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REDUCING DOMESTIC FOOD WASTE BY LOWERING HOME REFRIGERATOR TEMPERATURES

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ABSTRACT

Domestic refrigerators often operate at temperatures which are higher than ideal for chilled food storage, with several studies finding averages around 7°C. Reducing temperatures for example to 4°C could significantly extend storage lives, giving greater opportunity for use before disposal. However, the savings in costs and emissions associated with reduced waste must be balanced against those associated with increased energy consumption at lower temperatures.

Based on published storage lives of foods which are currently refrigerated and UK waste statistics, reducing from 7°C to 4°C could save £162.9 m of waste annually, with associated emissions of 270,000 tonnes CO_2e. Including certain foods which are not always refrigerated and removing others which do not benefit from refrigeration, the estimated savings increased to £283.8m and 578,383 tonnes CO_2e. Based on experimental assessment, the costs and emissions associated with increased fridge energy consumption were considerably lower at £80.9 m and 367,411 tonnes CO_2e.

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 in the UK is 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 (WRAP, 2009). Often, foods which should be refrigerated are kept in less than optimal conditions. Although appliances are generally designed to achieve average air temperatures of ≤5°C, and testing for energy label purposes must achieve this under laboratory test conditions, surveys of air temperatures in fridges in real household usage conditions have found average temperatures closer to 7°C (see James et al, 2008). In the most recent UK study of refrigerated food storage practices in the home (WRAP, 2010) the majority of domestic fridges were again found to operate 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.

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 such as 4^{o}C could extend the storage life of many of these foods, giving greater opportunity for their use and helping to avoid waste. In practice, 4°C should be achievable for most domestic fridges without risking food freezing in the coldest areas, and it would also limit the energy impact which becomes progressively worse the colder the temperature.

A key recommendation from the WRAP 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. The aims of the current study were therefore to:

- use literature review results to estimate storage life extensions of a range of products when stored at 4°C instead of 7°C
- combine these extensions with previously reported food waste figures and reasons for waste to devise a method for estimating the potential for waste reduction
- calculate the financial savings and reductions in embodied emissions associated with the saved waste
- estimate the potential for further savings from refrigerating some products which are not always stored in fridges (e.g. only 26% of apples are refrigerated in the home)
- determine the energy impact of running fridges at the lower temperature
- compare the costs and emissions associated the saved food waste with those associated with the increase in energy.

2.0 METHOD

2.1 Literature review of storage lives at 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. Deterioration kinetics for food quality factors such as the growth of spoilage bacteria are commonly described using exponential Arrhenius relationships and the relationship of shelf-life with temperature can also be described by exponential models (see for example Fu and Labuza, 1977). Therefore exponential curve-fitted trend-lines were added to the plotted data, and the resulting trend-line 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. In the current study which aimed to determine average trends for shelf lives with changing temperatures, it was expected that low R^2 values would be found, as the datasets included several sources of variability (including experimental factors and product factors as described in Results). Decisions on inclusion or exclusion of particular products from further analysis was therefore only partly based on R^2 values, with assessment of the logical trend in the data also being used to inform the decisions. For those products deemed to be acceptable for inclusion, the exponential equations of the trendlines were used to determine average storage lives at 7˚C and 4˚C.

2.2 Estimation of potential waste savings

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 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 allows more time for food to be used before being judged to have 'gone off' (within the limits of labelled 'use by' dates), leading to reducing waste.

Definitive data which would help determine the extent of the reduction in waste were not available, so the assumption was developed by the project team as follows. As the incidence of waste due to 'going off' is linked to perishability, it was assumed that reductions in such waste would be proportional to the increase in storage lives. For example, a 50% extension in storage life for a particular product was assumed to allow up to 50% of the waste previously classed as 'gone off' to be saved. However, it was considered that this approach was likely to result in estimates of the maximum potential savings offered by extended storage lives, and this it would be unlikely in practice that the maximum potential would be realised (as other factors will also influence whether a particular item of food is consumed). A final adjustment ranging from 75% to 25% depending on food type was therefore applied to account for food which would still be discarded during the extended storage life (Table 3).

