THE POTENTIAL FOR SAVING FOOD WASTE BY LOWERING HOME REFRIGERATOR TEMPERATURES

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ABSTRACT

A significant proportion of the 4.4 million tonnes of avoidable household food and drink thrown away each year in the UK comprises products that require, or benefit from, refrigerated storage e.g. meat and fish, dairy products, most fruit and vegetables. In some consumers' homes, refrigerated foods are kept in less than optimal conditions e.g. not in the refrigerator, 'unwrapped' or at refrigerator temperatures above 5°C. This can lead to rapid food spoilage, and also to food safety risks. Storage in the refrigerator at temperatures below 5°C could extend the storage life of many of these foods, giving greater opportunity for their consumption before they reach the end of their acceptable life.

This paper presents results from research funded by WRAP to determine relationships between chilled storage temperature and published storage lives of typical food products. The potential reductions in food waste which might result from extended storage lives if refrigerator temperatures were lowered to 4°C rather than the UK average of 7°C (WRAP, 2010) are estimated. To be balanced against these savings however is the increased energy consumption which results from running refrigerators at lower temperatures, and results from an experimental assessment of the impact of lowering fridge temperatures on energy consumption are presented. The costs and associated carbon dioxide equivalent (CO_2e) emissions associated with the saved waste and the increased energy are compared.

1.0 INTRODUCTION

One of the largest contributors to the 4.4 million tonnes of avoidable household food and drink waste thrown away each year (WRAP, 2009) is from products that require or benefit from refrigerated storage e.g. fresh / raw meat and fish, dairy products, most fruit and vegetables. Around 2.5 million tonnes of this waste is thrown away as a result of not being eaten before 'use by' or 'best before' dates or having been judged to have spoiled. Often, foods which should be refrigerated are kept in less than optimal conditions. For example, an extensive study of refrigerated food storage practices in the home (WRAP, 2010) found that the majority of domestic fridges operated at a mean air temperature of around 7°C. It was apparent that a proportion of the fridges tested (14 fridges, 29% of the sample) were operating at 9°C or above. Only 14 of the 48 fridges (29% of the sample) were found to be at mean air temperatures of 5°C or less. These results were comparable with previous domestic fridge air temperature surveys (see for example James et al, 2008). Such temperatures can lead to accelerated loss of quality and food spoilage, and ultimately food safety risks. In addition, products in the fridge are frequently left unwrapped after opening, and some products that would benefit from refrigeration e.g. most fruit (WRAP, 2008), are often kept at ambient temperatures in the kitchen. Storage at more appropriate fridge temperatures of 5°C or lower could extend the storage life of many of these foods, giving greater opportunity for their use and helping to avoid waste.

A key recommendation from the above 2010 research was to improve fridge use e.g. through communicating to consumers the importance of having the fridge at the right temperature and how to use a fridge thermometer. However, it was also recognised that running fridges at lower temperatures results in increased energy consumption, and the need for further research into the relative costs and environmental impacts of saving food waste in this way was identified.

This paper presents results from a literature search designed to determine reported storage lives of a range of products when stored at various chilled temperatures. The potential reductions in food waste which might result from longer storage lives at 4°C rather than the current UK average fridge temperature of 7°C are estimated and converted to financial savings and reductions in embodied carbon dioxide equivalent (CO_2e) emissions. Data on energy consumption of fridges operating at various chilled temperatures were found to be scarce, so the paper also details an experimental assessment of the energy impact of lowering fridge temperatures from 7°C to 4°C. The cost and CO_2e emissions associated with the increase in energy are compared with those from the saved food waste.

2.0 METHOD

2.1 Literature review to assess potential for storage life extension at lower chilled temperatures

Food products were chosen for literature review based on their potential for waste savings. Factors included their perishability at chilled temperatures, their sales volumes and the proportions reported to be wasted (WRAP 2009). The following 11 products were chosen: cod, salmon, chicken, ham, pork, strawberry, cherry, salad, broccoli, cream, milk. For each product, a literature review of reported practical storage life (PSL) values at chilled temperatures (e.g. -2°C upwards) was carried out. The sources used included peer reviewed academic journal papers, conference publications, reference text books and information from trade, professional associations and Non Governmental Organisations e.g. IIR (International Institute of Refrigeration).

