door seal can cost anywhere from £10 to £70 (Which?, 2014d). Conversely, there are other repairs, such as the replacement of a compressor unit, which need to be performed by a trained technician. In 2010, Which? (2014d) asked 99 companies for a quote to replace a compressor unit in a particular fridge freezer model; the results found that prices ranged from £118-£302. This demonstrates how much of an influence an installer, and perhaps location, can have on the affordability and payback periods related to the faults in cold appliances.

Even if the householder wants to undertake repairs, its not always possible. First of all there is a chance, if the model is particularly old, that the manufacturer no longer produces the parts for that model. Furthermore, manufacturing techniques can also prevent this. For example, there are certain cold appliances which are manufactured in a way that the door seal is actually integrated into the system, making it very difficult, or even impossible, to replace (DECADE, 1997).

It appears that there is a lack of guidance available to householders that would enable them to establish whether their appliance is over-consuming. Furthermore, there is a need for information that not only lets the householder know how much additional money their over-consuming appliance is costing them, but also how much it would cost to undertake remedial action. Finally, householders would benefit from manufacturers not only improving the lifetime of the commonly faulting components, but also designing the appliance in a way that allows for quick and easy repair of these components.

4 Major findings

- A number of studies have estimated what proportion of cold appliance are malfunctioning / consuming more energy than they were designed to and have begun to assess what types of appliances are most likely to suffer particular problems.
    - Palmer and Terry (2014) found that around 6 percent of appliances were malfunctioning.
    - Research suggests that older appliances are more likely to consume more energy compared to newer models. A study concluded that around 20 percent of cold appliances purchased before 1995 were faulty while only 3 percent of newer appliances were declared faulty (Palmer and Terry 2014).
    - Research undertaken by Which? demonstrates that the build-up of ice/frost is a problem in 15 per cent of freezers, 14 per cent of fridge-freezers, and 10 per cent of fridges (Which?, 2014a; Which?, 2014b; Which?, 2014c)
- The literature suggests that Low-income households, as well as those containing multiple pensioners are most likely to own over-consuming cold appliances.
- The literature has found there to be a range of factors that have the potential to increase the electrical consumption of a cold appliance. Including component faults; positioning; maintenance; ambient temperature; and the behaviour of the householder. Consequently the BRE study should attempt to ask the householder about as many of these factors as possible. This will enable researchers to understand how each occupant uses their appliance, as well as monitor as many factors as possible.
- It is relatively unknown how common each particular fault is in cold appliances. The BRE study must attempt to increase the knowledge in this area, and it is suggested that the upcoming focus group with industry experts is used to aid this.
- There is a need for research into the additional consumption related to faulty cold appliances. The current available data in this area contains very small samples, and subsequently should be reviewed with caution
- Finally it appears that there is a lack of guidance for householders that would enable them to establish whether their appliance is using more energy than it should, consequently costing them additional money. If the problems with an appliance are not identified, they cannot be tackled.

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