EVALUATION OF SUITABILITY OF RECYCLED DOMESTIC APPLIANCES FOR RE-USE

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ABSTRACT

Reasons for disposal of domestic refrigerators and whether some of the appliances could potentially be re-used was studied. Based on visual inspection, a simple operational test and an electrical inspection, 28% of appliances were considered suitable for re-use. Potentially, these appliances could be provided cheaply or without cost to low income households. It might be unethical to provide low income households with appliances that had high energy use or performance issues, therefore the appliances were tested to compare the temperature and energy performance with their original stated performance. In addition the appliances were compared to current energy efficient appliances. For appliances where manufacturers data was available it was found that 18 (out of 22) appliances used more energy when tested than provided on the energy label, 1 appliance used almost identical energy and 3 appliances used less energy. Compared to current appliances only 5 appliances were better than or equal to an ‘A’ rated appliance.

Key words: Domestic refrigeration, Recycling, Energy Efficiency.

1 INTRODUCTION

Worldwide there are about 1.5 billion domestic refrigerators in use (IIR, 2015). Refrigeration is a vital means to provide consumers with food that is of good quality and is safe microbiologically. Refrigeration can also help to reduce food waste as it enables consumers to store food for longer periods and to freeze food for long term storage and flexibility. Ownership of domestic refrigerators varies quite widely with greater saturation in North America, Western Europe and Pacific regions where approximately 60% of the population own a domestic refrigerator (Barthel and Götz, 2012). In other regions the uptake is far lower being as low as approximately 3% in South Asia.

The average life expectancy for a properly maintained refrigerator is between 14 and 17 years (SFGATE, 2017) which means that between 88 and 107 million domestic refrigerators are thrown away each year. In most countries these appliances enter a recycling plant where the appliances are broken down into base materials and components which are either re-used, re-cycled or placed into landfill sites. Refrigeration products contain a range of materials than cannot go to landfill or be released into the atmosphere. These include refrigerants which may be ozone depleting substances, greenhouse gases or explosive or toxic materials. They also contain ferrous metals, non-ferrous metals (mercury, lead, zinc, beryllium, cadmium, nickel and magnesium), plastic, rubber, glass, oil, polychlorinated biphenyls, hexavalent chromium, bromine and antimony (Department of Environment, 2014). Many of these materials need specialist disposal and recycling at end of life.

Limited information on the cost to recycle refrigerators is available. Stroop and Lambert (1998) state that 15 kg of CO_2 emissions are produced per appliance (excludes re-use of materials). In 2001 Lambert and Stroop claimed that the cost for recycling a typical domestic refrigerator was $20. Using inflation rates as calculated by the Bank of England (2017) this would equate to $30.36 in 2016.

The purchase of new refrigerated appliances is often not driven by the appliance no longer operating correctly. New purchases are often driven by a desire to have the latest model or by deterioration of refrigerator door seals, breakage of internal shelves or discolouration of the exterior (Department of Environment, 2014).

Even in developed markets a large proportion of refrigerators are purchased second hand. For example in Australia it was estimated in 2007 that 60% of refrigerators that had been replaced remained in use

(Department of Environment, 2014). Stroop and Lambert (1998) claimed that 50% of discarded Dutch refrigerators are exported or re-used. Whether enabling refrigerators to enter a second hand market is a good idea, is debatable. On one hand there is a benefit as fewer new refrigerators need to be manufactured and the material costs associated with the manufacture are avoided. In addition there are potential social, health and welfare benefits if the appliance if provided to a consumer who previously did not have access to domestic refrigeration.

There are also potentially negative aspects of refrigerators entering a second hand market. The average annual electricity consumption of domestic refrigerators varies according to location in the world and is claimed to be between 377 and 638 kWh per year per appliance, with an overall average of 450 kWh per appliance per year (Barthel and Götz, 2012). The energy used by refrigerators has reduced dramatically and so potentially energy and associated carbon savings can be achieved if old less efficient appliances are replaced by new efficient models. Barthel and Götz (2012) claim that worldwide annual electricity consumption by domestic refrigerators and freezers could be reduced from 649 TWh to 475 TWh by 2020 and to 413 TWh by 2030. This assumes that the most energy efficient option is selected as the replacement and includes the estimated 27 % increase in the number of cold appliances in use by 2020 and a 62 % increase by 2030. As second hand appliances may often be provided to consumers who have the lowest incomes it may not be considered socially responsible to provide an older appliance that is inefficient and expensive to operate.

