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Performance of domestic refrigerators in laboratory and home environments

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ABSTRACT

Data was collected on temperature control and energy consumption of domestic refrigerators in the home. Data from the survey was extracted to compare the performance of the refrigerators in the home with performance in a test environment.
Due to differences in internal and external appliance temperatures between laboratory and home data, the energy measured in the home was normalised to enable direct comparison between laboratory and home energy consumption. Overall without normalisation 61% of appliances consumed more energy in the home than the laboratory. After normalisation this value was increased to 85%. The rank order of energy use was also assessed and found to vary considerably between the laboratory and the home (irrespective of whether energy consumption was normalised for temperature effects). The reasons for the differences in energy use are discussed and suggestions made to provide consumers with a more transparent method to assess performance of refrigerated appliances in their homes.

Key words: Survey, Domestic refrigerators, Domestic freezers, Energy consumption, Laboratory testing

1 INTRODUCTION

Worldwide there are around 1.4 billion domestic refrigerators and freezers each of which are claimed to consume on average 453 kWh of energy per year (Barthel and Götz, 2012). This amounts to a total worldwide energy use of 649 TWh annually which according to the IEA equates to almost 4% of global electricity (IIR, 2015). The worldwide market for appliances is expected to increase. Barthel and Götz (2012) state that worldwide a 27% increase in cold appliances is expected by 2020 and that this will increase to 62% by 2030.
Improving the energy efficiency of refrigerators and freezers has a significant impact on future electricity consumption. A number of countries and areas have applied methods to reduce energy consumed by refrigerated appliances through the application of energy labelling and/or MEPS (minimum energy performance standards). The EU applied MEPS and energy labelling in 1993 and since that time the MEPS have been reduced. When labels were first introduced no appliances were labelled better than A. By 2011 all appliances were better than A rated and some had reached A+++ (Waide, 2011).
There is substantial information on energy used by domestic refrigerators under test conditions as all domestic refrigerators in Europe are energy labelled. In Europe most testing in laboratories is carried out to EN 62552:2013 (Household refrigerating appliances - Characteristics and test methods) and this standard is used for energy labelling of appliances. A more recent test standard; IEC 62552:2015 (Household refrigerating appliances - Characteristics and test methods) exists which is likely to be used in the future for energy labelling. Both tests require appliances to be tested in a specific test room with controlled ambient temperature and air flow. In the EN

62552:2013 the freezer and chiller section of appliances is loaded with a simulated load consisting of 'tylose' test packs. The food storage section (refrigerated section that operates between 0 and 8°C is not loaded and temperatures are measured at 3 positions in the vertical centre of the compartment using temperature sensors that are 'damped' by insertion into brass blocks. In the IEC 62552:2015 standard test for energy consumption none of the compartments are loaded and all temperature measurements is carried out using temperature sensors inserted into brass blocks or 500 g blocks of simulated food. None of the energy tests simulates usage of the appliance as appliance doors remain closed during the tests and the appliances are not loaded or used as they would be in the home. These tests therefore do not replicate real usage. Ideally testing should provide the consumer with some indication of how much energy an appliance should use in the home.

Although there is substantial information on performance of domestic appliances in test laboratories there is minimal information on whether tests carried out in a test room reflect performance of refrigerators in the home. Authors such as Bansal (2003) consider that a more lifelike test should be carried out but evidence also suggests that the test regime is a good estimate of usage in the home (MTP, 2007; Sidler et al., 1998). Real operating conditions of appliances are difficult to test in the laboratory since the behaviour of householders is quite varied. For example little information is available on the number of times appliance doors are opened, the types and temperature of the food placed in the appliance and the ambient temperature where the appliance is installed which does not remain constant over time. Several research activities have been carried out in order to evaluate the effects of operating conditions on the energy consumption of domestic refrigerated appliances. Meier (1995) found that the energy used by similar refrigerators varied widely in consumers' homes and that this was primarily due to ambient temperature and door openings whereas ambient humidity had a relatively minor impact on energy consumed.

As consumer usage of appliances is known to be extremely variable it is probably unrealistic to expect a test to be able to perfectly predict accurately usage in the home. However, it would be reasonable to expect that the best performing appliance in a test should also be the best performing in the home. This then means that if a consumer purchases a product with claimed low energy consumption (in a laboratory test) it should also have low energy when used in the home.