2.3 Energy impact of lowering fridge temperatures

Published data on energy consumption of fridges operating at various chilled temperatures were found to be scarce, so an experimental assessment of the energy impact of lowering fridge temperatures from 7°C to 4°C was undertaken.

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. As energy consumption is dependent on loading levels and whether the appliances have to pull down warm food or maintain stabilised food temperatures, three load levels were designed to simulate the range of loading normally found in domestic fridges:

- '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).

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 15% load, followed by pull-down and stabilisation after the addition of food up to70%. The load was then reduced back to 15% and the appliances allowed to stabilise, followed by pull-down and stabilisation after the addition of food up to 85%. Finally the load was reduced back to 15% load and the appliances allowed to stabilise once more. Thermostats were then adjusted with the aim of achieving average air temperatures of 4˚C, and the above test pattern repeated.

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 to 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).

3.0 RESULTS

3.1 Storage life extension

Numbers of literature review references and consistency of reported storage lives unsurprisingly varied depending on product (WRAP, 2013). 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 as an example in Figure 1.

To continue with the example of 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, the trend appeared logical and it was considered acceptable for determining an average relationship between storage life and temperature. Using the equation for the line suggested a useful extension to storage life of 2.7 days if the lower temperature could be adopted.

For products such as pork and salad, the R^2 values were low but trends were logical and the equations were used to give storage lives at 7°C and 4°C which it was felt could be taken as representative averages. For other products however, references were even scarcer and in some cases the reported PSLs were either scattered or did not result in logical curve-fits. For ham, cream, strawberry and cherry the R^2 values were incredibly low (<0.1) and for some the curve-fits suggested an illogical decrease in storage life at lower temperatures. These products were omitted from further analysis. A summary of the results for all of the products is given in Table 1.

3.2 Estimates of potential waste savings

Food normally stored in the fridge

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 from the review results.

Estimated waste savings were calculated for all included food groups, an example of which is the calculation for leafy, bagged salad:

- Avoidable waste is 36,000 tonnes p.a., of which 22,000 tonnes p.a. is 'not used in time' (WRAP, 2009)
- Proportion of this due to 'going off' = 30% or 6,600 tonnes p.a. (WRAP, 2009)
- 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. (based on results from the literature review)
- Apply a cautious estimate that 50% of this will still be discarded, as salad has 'use by' dates and some rejection based on appearance is likely (variable factors for different food types developed by the project team and WRAP colleagues)
- Final saving estimate is thus 1,613 tonnes p.a.

Added to the food waste savings in the review were two other food groups – these were root vegetables and fruit items which are not always refrigerated, but which store for longer if kept in the refrigerator e.g. apples and carrots. In this part of the analysis, only the proportions of these items which already *are* refrigerated (e.g. 26% for apples, 36% for carrots) were included, to assess the impact of reducing fridge temperatures on their storage lives and waste. In the absence of suitable review data and drawing on published waste analyses (e.g. WRAP, 2008), it was conservatively assumed that storage life extensions of up to 10% could be achieved. Tabulating these items with the results for the wider food groups gives the tonnage savings shown in Table 2. The estimated waste saving for the included categories of food at the lower fridge temperature was 71,035 tonnes per annum 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, so the total *waste saved* figures would be higher if every eligible food type was included.

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 3.

Food not normally stored in the fridge

In addition to the amounts above, the impact of refrigerating the proportions of the items which are *not* normally refrigerated (e.g. 74% of apples, 64% of carrots) was also assessed. Bringing such items from ambient temperature to refrigerated temperature can achieve significant storage life extensions (e.g. between 7 and 17 days, WRAP 2008). With such extensions, it was assumed that a much higher 50% of the waste from such categories could be saved during this period, and the tonnages saved are shown in Table 4. Also shown are savings from removing the small proportion of bananas which are currently stored in the fridge, as these would store for longer at ambient temperatures. The total estimated additional tonnage saved was 81,172 tonnes per annum for the UK.