For each reference found, the reported PSL and storage temperature(s) were recorded, together with details such as packaging and previous treatment. Details of the method used to judge the end of the storage period (sensory e.g. panel scoring of taste, odour; chemical e.g. thiobarbituric acid levels for detection of rancidity; microbiological e.g. total viable counts of bacteria, numbers of spoilage bacteria etc.) were also recorded. The PSL values for each product were tabulated and plotted against storage temperature. Exponential curve-fitted trend-lines were added, and the resulting equations and their coefficients of determination (R^2 values) noted. The R^2 value ranges from 0 to 1 and denotes how well a trend-line fits the data on which it is based, in other words, the closer the R^2 value is to 1, the better the fit of the trend-line to all of the data on the chart. For those products with acceptable curve-fits, the exponential equations were used to determine storage lives at 7˚C and 4˚C.

2.2 Estimation of potential for saving waste based on extended storage life

To estimate the potential for saving waste which these extensions to storage life might offer, a method based on previously reported reasons for waste (WRAP 2009) was devised. These reasons show that while some food waste is avoidable e.g. that 'not used in time', other waste is unavoidable e.g. bones, some peelings. The amounts of each type of food wasted tend to vary with the degree of perishability, i.e. foods which spoil quickly are more likely to be disposed of due to reasons such as 'going off'.

The estimation method was therefore based on the total tonnage of reported avoidable waste for each type of food reviewed. The total for each food type was first multiplied by the proportion wasted because it was 'not used in time'. This figure was then multiplied by the proportion reported to be thrown out due to 'going off'. The assumption was then made that extending storage life allowed more time for the food to be used[1], and that the additional amount which would be used would be proportional to the increase in storage life e.g. 50% more storage life could allow up to 50% of waste previously classed as 'gone off' to be saved. This figure was taken as an estimate of the maximum potential saving due to extended storage life, but it was considered unlikely that the maximum potential would be realised (as other factors will also influence whether a particular item of food is consumed), so a final adjustment was applied to account for food which would still be discarded during the extended storage life (Table 3).

[1] *Within the limits of the 'use by' date.*

2.3 Experimental study of energy impact of lowering fridge temperatures

A test plan was devised to evaluate the energy performance of typical models of domestic fridges at nominal average air temperatures of 7°C and 4°C when loaded to three different levels:

- 'empty' – representing a poorly stocked fridge just before a main shop is added (approximately 15% full by volume)
- 'normal' – representing the addition of products in a main shop which are normally refrigerated (approximately 70% full by volume)
- 'normal plus additional' – representing the addition of products in a main shop which are normally refrigerated, plus some products which are not normally refrigerated but which would benefit from refrigeration (approximately 85% full by volume).

Three best-selling appliances were selected, all of which were A-rated for energy – two stand-alone fridges (denoted Fridge 1 - the 130 litre net volume Beko CHILL53W and Fridge 2 - the 112 litre net volume Lec L5010W) and one fridge-freezer (denoted Fridge-Freezer 3 - the 150 litre net fridge volume Hotpoint RFAA52S). While the energy consumption of stand-alone fridges is directly related to the temperature of operation, consumption of fridge-freezers is complicated by the fact that in most models a single thermostat sited in the fridge section is used to control both the fridge and the freezer temperatures. Adjusting this thermostat therefore affects not only the fridge temperature but also the freezer temperature, compounding the energy impact.

The appliances were installed in a controlled environment test room running at 20.5˚C ± 0.5˚C and 50% ± 5% relative humidity (RH) to approximate typical domestic kitchen conditions. They were installed in a rigid metal frame at floor-level to which was attached an automatic door opening mechanism, which was in turn connected to the fridge doors. The mechanism was set to apply a simulated door opening pattern of a 10-second, 60 degree opening every 20 minutes between the hours of 08.00 and 22.00 each day.

