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Project title:	Feasibility of the IoT for domestic refrigerators, food safety and waste
Principal investigator (institution):	Simon Pearson
Co-investigators/partners	Argyrios Zolotas, Jin Chu, Christian James, Graham Purnell, Stephen J. James
Description	The overall aim of this project was to establish the feasibility of using the Internet of Things (IoT) to support the safe handling and storage of foods within the domestic refrigerator. Questionnaires and surveys were conducted to assess the practices and views of consumers and the current performance of domestic refrigerators. This project was supported by Tesco plc.
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Project timeframe	4 months
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Feasibility of the IoT for domestic refrigerators, food safety and waste

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1 Executive summary

This was a multi-disciplinary project combining the food quality expertise of the National Centre for Food Manufacturing (University of Lincoln) and the food refrigeration expertise of the Food Refrigeration and Process Engineering Research Centre (Grimsby Institute), with the knowledge of IoT systems at the Department of Control System Engineering (University of Lincoln) and the UK consumer panel of Tesco plc., the biggest food retailer in the UK.

The overall aim of this project was to establish the feasibility of using the Internet of Things (IoT) to support the safe handling and storage of foods within the domestic refrigerator. In doing so it sought to:

a. Understand if the IoT can be used to control domestic refrigerators and identify the likely benefits.

b. Establish the potential impact on food safety and waste.

c. Carry out a benchmark study to understand the performance of refrigerators and potential to improve control.

The project was structured in three parts:

1. Part One: Survey consumer understand and attitudes to refrigerators and IoT.
2. Part Two: Monitor the actual performance of domestic refrigerators in the home.
3. Part Three: Examine how the IoT could be used to develop truly SMART refrigerators, change consumer behaviours and effect SMARTer uses of existing refrigerators.

The study showed that relatively few consumers understand how well their refrigerator was performing and just 7% of survey respondents (n=711) measure actual temperature. In our refrigeration monitoring we showed very wide variances in temperature performance between refrigerators, and also considerable variations of temperature within an individual fridge. We used a fuzzy clustering approach to show that a group of refrigerators were poorly controlled and had measured temperatures well above the FSA guidelines of 5 degrees. IoT has the potential to identify poorly performing refrigerators and an opportunity to bring about behavioural changes which may help underpin food safety in the home. We recommend that changes to International standards for domestic refrigerators are considered to raise awareness of the importance of refrigeration temperature, in particular it should be considered

that all new refrigerators should be equipped with a digital display of the actual temperature.

Acknowledgements

The authors would like to thank Tesco in supporting this project and those members of the public who provided their time, assistance, data and opinions for this project.

This project was funded by the RCUK, FSA and ITaaU through the RCUK Digital Economy Theme, Challenge are network in IT as a Utility, EPSRC grant EP/K003569/1.

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2 Aims and objectives

The overall aim of this project was to establish the feasibility of using the Internet of Things (IoT) to support the safe handling and storage of foods within the domestic refrigerator.

To achieve this aim the project was carried out with a multi-disciplinary team combining the food quality expertise of the National Centre for Food Manufacturing (University of Lincoln) and the food refrigeration expertise of the Food Refrigeration and Process Engineering Research Centre (Grimsby Institute), with the knowledge of IoT systems at the Department of Control System Engineering (University of Lincoln) and the UK consumer panel of Tesco plc., the biggest food retailer in the UK.

In order to achieve the aim the project was set up to:

1. Conduct a large scale underpinning survey of the temperature performance of domestic refrigerators and support this with controlled laboratory studies.