The financial value of this further avoided food waste and its embodied CO_2e emissions were derived using the same conversion factors as above, and are shown in Table 5.

Combining the measure of reducing fridge temperatures from an average of 7°C to an average of 4°C with that of refrigerating more of certain foods like apples and carrots could therefore offer the potential for saving up to 152,207 tonnes of food per year in the UK, worth an estimated £283.8m and associated with 578,383 tonnes of CO_2e.

3.3 Energy impacts

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. Food and test room temperatures and RHs in the appliances and the test room are excluded here for brevity, but can be found in WRAP, 2013.

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. Although not ideal, the temperature reductions achieved (3.4°C, 2.0°C and 2.4°C) were therefore accepted after considerable adjustments over several weeks. The energy increases associated with these temperature reductions were normalised in the data analysis to represent 3°C by linear interpolation / extrapolation as described below.

Annual energy consumptions were derived from the values for all stable periods, and from the differences in pull-down energies for the different loads. It was assumed that loading would be a weekly occurrence following a major shop, so the annual amounts were based on 365 stable days and 52 additional amounts of energy due to pull-down days (Table 6). For reference, the manufacturers' stated energy consumption values taken from the appliances' energy labels were as follows: fridge 1 was labelled at 116 $kWh.annum^{-1}$, fridge 2 at 117 $kWh.annum^{-1}$, and fridge-freezer 3 at 268 $kWh.annum^{-1}$.

To determine the impact of lowering air temperature solely for foods currently refrigerated, the differences between energy consumptions for 70% / 15% ('normal') loading at 4°C and 7°C were calculated. The impact of adding additional food items which are not always refrigerated was similarly determined by calculating the differences between energy consumptions with 85% /15% ('normal plus additional') loading at 4°C and 70% / 15% ('normal') loading at 7°C. Both sets of annual energy increases were then 'normalised' i.e. adjusted linearly for a 3-degree reduction in proportion to the actual temperature reductions listed above (Table 7).

Finally the estimated annual energy increases 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 €0.1386 (DECC, 2011).
- UK conversion factor for electricity 0.5246 kg $CO_2.kWh^{-1}$ (Carbon Trust, 2011).

Applying these assumptions and data gave the energy impacts and the costs and emissions shown in Table 8.

4.0 DISCUSSION

The study used a combination of literature review and experimental measurement, and it is recognised that there were limitations to the scope and accuracy of each. For the literature review, the accuracy of curve-fitting to produce a shelf-life versus temperature profile is highly dependent on the number and consistency of referenced values. For some products the review found insufficient values and / or wide scatter in shelf life data, both of which can lead to potentially inaccurate curve-fitting with low R^2 values. However, for those products where apparently logical shelf life relationships could be derived, it was considered acceptable to use the relationships to generate indicative estimates of average shelf life extensions. Notwithstanding this, all of the curve-fits would benefit from greater numbers of references, and also from experimental verification under suitably controlled conditions.

There was a lack of data on which to base a method for converting shelf life extensions into waste savings at different domestic refrigerator storage temperatures. Truly comparative data would be difficult to obtain, requiring not only that a suitably sized and representative sample of household fridges be run at average temperatures of 7°C and 4°C, but also that factors such as included food types, initial quality and consumption behaviour be carefully monitored or controlled during storage at each temperature. Assumptions for waste savings were therefore developed based on proportionality with shelf life extensions and suitably cautious safety factors, but it is acknowledged that these were somewhat arbitrary in nature. Changing these assumptions or developing alternatives would alter the balance of results but again it was considered that the estimates of waste reduction were acceptable as indicative values.

The experimental energy measurements highlighted the difference between stand-alone fridges and fridge-freezers. The energy 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. For reasons of economy, the measurements were made using only two fridge models and one single thermostat fridge-freezer, which were selected from best-selling product ranges and were therefore relatively inexpensive and simpler in their design. It would be interesting to repeat the measurements using more sophisticated dual compressor or dual control appliances, although such types make up only a small proportion of current appliance stocks.