Air temperatures on each of the fridge shelves and in the door were measured using calibrated t-type thermocouples connected to Datascan datalogging modules (Measurement Systems, UK). Power was measured for each appliance using calibrated power meters (Northern Design, UK). Average temperature and power values were recorded together with room temperature and RH every minute using Orchestrator software (Measurement Systems, UK). For the fridge-freezer, additional thermocouples were placed inside each shelf in the freezer to measure air temperatures. Temperatures in distributed samples of food from each of the three load types were measured and recorded using similar thermocouples attached to portable Evo dataloggers (Comark, UK).

Each appliance was initially loaded to the 15% level and set to the manufacturer's recommended thermostat setting, which after stabilisation was found to give average shelf air temperatures close to 7˚C. Measurements were recorded for the initial load of 15%, the addition of food up to70%, reduction of load back to 15%, the addition of food up to 85%, and finally return to 15% load. Thermostats were then adjusted with the aim of achieving average air temperatures of 4˚C, and the above test pattern repeated.

3.0 RESULTS

3.1 Literature review of potential storage life extension

Numbers of references and consistency of reported storage lives unsurprisingly varied depending on product (the full list of references is too long to include in the current paper, but will be published in a forthcoming WRAP report, to be available at http://www.wrap.org.uk). For some products large numbers of references were found, and the effect of lower temperatures on storage lives was logical, such as cod for which results are shown in Figure 1.

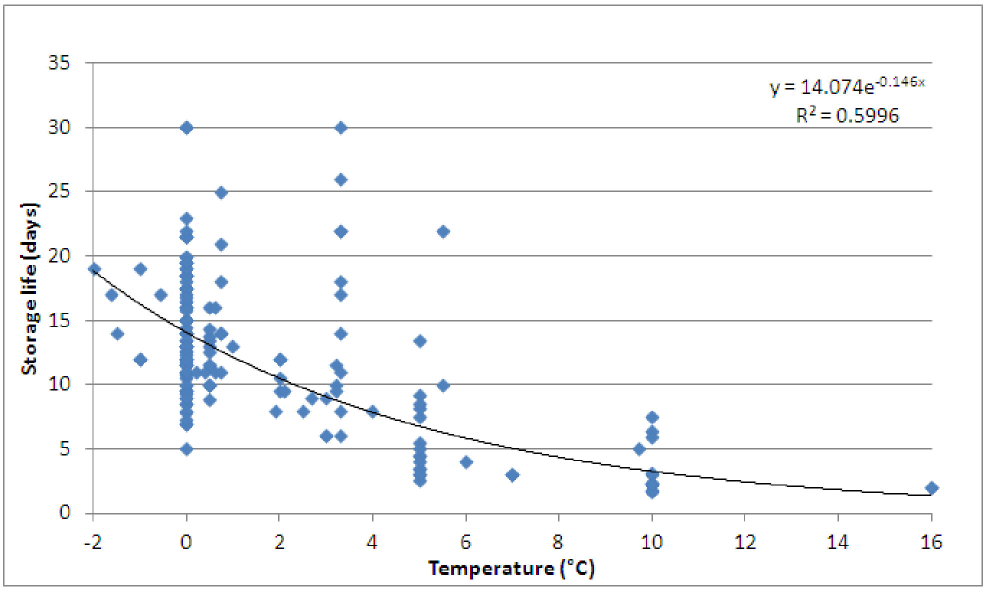

Figure 1. Reported Practical Storage Lives of chilled cod

For cod, the majority of reported values were for storage at 0°C, reflecting the traditional 'storage on ice' temperature for fish. However, considerable scatter was found at this and at other individual temperatures. Reasons for scatter include 'product factors' such as method of catch and processing, chilling method and speed, time to shore, transport time, condition of fish (whole / gutted / fillets), packaging material, and use of modified atmosphere in some packs. There were also 'experimental factors', such as measurement type (sensory, chemical, microbiological) and shelf life cut-off criteria e.g. different levels of bacteria, different sensory scoring. Although the coefficient of determination (the R^2 value) for the exponential curve-fitted line was not high, it was considered acceptable for determining an average relationship between storage life and temperature. Using the equation for the line gave the storage life values shown in Table 1, which suggest a useful extension to storage life of 2.7 days if the lower temperature could be adopted.