The aim of this work was to determine whether refrigerated appliances destined for recycling could be re-used and whether their performance (temperature and energy) compared favourably with modern available appliances.

2 METHOD

The work was carried out in 2 stages:

1. Stage 1. An initial assessment of 100 domestic refrigerators to determine why they were being recycled.
2. Stage 2. Appliances from stage 1 that were potentially suitable for recycling were tested to ascertain their performance (temperature and energy) and results compared to the stated performance of the appliance and to current day appliances.

2.1 Stage 1

One hundred domestic refrigerators that were destined for recycling were obtained from a recycler. The appliances were examined to determine the reason(s) why they had been condemned. The 100 appliances were a mix between chillers, freezers and fridge-freezers of various ages and conditions. All appliances had direct expansion type refrigeration systems.

Appliances were assessed either using a visual inspection, or in some cases a physical inspection. Visual inspection aimed to gather information on the appliance type, manufacturer, model, size, temperature class, year of manufacture, energy usage, refrigerant, information on components, star rating of freezer and other attributes such as special features and control settings.

Physical inspection included:

1. PAT (Portable Appliance Test) – the appliance was tested for earth bond, insulation and current leakage.
2. Door seals. All seals were tested with an 80 gsm A4 sheet of paper to determine the grip of the seal. Where the paper was not gripped or there were visible gaps the seals were rated as poor or awful.
3. The appliance defrost drain (if present) was assessed visually and by probing with a piece of wire to see if the drain was blocked.
4. If the appliance passed a PAT the appliance was placed into an environmentally controlled room at 30°C. The appliance was switched on with a thermocouple sensor placed in the geometric centre of each cavity. Temperature readings were taken to determine whether the appliance was capable of maintaining a temperature suitable for storage of food.

All appliances were assessed for re-use. Appliances were deemed unsuitable for re-use if:

1. They failed the PAT.
2. They were unable to operate at a suitable temperature for food storage (the thermostat setting was adjusted if necessary).
3. They had more than one shelf or drawer missing or damaged.
4. The interior and exterior condition was poor.
5. The door seals were in poor condition (rated as poor or awful).
6. The door hinges were damaged (rated as damaged).
7. The condenser was damaged (rated as dirty or damaged).
8. The defrost drain was blocked and could not be unblocked.
9. The appliance light was faulty and could not be replaced simply.

2.2 Stage 2

The energy used by the appliances considered suitable for re-use was assessed using a method that closely followed BS EN 62552:2013 (Household refrigerating appliances - Characteristics and test methods) test standard.

The tests carried out determined:

1. Energy used by the appliances. Energy use was obtained from 2 tests at the set point temperatures required in BS EN 62552:2013. Energy use was obtained by interpolating (or occasionally extrapolating if interpolation was not possible) between the 2 tests to provide the energy use at the exact temperature stipulated in the standard (for that particular appliance type).
2. Temperature control of the appliances. Freezers were loaded with standard Tylose test packs and M-packs (measurement packs with a calibrated t-type thermocouple in the geometric centre). Chilled compartments had brass cylinders with a t-type thermocouple in their geometric centre placed in the measurement positions stipulated in BS EN 62552:2013

The energy used by the appliances that could potentially be re-used were compared to the energy used by new A, A+, A++ and A+++ appliances of similar type and size.

3 RESULTS

3.1 Stage 1

3.1.1 Information on appliances examined

Appliance types were categorised as shown in Figure 1. Eight percent of appliances were built-in type appliances. Appliance sizes (gross volume) varied from 84 to 532 litres. Most appliances were between 100 and 350 litres, the under-counters being around 100 to 200 litres and the uprights being 250 to 350 litres. By far the majority (66%) of appliances operated on iso-butane (R600a). Determining the age of the appliance was difficult and the age of only 18% of appliances could be determined from information on the appliance rating plate or from information on the compressor. In these cases the appliances ranged from 2 to 21 years old. It should be noted that a number of appliances (12%) contained Dichlorodifluoromethane (R12) which is a CFC that has been banned since 1994 in Europe. Therefore these appliances must have been at least 21 years old.