The data from this survey was used to look at the feasibility to:

2. Identify how consumers could exploit the IoT for domestic refrigerators, such as;
    - Provision of rapid advice on refrigerator temperature performance, thereby improving safety and reducing waste.
    - Ability to influence the improved behavioural use of a domestic refrigerator (reduce door opening, correct positioning of food within the unit, uptake of advise on food safety and risks, etc).
    - Provision of advice on how to utilise food before use by dates (e.g. provision of consumer specific recipes, alternative process, etc).
    - Active control of the refrigerator to improve temperature control (e.g. for enhanced responses to food loading and door opening behaviour).
    - Understand whether domestic refrigerators could be networked to National Grid demand management strategies and other domestic devices to reduce domestic peak power loads.
3. Provision of technical advice and assessment of barriers / needs to make the domestic refrigerator “SMART”, and facilitate SMARTer use of the domestic refrigerator, and increased IoT functionality, for example assessment of;
    - Embedded bar code scanners to monitor food stock level and use-by dates.

- Embedded RFID sensors to monitor stock levels.
- Stock purchasing advice to reduce waste / improve safety.
- Network security and risks from IoT compliant domestic refrigerators.
- Data handling, storage and retrieval requirements.

In doing so it sought to:

a. Understand if the IoT can be used to control domestic refrigerators and identify the likely benefits.

b. Establish the potential impact on food safety and waste.

c. Carry out a benchmark study to understand the performance of refrigerators and potential to improve control.

d. Identify potential policy changes which may be required to improve the safety and functionality of domestic refrigerators.

The project was structured in 3 parts:

1. Part One: Survey consumer understand and attitudes to refrigerators and IoT.
2. Part Two: Monitor the actual performance of domestic refrigerators in the home.
3. Part Three: Examine how the IoT could be used to develop truly SMART refrigerators, change consumer behaviours and effect SMARTer uses of existing refrigerators.

3 Methods

3.1 Consumer questionnaire

A consumer survey was designed to examine:

1. observations of refrigerator characteristics;
2. consumer shopping patterns and practices, food storage practices and expectations;
3. views on packaging instructions;
4. Consumer knowledge of and interest in smart refrigerators and applications.

The survey was, in part, based on the 1991 survey undertaken by FRPERC for MAFF (Evans et al., 1991) and a 2010 survey (Anon., 2010) undertaken by Campden BRI for WRAP (which in turn was based on the 1991 survey).

3.2 Refrigerator performance survey

As already mentioned the survey of refrigerator performance was based, in part, on the 1991 survey undertaken by FRPERC for MAFF (Evans et al., 1991) and the 2010 survey (Anon., 2010) undertaken by Campden BRI for WRAP.

Air temperatures were measured in refrigerators in three locations; top and bottom shelf, and door. The temperatures were measured using miniature data loggers (Logtag TREX-8 [top and bottom shelf] and TRIX-8 [door], LS Technology, Winterbourne Zelston, Dorset, UK) with an accuracy of ±0.5°C. Temperatures were recorded at two-minute intervals for a week, which included two weekend days. Participants were asked to continue using their refrigerators in their normal manner. They were not asked to keep a detailed diary of refrigerator use (for fear of this prompting them to change from their normal use and potentially affect the validity of the results). The participants were supplied with instructions on where to place the temperature dataloggers. They were retrieved by the participants at the end of the measurement period and returned for data analysis.

4 Key findings

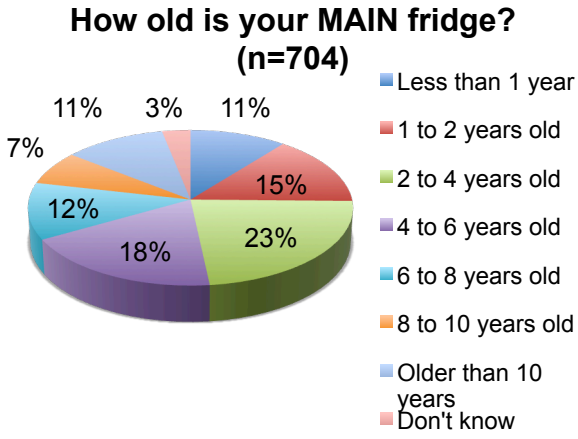
4.1 Consumer questionnaire

In total three questionnaires were circulated to participants:

1. 32 hard copy questionnaire (53 questions)
2. 76 on-line questionnaire (53 questions)
3. 711 initial Tesco short questionnaire (15 questions)

The full responses to all of the questions asked can be found in the appendices.