Table 1. Curve-fitted storage lives for chilled cod at 7 and 4˚C

Temperature (°C)	*Storage life (days)*
7	5.1
4	7.8

For other products however, references were scarce and in some cases the reported PSLs were either scattered or did not result in logical curve-fits. Examples of this were ham and cream, for which the curve-fits suggested a decrease in storage life as temperature reduced. As there is no logical explanation for this, these products were omitted from further analysis. A summary of the results for all of the products is given in Table 2.

3.2 Estimates of the potential for waste reduction based on extended storage lives

For some products, the findings from the literature review were used as representative storage life extensions for wider food groups for which food waste tonnages were known. These were:

- cod and salmon storage lives were used to represent 'all fresh fish', and the average storage life extension for these two products was applied in the calculation;
- chicken and pork were considered for representation of 'all fresh meat' but the average shelf life extension was scaled down to 50% as the value for pork (67%) was considered to be higher than likely for all meat products;

- broccoli was used to represent ‘other vegetables’ (including broccoli, whole heads of lettuce, leeks, cucumber, spring onions, peppers, tomatoes, mushrooms, other fresh vegetables);
- bagged leafy salad and milk were retained as separate categories;
- fruit make up an important waste category, so it was intended to use strawberry and/or cherry as representatives, but as neither yielded useful curve-fits this category was excluded.

Table 2. Calculated storage life extensions due to lower temperature

Product	Storage life at 7˚C (d)	Storage life at 4˚C (d)	Extension (d)	Extension (%)
Cod	5.0	7.8	2.8	55
Salmon	4.7	7.7	3.0	65
Chicken	5.8	8.7	2.9	50
Ham	*References scarce, poor correlation*			
Pork	4.8	8.0	3.2	67
Strawberry	*References scarce, poor correlation*			
Cherry	*References scarce, poor correlation*			
Salad	7.0	10.4	3.4	49
Broccoli	8.9	11.3	2.4	27
Cream	*References scarce, poor correlation*			
Milk	8.0	12.1	4.1	51

An example of the calculation for leafy, bagged salad is as follows:

- Avoidable waste is 36,000 tonnes p.a., of which, waste 22,000 tonnes p.a. is ‘not used in time’
- Proportion of this due to ‘going off’ = 30% or 6,600 tonnes p.a.
- Storage life extension from lower temperature = 48.9%, so maximum potential saving is 48.9% of 6,600 tonnes p.a. = 3,225 tonnes p.a.
- Apply a cautious estimate that 50% of this will still be discarded, as salad has ‘use by’ date and some rejection based on appearance is likely.
- Final saving estimate is thus 1,613 tonnes p.a.

Tabulating the results for the wider food groups gives the tonnage savings shown in Table 3. The estimated waste saving for the included categories of food at the lower fridge temperature is 67,216 tonnes p.a. in total for the UK. Savings of vegetables and milk make up the majority of the savings in tonnage partly due to their high sales volumes. It should be borne in mind that the list of foods in the categories is not exhaustive (e.g. fruit was excluded due to lack of data, not because there is no waste to be saved), so the total *waste saved* figures would be higher if every eligible food type was included.

Table 3. Estimates of waste reduction due to extended storage lives

Product	Avoidable waste (t)	'Not used in time' (t)	Thrown away "going off" (%)	Thrown away due to "going off" (t)	Storage life difference (%)	Potential saving realised (%)	Waste saved (t)
Vegetables	264,000	197,205	80%	157,764	27.0%	75%	31,947
Milk	360,000	200,000	50%	100,000	51.3%	50%	25,660
Fresh meat	200,000	130,000	20%	26,000	59.8%	50%	7,780
Salad	36,000	22,000	30%	6,600	48.9%	50%	1,613
Fresh fish	9,600	7,200	20%	1,440	59.9%	25%	216
Total	869,600	556,405		291,804			67,216

The financial value of the food saved and its embodied CO_2e were then derived using the average costs per tonne of each food category (Defra, 2011) and the average conversion factor of 3.8 tonnes of CO_2e per tonne of food produced (WRAP 2009, Appendix E) as shown in Table 4.