Only 3 appliances were thought to have undergone any remedial work (assumingly to repair them). Of these; in 1 appliance the skin condenser had been removed from the refrigeration circuit and it appeared that a new compressor had been fitted (the appliance was a fridge-freezer with 2 compressors). Another appliance had the insulation at the rear of the appliance cut away to expose the thermostat. It appeared that the thermostat had not been replaced and the appliance was unable to reduce to a suitable food storage temperature when tested. The third appliance had a refrigerant line tap still attached to the refrigeration pipework. The appliance was able to operate at a suitable food storage temperature and so it may be possible that the compressor was replaced or the appliance had been re-gassed with refrigerant.

3.1.2 Energy used by appliances

Very little information was available on energy used by the appliances. Only 12 appliances had an energy use per 24 hours listed on the appliance rating plate. Ten appliances had an energy label, with 3 being labelled ‘A+’, 6 labelled as ‘A’ and 1 labelled as ‘B’. The power input to the appliance was commonly available on the appliance label. However, this only provided an indication of peak power and not energy usage and so was not especially useful in determining the total energy used by the appliance.

3.1.3 Thermostat setting

Thermostat setting may be an indicator of whether an appliance was operating correctly. Users may increase the setting (attempting to reduce the temperature in the appliance) if there was a long term fall off in performance caused by refrigerant leakage, reduced condenser capacity or increases in heat loads caused by damage to seals or the insulation. The greatest proportion of appliances (49%) where the thermostat setting was available, were set to maximum or near maximum setting (at least 80% of the full dial setting).

3.1.4 Re-use of appliances

Twenty-eight appliances were considered suitable for re-use. Of these, 13 had no faults and 15 had very minor faults that would not prevent re-use (generally a shelf or drawer missing or cracked).

3.1.5 Reasons for failure/recycling

The main reasons for an appliance being recycled were examined. Most appliances (74%) had more than 1 reason for failure and 13% of appliances had 5 or 6 failures. Reasons for failure are shown in Figure 2. The majority of appliances were deemed to have been rejected due to drawers or shelves being damaged or lost and internal condition of the appliance becoming poor.

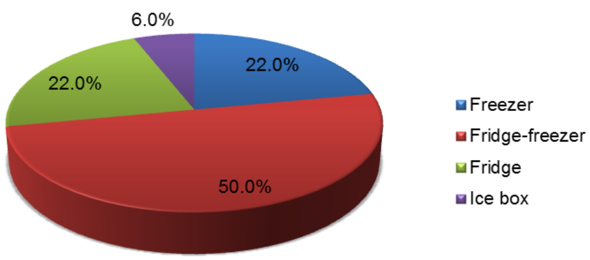

Figure 1. Appliance type categories.

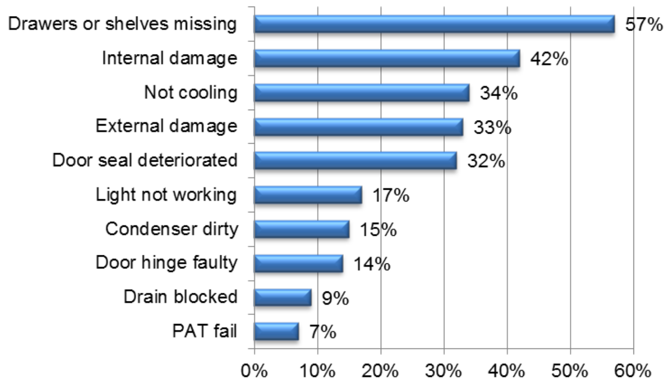

Figure 2. Reasons for failure.