Respondents were asked how many refrigerators they owned and the age of their refrigerators (Figure 4.1, below).



The majority (70%) of respondents owned only one refrigerator. The majority of these refrigerators were less than 4 years old (49%), this a similar finding to other surveys for example the 2010 WRAP survey reported that 51% were less than 4 years old (Anon., 2010).

Figure 4.2 Types of domestic refrigerators

Eight different sub-types of domestic refrigerators were identified in this project (Fig 4.2). The most popular type of refrigerator was a refrigerator-freezer with freezer below and refrigerator above (44%), and the second most popular refrigerator (17%) was a under counter unit without ice-box (**Figure 4.1**). Other studies have reported a far higher majority for refrigerator-freezers. For example, a recent survey across the island of Ireland (Anon., 2015) found that 70% of the refrigerators in the homes they surveyed were refrigerator-freezers.

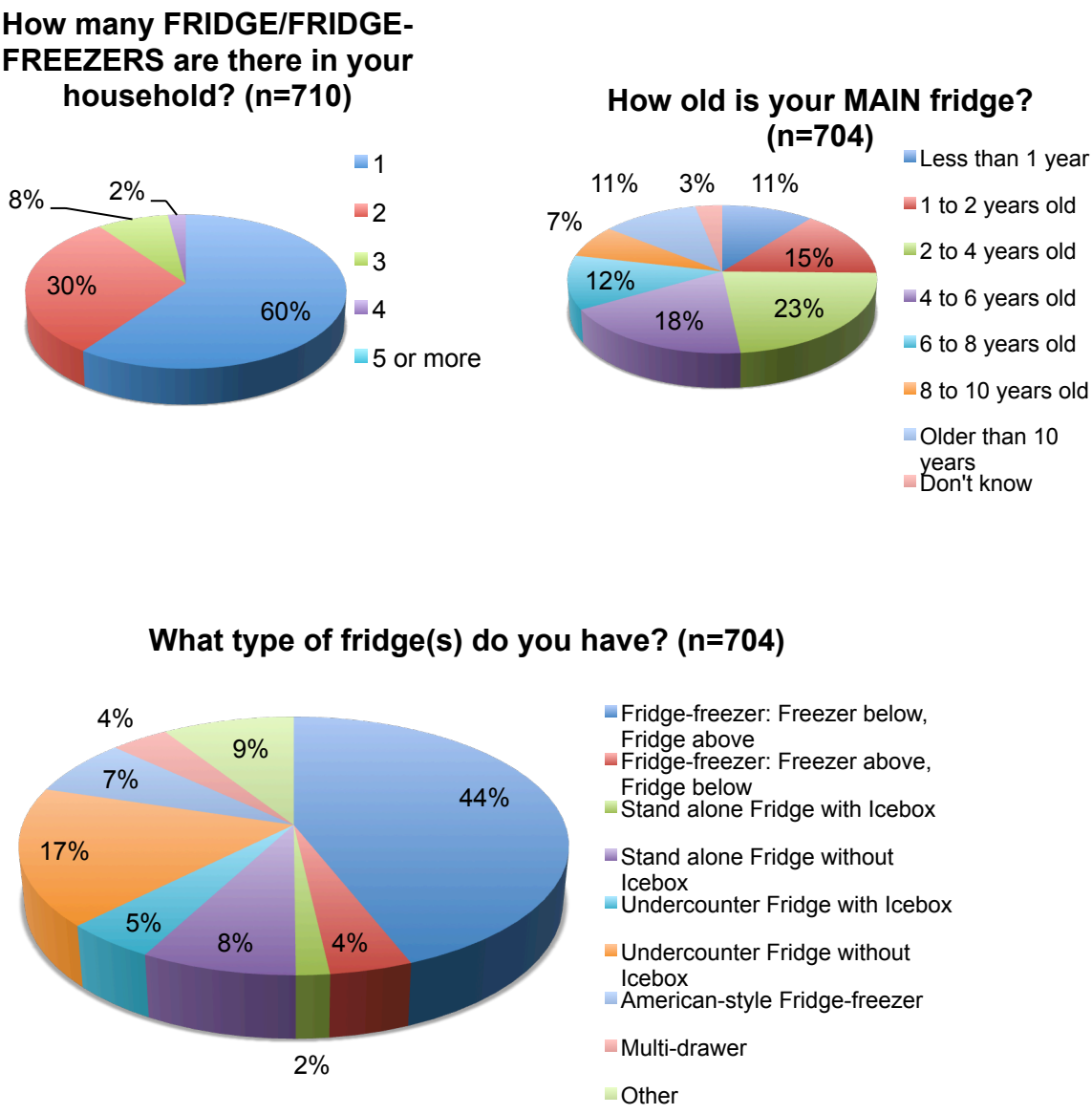