The aim of this work was to determine whether a laboratory test provides a reasonable assessment of usage in the home. Information on appliances was collected from a recent large scale survey in the UK (Gemmell et al, 2017; Biglia et al, 2018). The survey involved around 1,000 domestic refrigerators and freezer appliances. During the survey the following data were monitored: (1) ambient temperature of the room where the appliance was installed, (2) internal compartment temperature in the appliance compartments and (3) power consumption. Householders were also questioned about the management of their appliance in respect of door openings, quantity of food loaded in the appliance and shopping habits. Appliance models were also recorded in order to obtain information on storage volume and the energy label for the appliance. Results of the work are analysed to assess the relationship between performance in a test facility and the home.

2 METHOD

2.1 Trial design

A large-scale survey was conducted across England in which 998 cold appliances were monitored in 766 properties (Biglia et al, 2018). Data was collected over a period of 9 months, from March to November 2015. Simultaneous measurements of the temperature inside and outside of the cold appliances, as well as the electricity consumption were taken over a period of seven days. The cold appliances monitored in the work survey included: (1) Fridge-freezers; (2) Refrigerators with an ice-box; (3) Larder fridges; (4) Chest freezers and (5) Upright freezers.

Data and information on appliances were collected by interviewers. On the first visit to each property the interviewers installed the monitoring equipment and obtained information about each appliance. One week later they returned to remove the equipment and data was downloaded ready

for analysis. The appliances were monitored for seven days to ensure the data reflected the performance of the cold appliances as accurately as possible.
The temperatures both inside and outside the appliance were monitored using TinyTag Transit 2 data loggers with a monitoring range of -40°C to 70°C, a reading resolution of 0.01°C and a reading accuracy of <0.8°C between -40-0°C, and <0.4°C between 0-50°C. One data logger was placed on the middle shelf of each appliance compartment in a plastic bag and one was attached to the outside of the door of the appliance.
The electricity consumption data of each cold appliance was collected using a Watts Up PRO monitor and data logger with an accuracy of +/- 1.5%. Each appliance was connected to the data logger, which itself was plugged into the wall socket. The electric power in Watts was monitored every 30 seconds for the period the appliance was plugged in.
Only complete data sets where appliance volume and information on the manufacturers claimed energy use could be used in the analysis to compare real life versus laboratory performance. This reduced the data set to 124 appliances (around 12.4% of the total data set). Table 1 presents the numbers of each type of cold appliance with valid monitoring data.

Table 1: Numbers of cold appliances in the survey

Appliance type	Total number in survey	Number available for analysis
Fridge-freezer	524	79
Larder refrigerator	145	18
Upright freezer	186	18
Chest freezer	86	7
Refrigerator with ice-box freezer	57	2
TOTAL	**998**	**124**

2.2 Analysis of data

Data were analysed to determine whether there was any relationship between energy used in the survey and the energy usage claimed by manufacturers (measured in a test laboratory).
A direct comparison between energy used in a laboratory and in the home is not necessarily fair. In particular the temperature performance of the appliance may vary when assessed in the laboratory and the home. In the laboratory (using EN 62552:2013) the energy consumption is assessed in an ambient of 25°C and at an average internal temperature of 4°C for the fresh food compartment and ≤-18°C in the freezer. A temperature normalisation was carried out to enable direct comparison between appliances. Fresh food compartments were normalised to 4°C, freezer compartments to -18°C and ambient temperature was normalised to 25°C using Eq. (1)

$$E_{\mathrm{n}} = E \cdot f_{\mathrm{n}} \qquad \text{(Eq 1)}$$

where E_{n} is the normalised energy (kWh per year), E is the monitored energy (kWh per year) and f_{n} is the normalisation factor, which in case of fridge-freezers and refrigerators with an ice-box was defined as

$$f_{\mathrm{n}} = \frac{\left(\frac{T_{\mathrm{rf,std}} - T_{\mathrm{a}}}{T_{\mathrm{rf}} - T_{\mathrm{a}}}\right) + \left(\frac{T_{\mathrm{fz,std}} - T_{\mathrm{a}}}{T_{\mathrm{fz}} - T_{\mathrm{a}}}\right)}{2} \qquad \text{(Eq 2)}$$