Table 4. Cost and embodied CO_2e of saved food waste

Product	Estimate of tonnage saving (t)	Cost per tonne (£.t^{-1})	Estimated value of waste saved (£m)	Embodied emissions CO_2e (t)
Vegetables	31,947	1,600	51.1	121,399
Milk	25,660	670	17.2	97,508
Fresh meat	7,780	6,190	48.2	29,563
Salad	1,613	3,960	6.4	6,128
Fresh fish	216	9,280	2.0	820
	67,216		124.9	264,491

3.3 Energy impact of lowering fridge temperature (initial results)

Average air temperatures above the shelves in the appliances are shown in Figure 2 for an example period of 72 hours following loading to 70% full at 7°C. The initial rise in temperatures after loading can be seen, followed by pull-down within the first 24 hours and subsequent stable operation. The impact of the typical cyclical operation of the refrigeration systems on air temperatures can be observed. The periods with greater oscillations result from the operation of the door opening regime.

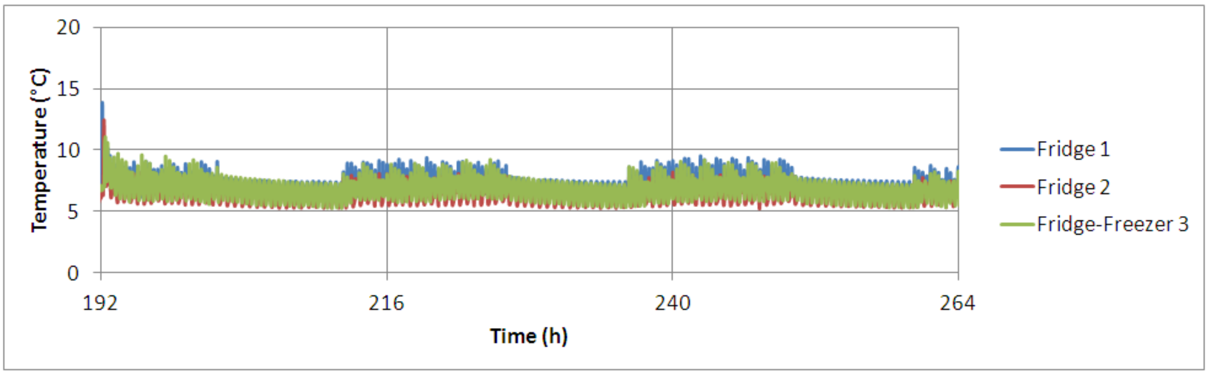

Figure 2. Average air temperatures above the shelves of the three appliances

Average air temperatures and daily energy consumption figures for the three appliances are presented in **Error! Reference source not found.**. Food and test room temperatures and RHs in the appliances and the test room are not presented in this paper, but will be available in a forthcoming WRAP report together with the results for 85% loading (see http://www.wrap.org.uk).

While initial setup to achieve nominal average air temperatures close to 7°C was relatively straightforward, changing the thermostat settings (all on analogue dials) to achieve 4°C proved challenging. Some changes made little difference to temperature, while others forced the fridges to run continuously and overshoot the desired temperature, resulting in partially frozen food and significantly higher energy consumption. The temperature reductions shown above, although not ideal, were therefore accepted after considerable adjustments over several weeks.

Table 5. Average air temperatures and energy consumption for the three appliances

Setting	Parameter	Unit	Fridge 1	Fridge 2	Fridge-freezer 3
7°C	Average stable air temperature	°C	7.2	7.0	6.7
	Average stable energy	$kWh.day^{-1}$	0.252	0.221	0.682
	70% pull down	$kWh.day^{-1}$	0.274	0.247	0.702
4°C	Average stable air temperature	°C	3.8	5.0	4.4
	Average stable energy	$kWh.day^{-1}$	0.291	0.241	0.757
	70% pull down	$kWh.day^{-1}$	0.350	0.271	0.770
Difference	Temperature reduction	°C	3.4	2.0	2.3
	Increase stable energy	$kWh.day^{-1}$	0.039	0.020	0.076
	Increase 70% pull down energy	$kWh.day^{-1}$	0.076	0.024	0.069