Figure 4.1. How many, how old and what types of refrigerator respondents' had

When asked about the temperature of their refrigerator the majority of respondents did not know what temperature their refrigerator was currently running at or what the recommended temperature (<5°C) should be (Fig 4.4).

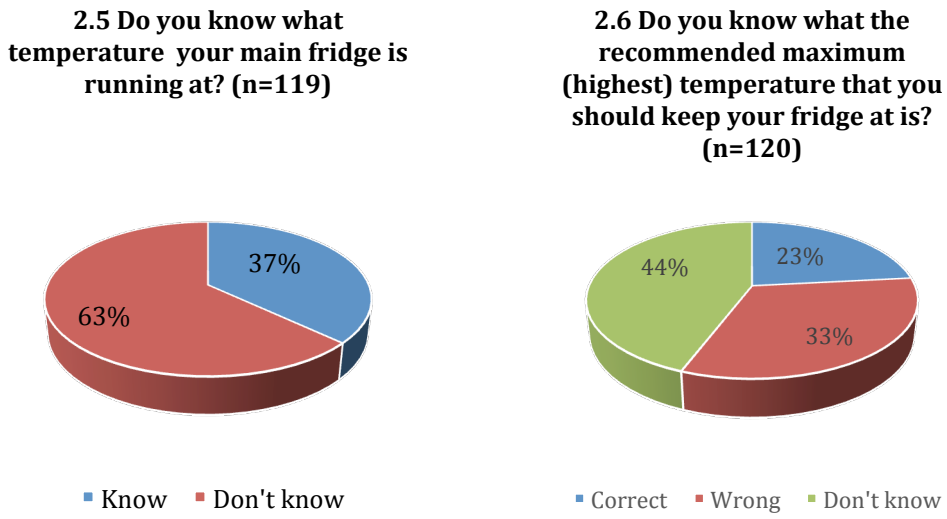


Figure 4.2. Respondents' answers to questions 2.5 and 2.6, insight into optimal refrigerator temperatures.

This is in contrast to the 2010 WRAP survey (Anon., 2010) which reported that only 21% of their respondents did not know what the recommended temperature is, but is similar to other surveys that have shown a lack of knowledge (James et al., 2008). There is a clear lack of understanding of refrigeration temperatures. Anecdotally, respondents comments appear to show that many people take it for granted that a refrigerator should keep all the food at a "safe temperature", this is not supported by the refrigerator temperature survey carried out as part of this study.