while for larder fridges, chest and upright freezers it was defined as

$$f_{\mathrm{n}} = \left(\frac{T_{\mathrm{rf,std}} - T_{\mathrm{a}}}{T_{\mathrm{rf}} - T_{\mathrm{a}}}\right) \quad \text{or} \quad f_{\mathrm{n}} = \left(\frac{T_{\mathrm{fz,std}} - T_{\mathrm{a}}}{T_{\mathrm{fz}} - T_{\mathrm{a}}}\right) \qquad \text{(Eq 3)}$$

where $T_{\mathrm{rf,std}}$ is the fresh food standard and recommended internal temperature (4°C), $T_{\mathrm{fz,std}}$ is the freezer standard and recommended internal temperature (-18°C), and T_{a} is the test laboratory ambient temperature (25°C), T_{rf} is the monitored mean refrigerator internal temperature and T_{fz} is the monitored mean freezer internal temperature. Based on an analysis of the models examined an assumption was made that the compartments in fridge-freezers were of approximately similar volume.

3 RESULTS

3.1 Energy used in the home versus energy used in the laboratory before normalisation

The annual energy claimed by the manufacturers in a test laboratory versus the annual energy used in the home is compared in Figure 1. It can be seen that there was considerable variation between the energy used in the laboratory and the home. In terms of the percentage differences between what was claimed by the manufacturers and what was measured in the home; 60.6% of appliances used more energy in the home than they did in the laboratory.

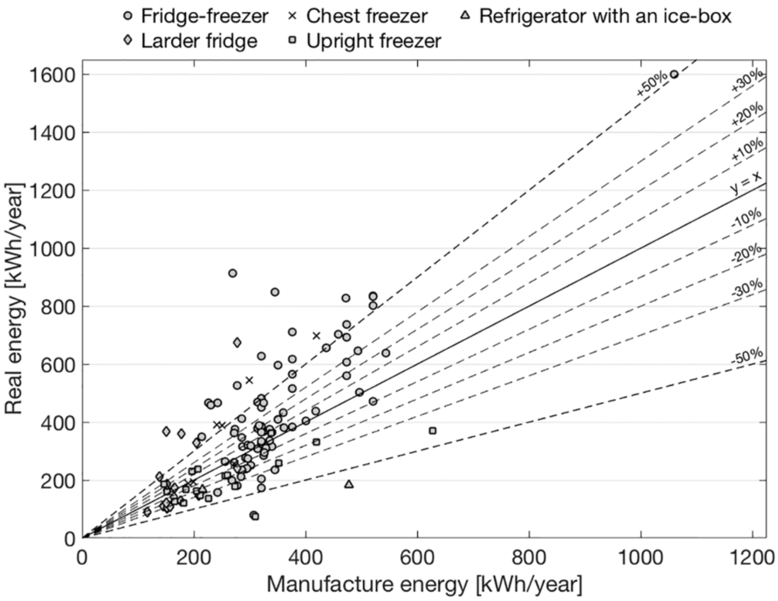

Figure 1: Energy claimed by manufacturers versus energy used in the home (non-normalised data)

If differences between energy measured in the home and in the laboratory occur this would be less significant if the rank order of energy consumed did not change. The consumer would then only be misled on the actual energy the appliance used but the best appliance in the laboratory would also be the best performing appliance in the home. Figure 2 shows the rank order for each appliance type in the laboratory and in the home. It can be seen that considerable differences occurred between the rank order in each situation.

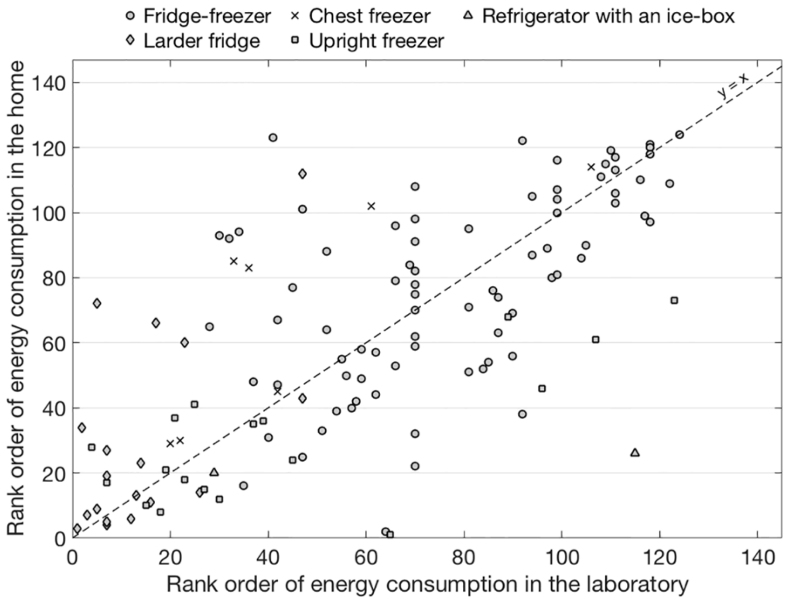

Figure 2: Rank order of energy used by appliances in the laboratory and the home (non-normalised)