Average annual increases in energy were derived from the values for all stable periods, and then adjusted linearly for a 3-degree reduction. This gave increases of 11.6 $kWh.year^{-1}$ for the fridges and 36.1 $kWh.year^{-1}$ for the fridge-freezer. The increase for the fridge-freezer was significantly higher than that for the stand-alone fridge, and this was because it was controlled by a single thermostat in the fridge section which meant that lowering the fridge temperature also reduced the freezer temperature by a similar amount. However, not all fridge-freezers are controlled in this way. Those with dual controls (and either dual compressors, refrigerant flow diverters or air baffles controlling air flow from the freezer to the fridge) would allow independent control of fridge temperature without the high energy penalty measured on the single thermostat appliance.

Over and above the increase in energy for stable operation at a lower temperature, there would also be an additional increase due to the pull-down periods for added food. These increases were derived from the difference in pull-down energy at the two temperatures following addition of food to the 70% loading level, and as it was assumed that this would be a weekly occurrence, these additional amounts were added to 52 of the 365 days considered. This added 2.7 and 4.7 $kWh.year^{-1}$ to the figures above for fridges and fridge-freezers respectively. Finally these figures were expanded to national figures for the UK based on the following assumptions, references and factors:

- Each of the approximately 26 million households in the UK has one main fridge or fridge-freezer.
- 32% of these are fridges, 68% are fridge-freezers (based on 2010 sales data, GfK 2012).
- Up to 65% of fridge-freezers are single thermostat, 35% are dual control (Lot 13, 2005). It was assumed that energy impact on dual control appliances would be similar to fridges.
- Each kWh of domestic electricity costs on average 11.55p (DECC, 2011).
- UK conversion factor for electricity 0.5246 kg $CO_2.kWh^{-1}$ (Carbon Trust, 2011).

Applying these assumptions and data gives the costs and emissions shown in **Error! Reference source not found.**.

Table 6. Increased energy associated with lowering fridge temperature and its costs and emissions

Product	Annual UK energy increase (1000 kWh)	Increased cost (£ m)	Increased emissions CO_2e (t)
Fridges	118,588	13.7	62,212
Dual control fridge-freezers	88,200	10.2	46,270
Single control fridge-freezers	468,878	54.2	245,974

	675,667	78.0	354,455

4.0 DISCUSSION

While the estimated financial value of the food waste which could be saved (£124.9 m) was greater than the estimated increase in energy costs (£78.0 m), the associated emissions were estimated to be greater for the increased energy (354,455 tonnes CO_2e) than for the saved waste (264,491 tonnes CO_2e). This may in large part be due to the exclusion of some types of food from the waste categories, such as soft fruit, cheese etc. These were excluded not because there is no potential for saving waste, but because the literature search returned poor quantity and quality of PSL values for these food types and it is likely that waste from some of these food types could be saved by lowering fridge temperatures. The total potential for saving food waste could therefore be under-estimated in this analysis. Furthermore, potential food safety risks are minimised by running fridges at temperatures below 5°C as recommended for example by the UK Food Standards Agency (2012). This represents an additional and unquantified benefit, in addition to the potential waste saving.

The experimental work provided useful indications of the energy impact of lowering fridge temperatures, but it was limited to two particular fridge models and one single thermostat fridge-freezer. These appliances were selected from best-selling product ranges, and were therefore relatively inexpensive and simpler in their design. The inclusion of a greater number of appliances, and in particular those equipped with more sophisticated controls, would be beneficial in checking that both the average measured figures and the assumptions applied are appropriate when considering national (and wider) fridge stocks.

Considerable improvements in energy efficiency of household refrigerators have been achieved in recent decades, as evidenced by addition of A+ and better categories to the energy labelling scheme and removal of the previous worst categories from E to G. However, the results in this paper suggest that energy efficiency is still a major consideration in decisions on how to operate and use household refrigerators.

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