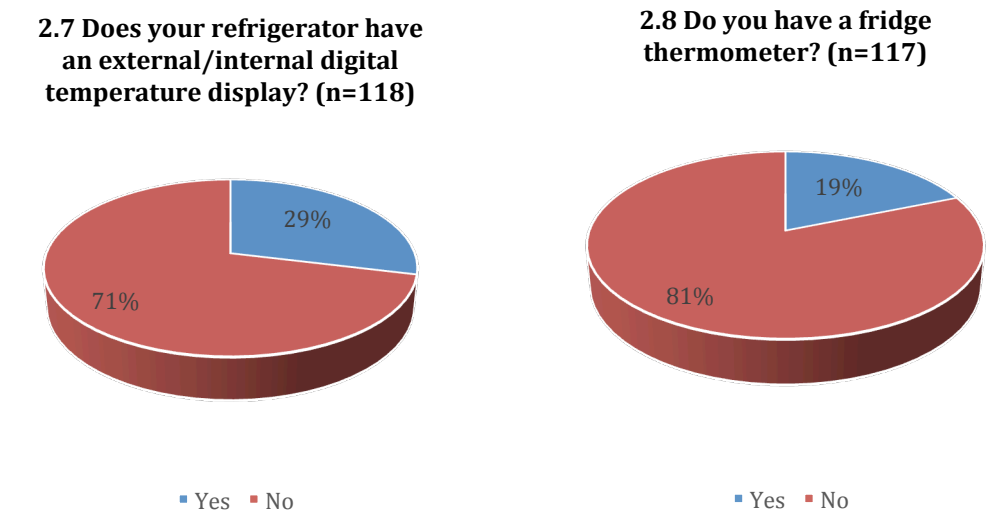
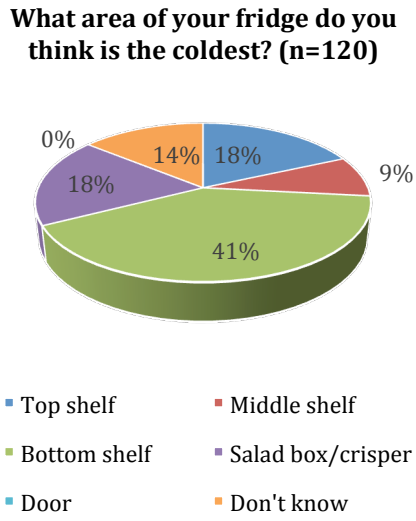


Figure 4.3. Respondents' answers to questions 2.7 and 2.8, insight into temperature monitoring.

Few refrigerators (29%) owned by respondents had a digital display of the temperature of the refrigerator, and few (19%) owned refrigerator thermometers. This figure on thermometer ownership is better than other UK studies that have reported ownership levels of 9% (Anon., 2010) and 6% (Anon., 2015). These responses suggest that there is a lack of feedback data to empower effective control of refrigerator temperatures by their users. In addition, the responses show that the majority of refrigerators (>75%) were not directly controlled by a temperature setting



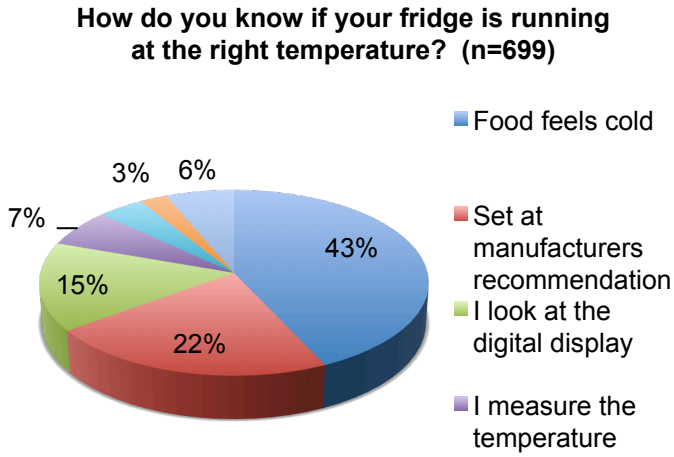


Figure 4.4). Furthermore relatively few respondents were activaly checking refrigerator perfromance against measured temperature, only 7% measured temperature and 15% used internal digital displays for a reference. 43% simply assumed the refirgerator was operating as it “felt cold”.

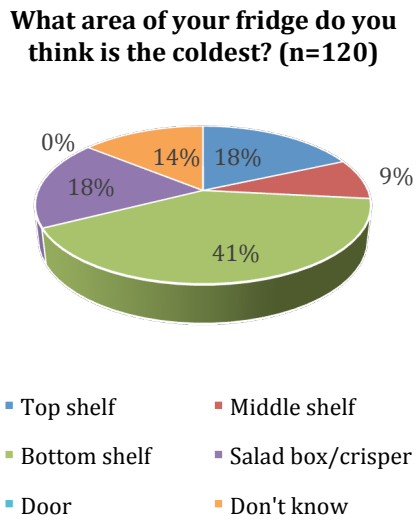


Figure 4.4. Respondents' answers to questions 2.12 and 2.13, insight into views of refrigerator performance.