3.1.6 Failure of appliance types

The percentage of failures within each appliance type is presented in Figure 3. Whether failures varied between appliance types was investigated using a Chi-Square test. However, the data set did not contain sufficient replicates to provide a robust analysis (this was especially the case for fridges with an ice box where there were only 6 replicates). There did appear to be some indications of failures directly related to appliance type. For example items such as missing drawers or shelves were higher in fridges and fridge-freezers where it would be expected that there would be more continued and regular usage. There appeared to be a greater level of damage to the outside of appliances in freezers and fridges with ice boxes. Ice box appliances appeared to have a greater level of drain blockage.

It also appeared that freezers and fridges with ice boxes tended to be rejected for recycling when they had slightly more faults than fridges or fridge-freezers. In addition only 18.2% of freezers had no more than 1 fault compared to the other appliance types where 27.3-33.3% of appliances were recycled with no more that 1 fault.

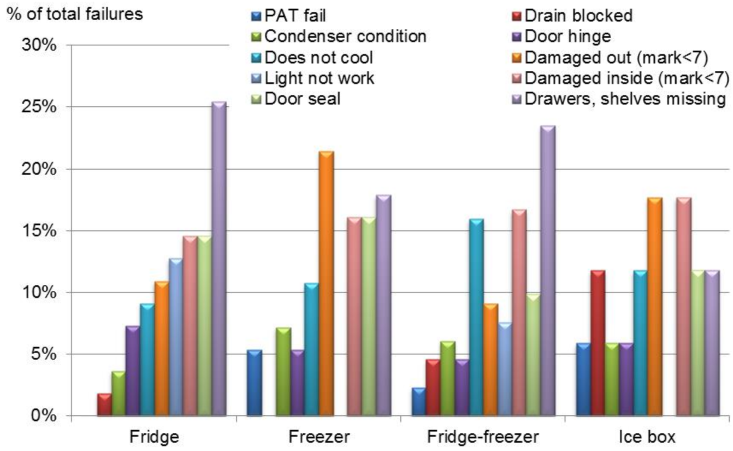

Figure 3. Failure category for all appliance types.

3.2 Stage 2

One cabinet out of the 28 was removed from the tests as it was found to no longer work when tested.

3.2.1 Energy consumption in test compared to original performance

Manufacturers data on the energy used by 5 appliances was missing and these appliances could not be included in the analysis. Figure 4 shows the stated annual energy consumption of all the 22 appliances and compares it to the energy consumption in the tests carried out. Eighteen (81.8%) of the appliances used more energy than was claimed by the manufacturer. Three (13.6%) of the appliances used less energy than claimed and 1 appliance (4.5%) used almost identical energy to that claimed.

One chiller used considerably more energy than claimed originally. It was possible that the appliance had lost some refrigerant after the initial stage 1 temperature test as the compressor operated 100% of the time and the minimum temperature achieved in testing was 8°C (which is higher than would be considered 'normal').

The results were divided by appliance type (freezer, chiller, ice box or fridge-freezer). Only 1 ice box appliance was included in the analysis and therefore there were insufficient data to provide any meaningful results. An ANOVA (analysis of variance) demonstrated that there were no significant ($P>0.05$) differences between the freezer, chiller or fridge-freezer appliance groups.

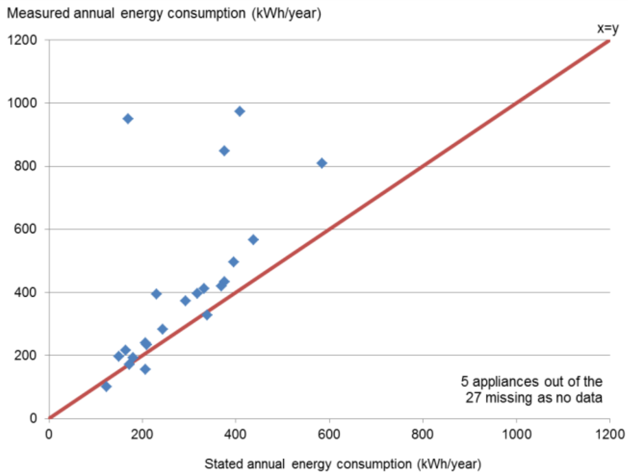

Figure 4. Energy consumption of the appliances when new and when tested.