5.0 CONCLUSIONS AND RECOMMENDATIONS

Based solely on reducing the storage temperatures of those foods which are currently refrigerated in the home, the estimated financial value of the food waste which could be saved due to extended storage lives was £162.9 m, while the estimated increase in energy costs required to run fridges at the lower temperatures was lower at only £70.6 m. However, the savings in emissions associated with the saved food (270,000 tonnes CO_2e) were estimated to be less than the emissions increase due to higher energy use (320,805 tonnes CO_2e).

Extending the estimates to include refrigeration of certain foods which are not always stored in the refrigerator (e.g. apples and carrots), and to include removal from the fridge of some which do not benefit from chilled storage (bananas) increased the financial value of the saved food to £283.8 m and the associated emissions to 578,383 tonnes CO_2e. Both of these significantly exceeded the energy impacts, which only increased by relatively small amounts to £80.9 m and 367,411 tonnes CO_2e as a result of adding the additional foods. Actual results achieved will of course vary between households depending on their food storage and consumption patterns and on appliance type, but the experimental results suggest that reducing fridge temperatures to 4°C should be recommended to consumers as an approach to reducing food waste.

Some additional measures would help consumers in achieving such savings, including information on how and where to measure fridge temperatures, availability of cheap but easy to read and accurate thermometers, clear instructions on thermostat operation and greater in-store and on-pack labelling promoting optimum storage conditions. In addition, an expanded study of a greater number of appliances, in particular including those equipped with dual compressors and more sophisticated controls, would be beneficial in checking that the measurements and the assumptions applied are appropriate when considering national (and wider) fridge stocks.

6.0 ACKNOWLEDGMENTS

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Product	Storage life at 7˚C (d)	Storage life at 4˚C (d)	Extension (d)	Extension (%)	Curve-fit R^2 value
Cod	5.1	7.8	2.7	53	0.597
Salmon	4.8	7.9	3.1	65	0.451
Chicken	5.8	8.7	2.9	50	0.486
Pork	4.8	8.0	3.2	67	0.217
Ham	-	-	-	-	0.043
Bacon	-	-	-	-	0.008
Salad	7.0	10.4	3.4	49	0.266
Broccoli	8.9	11.3	2.4	26	0.299
Strawberry	-	-	-	-	0.013
Cherry	-	-	-	-	0.003
Milk	8.0	11.9	3.9	49	0.325

Table 1. Calculated storage life extensions due to lower temperature

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)
Leafy Salad Veg	270,000	201,000	80	160,800	26.5	75	31,959
Milk	360,000	200,000	50	100,000	48.8	50	24,400
Fresh meat	200,000	130,000	20	26,000	58.3	50	7,579
Bagged Salad	36,000	22,000	30	6,600	48.9	50	1,613
Fresh fish	9,600	7,200	20	1,440	58.8	25	212
Root veg *	51,000	40,500	80	32,400	10.0	50	1,620
Fruit *	99,150	91,300	80	73,040	10.0	50	3,652
Total	1,025,750	692,000		400,280			71,035

* For these categories the tonnages used are those currently stored by consumers in the fridge e.g. the tonnage related to the 26% of apples which are refrigerated.

Table 2. Estimates of waste reduction due to extended storage lives for foods already refrigerated

Product	Estimate of tonnage saving (t)	Cost per tonne (£.t^{-1})	Estimated value of waste saved (£m)	Embodied emissions CO_2e (t)
Leafy Salad Veg	31,959	2,590	82.8	121,444
Milk	24,400	620	15.1	92,720
Fresh meat	7,579	6,300	47.7	28,800
Bagged Salad	1,613	3,930	6.3	6,129
Fresh fish	212	9,570	2.0	806
Root veg	1,620	1,154	1.9	6,156
Fruit	3,652	1,910	7.0	13,878
Total	71,035		162.9	269,933