3.2 Energy used in the home versus energy used in the laboratory after normalisation

When the energy measured in the home was normalised to the same internal and ambient temperatures as in the laboratory this had a significant effect on results with the main effect being to increase energy consumed in the home. This was primarily due to the ambient temperatures in the survey being in most cases less than the temperature in the laboratory test (25°C). The mean ambient temperature in the survey for the appliances analysed was 18.9 ± 2.6°C (Biglia et al, 2018). Some differences in energy use after normalisation were also due to internal appliance temperatures. However, these had less impact as before normalisation mean refrigerator temperatures were 4.6 ± 2.3°C and mean freezer temperatures were -20.4 ± 4.4°C (Biglia et al, 2018).

Figure 3 shows the comparison between energy used in the laboratory versus that measured in the home after the data was normalised for temperature differences. Overall 85% of appliances used more energy in the home than in the laboratory.

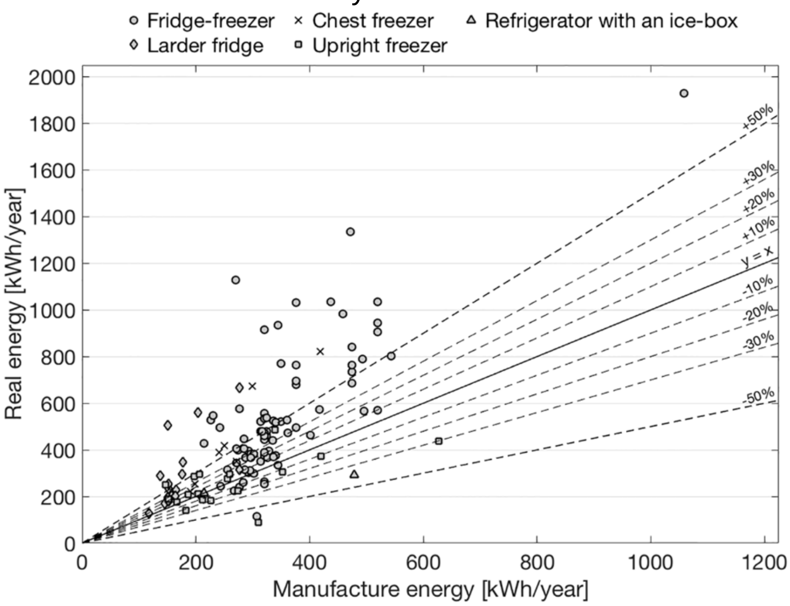

Figure 3: After normalisation for temperature: energy claimed by manufacturers versus energy used in the home

The impact of the normalisation on rank order of the energy used by the appliances is shown in Figure 4. Normalisation marginally improved the correlation between rank order in the laboratory with rank order in the home.

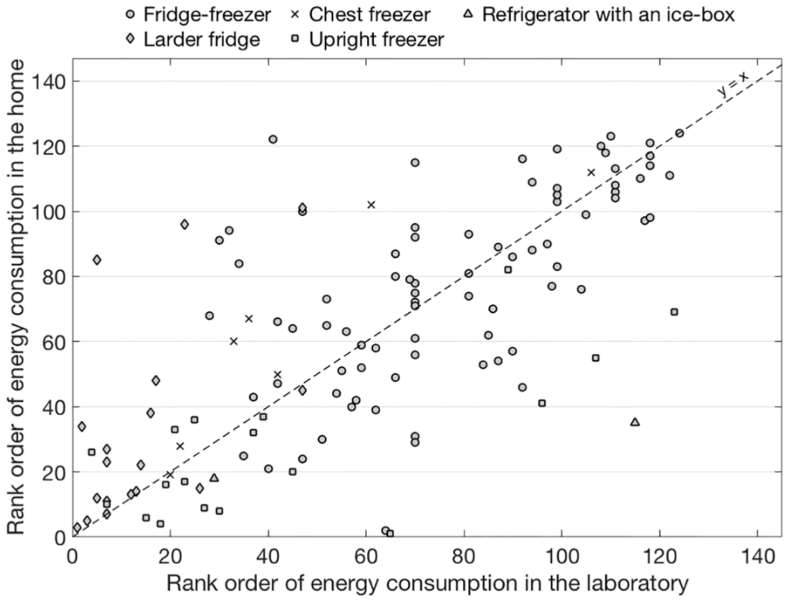

Figure 4: Rank order of energy used by appliances in the laboratory and the home (normalised)