3.2.2 Energy consumption in test compared to current appliances

The energy consumed by the appliances tested was compared to current appliances available on the market. This was achieved through calculating the AEC (Annual Energy Consumption) range for current A, A+, A++ and A+++ appliances for a given equivalent volume. The equivalent volume of the appliances tested and their AEC were then superimposed onto the graphs to compare current appliance performance with the performance of the appliances tested. For the analysis the appliances were separated into chillers, freezers and fridge-freezers (which included the ice box appliances). Only 1 out of 4 of the chillers, 2 out of 5 of the freezers and 2 out of 17 of the fridge-freezers that were tested were better than or equal to current A rated appliances. None of the appliances tested was better than a current A+ appliance.

3.2.3 Payback periods for appliances that could be re-used

Even if the appliances that could potentially be re-used were more expensive to operate there still may be an argument for consumers to re-use them if the cost of the additional energy was less than the purchase price of a new appliance (even if this might not be the lowest carbon option). The cost for operating the re-used appliances were compared to operating an equivalent current A+ appliance. The costs for a new appliance was taken from SEC (2009) and increased using the Bank of England (2017) inflation rates (£414 for a refrigerator, £467 for a freezer and £641 for a fridge-freezer). The figures for new appliances appeared quite high and so figures were also extracted from the internet for the cheapest appliance within each category to provide a minimum and maximum new cost for appliances (£123 for a refrigerator, £149 for a freezer and £190 for a fridge-freezer). The additional energy used by these appliances was converted into an additional annual cost using a value of 14.37 p/kWh (Energy Savings Trust, 2017). The benefits in buying a new appliance versus re-using an old appliance are presented in Figure 5 and indicate that it was difficult to justify the purchase of a new appliance solely on the additional energy costs unless the new appliance was cheap to purchase and the re-used appliance was kept for more than 10 years.

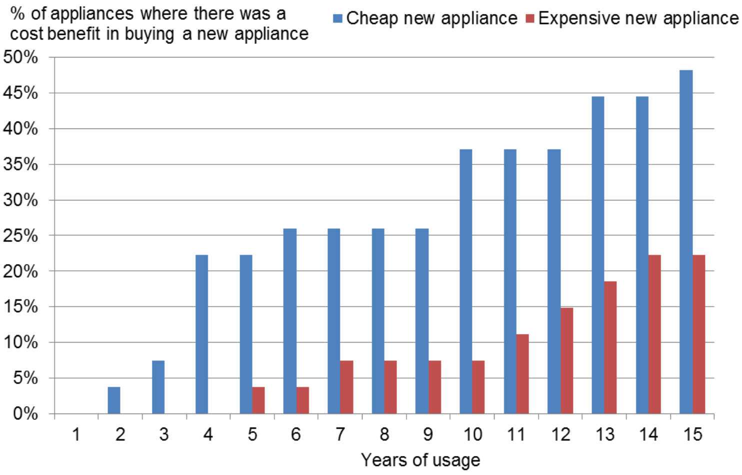

Figure 5. Benefit in buying a new appliance versus using a re-used appliance.

3.2.4 CO_{2e} impact on recycling appliances

The impact of re-using the recycled appliances was assessed. The analysis was based on the carbon used to manufacture, operate and recycle a new A+ refrigerator compared to the carbon used to recycle and operate a re-used refrigerator. The carbon used for manufacturing a typical domestic refrigerator was assumed to be 257 kg CO_{2e} and was based on data from Xiao et al (2015). The carbon associated with recycling was assumed to be 15 kg CO_{2e} based on information from Kim et al (2006).

An assumption was made that when a user decided to replace their refrigerator and purchase a new A+ rated model that another user could re-use the refrigerator (scenario B). Alternatively the other user could purchase a new A+ rated model instead of accepting the re-used refrigerator (scenario A) (Figure 6).