Table 3. Cost and embodied CO_2e of saved food waste

Product	Avoidable waste (t)	'Not used in time' (t)	Thrown away "going off" (%)	% stored in the fridge	Tonnage that would benefit from being moved to or from the fridge	Potential saving realised (%)	Waste saved (t)
More stored in the fridge							
Apple	180,000	170,000	136,000	26	100,640	50	50,320
Citrus fruit	67,000	55,000	44,000	20	35,200	50	17,600
Carrots	46,000	40,000	32,000	64	11,520	50	5,760
Cabbage	53,000	23,000	18,400	60	7,360	50	3,680
Cauliflower	10,000	8,000	6,400	71	1,856	50	928
Peppers	16,000	13,000	10,400	89	1,144	50	572
Other root veg	22,000	14,000	11,200	81	2,128	50	1,064
Less stored in the fridge							
Bananas	83,000	78,000	62,400	4	2,496	50	1,248
Total	477,000	401,000	320,800		162,344		81,172

Table 4. Estimates of annual UK waste reduction due to storing fresh fruit and vegetables in the correct location, due to extended shelf lives

Product	Estimate of tonnage saving (t)	Cost per tonne (£)	Estimated value of waste saved (£m)	Embodied emissions CO2e (t)
More stored in the fridge				
Apple	50,320	1,495	75.2	191,216
Citrus fruit	17,600	1,660	29.2	66,880
Carrots	5,760	910	5.2	21,888
Cabbage	3,680	1,350	5.0	13,984
Cauliflower	928	1,780	1.7	3,526
Peppers	572	2,950	1.7	2,174
Other root veg	1,064	1,670	1.8	4,043
Less stored in the fridge				
Bananas	1,248	920	1.1	4,742
Total	81,172		120.9	308,454

Table 5. Costs and embodied emissions in saved waste due to extended storage lives for foods not already refrigerated or which would benefit from not being in the fridge

Nominal Temperature (°C)	Load	Stage	Annual energy consumption (kWh)		
			Fridge 1	Fridge 2	Fridge-freezer 3
7	70% / 15%	Stable	90.8	80.9	248.5
	70%	Pull-down	1.3	1.3	1.1
		Total	92.1	82.2	249.5
	85% / 15%	Stable	93.1	80.3	249.4
	85%	Pull-down	2.2	2.4	2.0
		Total	95.3	82.7	251.4
4	70% / 15%	Stable	106.7	87.6	277.0
	70%	Pull-down	3.0	1.6	0.8
		Total	109.7	89.2	277.7
	85% / 15%	Stable	105.6	88.4	276
	85%	Pull-down	13.9	3.2	1.7
		Total	119.5	91.6	277.7

Table 6. Annual energy consumptions at 7°C and 4°C for the three appliances

Scenario	Annual energy increase (kWh)		
	Fridge 1	Fridge 2	Fridge-freezer 3
Lowering fridge temperatures to 4°C with currently refrigerated foods	17.6	7.0	28.2
As above, plus adding additional foods	27.4	9.4	28.2
Temperature difference	*3.4*	*2.0*	*2.3*
Total 'normalised' energy impact	24.2	14.1	36.8

Table 7. Measured energy increases for lowering fridge temperatures when loaded with currently refrigerated foods and for adding additional foods which currently are not always refrigerated

Scenario	Annual UK energy increase (1000 kWh)	Increased cost (€ m)	Increased emissions CO_2e (t)
Lowering fridge temperatures to 4°C with currently refrigerated foods	611,523	70.6	320,805
Adding foods which are currently not normally refrigerated	88,840	10.3	46,606
	700,363	80.9	367,411

Table 8. Energy impacts associated with lowering fridge temperatures and adding foods which currently are not always refrigerated