3.3 Energy used by similar appliance models

Within the survey population there were a limited number of replicate appliance models. The normalised energy consumed by these appliances was compared to assess the impact of the same appliance operating in different households. Figure 5 shows the results from 40 appliances divided across 9 appliance models. In almost all cases the appliances used more energy in the home than had been measured in the laboratory. The results indicate that on occasions the energy used by an appliance in different homes was quite similar. Conversely differences in the energy consumed by the same appliance model could also vary widely, by often as much at ±100%. This indicates that usage in the home has a significant impact on energy consumption.

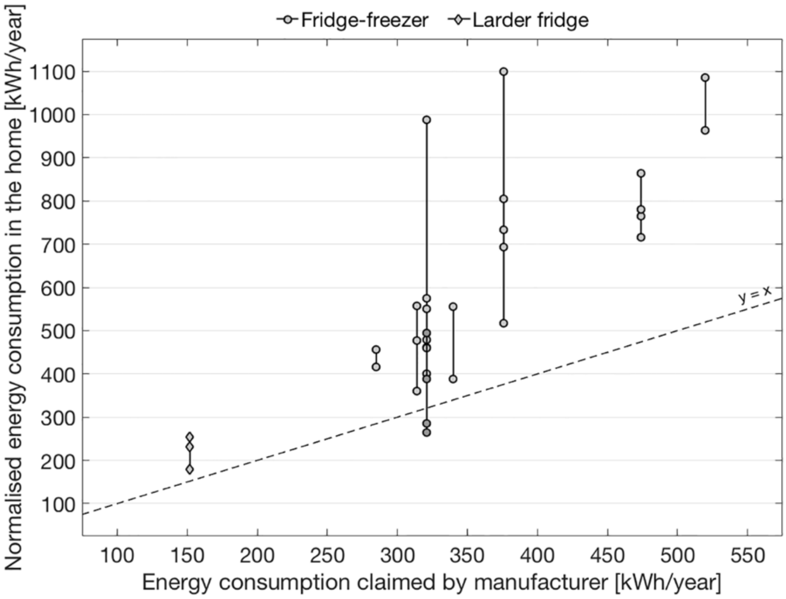

Figure 5: Energy used by the same appliance model in different households

4 DISCUSSION AND CONCLUSIONS

Reducing energy consumption is a major policy driver for many governments. To be able to accurately identify the best performing domestic refrigerated appliances is an important aspect of developing policy and encouraging consumers to purchase the most efficient appliances. This work indicates that although there has been an increased uptake of ‘A’ rated and better appliances since 2000 this may not necessarily be reducing energy consumption as much as policy makers anticipate.

It is not surprising that the energy consumed by domestic appliances can vary. However, it seems reasonable to expect that any laboratory test should provide a reasonable average indicator of energy used in the home. This was shown not to be the case as on average energy used in the home was on average 19% higher in the home than the laboratory.

The difference between laboratory and home energy consumption would be less of an issue if the rank order of the energy used by appliances was similar in both environments. Although consumers would not have an accurate indication on how much energy an appliance uses they would be able to identify the lowest energy consuming option. An analysis of the rank order of appliances in laboratory and home use demonstrated that the rank order was extremely variable.

Even when the same appliance model was compared across several households there were often differences in energy use of over 100%. This would indicate that although the laboratory test tends to under estimate the energy consumed in the home that it would be challenging to develop a comprehensive laboratory test that reflected the range in real life usage accurately. Further work is required to better understand how consumer usage of appliances affects energy use. This could lead to more realistic laboratory tests that provide more accurate information on performance of appliances to householders. This should ideally provide a means to ensure that appliances identified as being energy efficient in the laboratory are also efficient when used in the home. It is suggested that such a test for energy consumption should include some form of usage such as door openings or food temperature reduction that better mimics the way consumers use refrigerated appliances in the home.

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