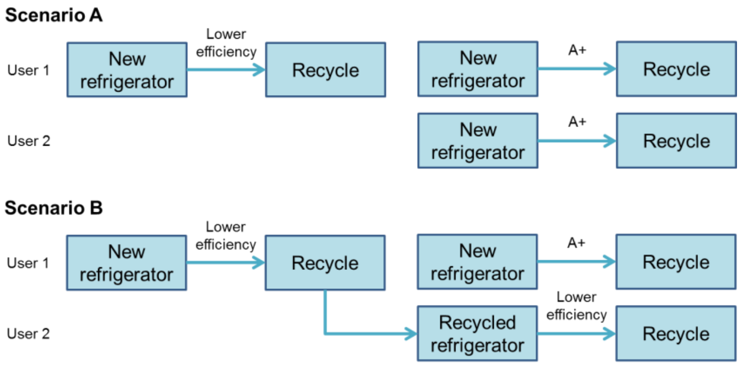

Figure 6. Assumption applied when comparing the impact of recycling on CO_{2e} emissions.

If N = CO_{2e} emissions from a new appliance, R = CO_{2e} emissions from a recycled appliance and y = year, then the difference between scenario A and scenario B over time is:

$$\Delta AB = N + R + \sum_{0y}^{ny} Energy\ used\ by\ lower\ efficieny\ applaince - Energy\ used\ by\ A^{+} appliance$$

Therefore the carbon benefit of purchasing a new appliance or of recycling an old appliance can be calculated. Results are shown in Figure 7. It can be seen from a carbon emission perspective that there is a only a major benefit in purchasing a new appliance if the appliance is used for extended periods.

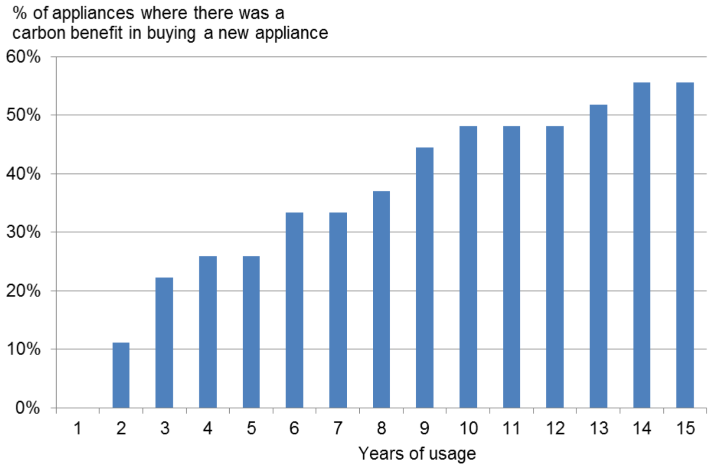

Figure 7. Carbon benefit in buying a new appliance versus using a re-used appliance.

4 DISCUSSION AND CONCLUSIONS

Out of the 100 appliances examined, 28 were suitable for re-use. Of these, only 4 appliances from the 22 with known energy consumption used equal or less energy than claimed by the manufacturer when new. The analysis assumed that the energy usage claimed by the manufacturer was correct. If a margin of 10% tolerance was allowed, 15 of the appliances would still use more energy than when new. It would be expected that appliances would use more energy as they age. For example Biglia et al (2017) found that appliances under 2 years of age used approximately one third of the energy used by appliances over 11 years of age.

It would therefore be expected that considering energy usage and cost to operate the appliance the lowest cost option would be to replace old appliances with a new efficient model. This was not found to be the case for most of the appliances examined. There was a clear monetary case to re-use recycled appliances, especially if the cost of a new appliance was high. This was because in approximately half the cases the energy used by the re-used appliance was less than 30% more than an equivalent A+ rated appliance. As the additional energy cost was relatively small in comparison to the cost of a new appliance this favoured re-using recycled appliances.

From a carbon emissions perspective there was also an argument to re-use some appliances. The carbon emissions during manufacture were quite critical in this assessment and figures presented in the literature can vary. The figure used in the analysis (257 kg CO_{2e}) was relatively low in comparison to the figure of 400 kg CO_{2e} which was used by VHK and ARMINES (2010) for a typical appliance. Figures presented for the carbon emitted in recycling tend to be less variable and are generally reported as being a small proportion of the overall carbon emitted. As the carbon used in manufacturing increases, the bias towards re-using appliances also increases.

Overall there is an argument that at least some appliances should be re-used from both a monetary and carbon perspective. If appliances best suited to re-use could be identified this would provide both consumers with access to economic refrigeration and would also provide a means to reduce carbon emissions.

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