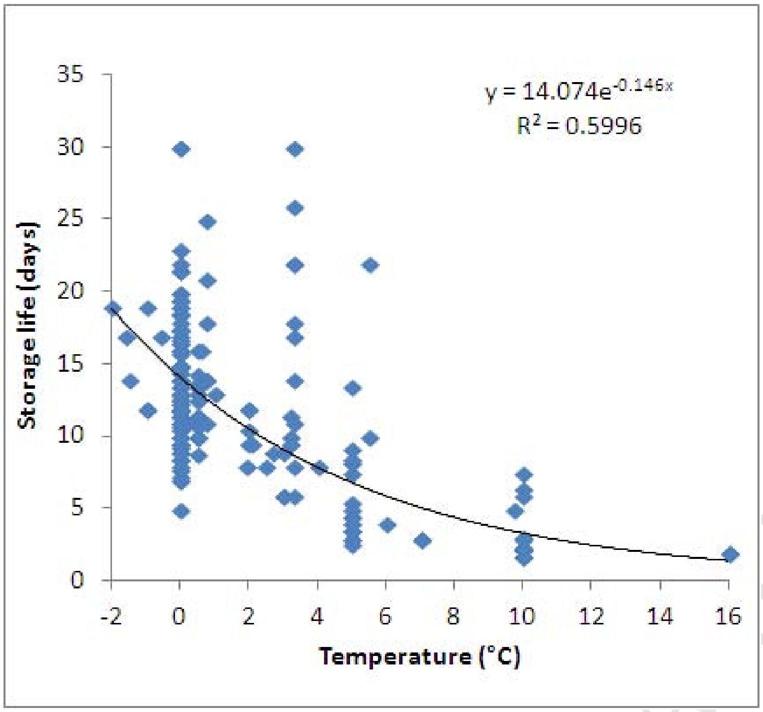

Figure 1. Reported Practical Storage Lives of chilled cod

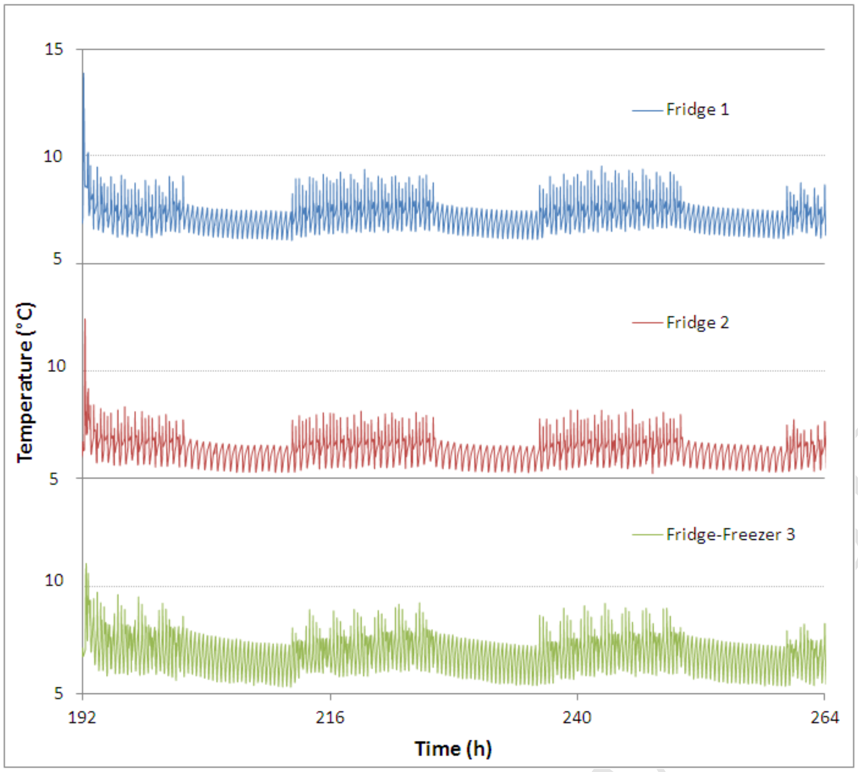

Figure 2. Average air temperatures above the shelves of the three appliances (note three separate temperature axes, all from 5 to 15°C)

- Lower refrigerator temperatures can extend storage lives and reduce food waste.
- However, lower temperature operation also increases energy consumption.
- The annual UK-wide impact of lowering refrigerators from 7°C to 4°C was assessed.
- Saved waste was estimated at £283.8m, associated with 578,383 tonnes CO_2e.
- Energy impact was estimated to be lower at £80.9 m and 367,411 tonnes CO_2e.