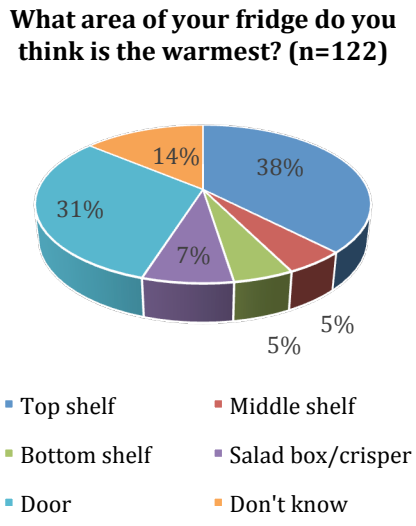
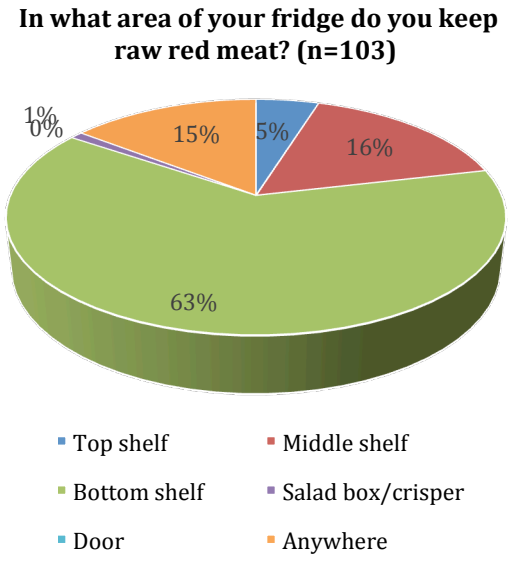


Figure 4.5. Respondents view on stratification.

In terms of temperature stratification, the largest group (41%) of respondents believed that bottom shelf of their refrigerator was the coldest area, and that the door (38%) and top shelf (31%) were the warmest (Figure 4.5). In

general, most refrigerator survey's have found that in the majority of refrigerators the bottom shelf is the coolest area. However, this is not true in some designs (James et al., 2001).

The FSA advises consumers to store different kinds of food in different areas in their refrigerator (Figure 4.6). Raw meat, poultry and fish should be stored on the bottom shelf in the refrigerator to avoid drip and cause cross contamination on other foods. From our survey, 37% of the people do not store raw meat on the bottom shelf, and 62% do not store ready meals on the top shelf.



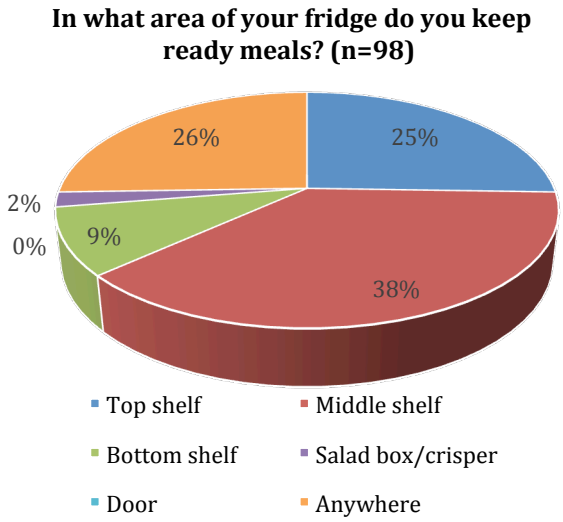


Figure 4.6. Understanding of FSA advice on where to store food in the refrigerator

Over half of the respondents (58%) did not know what a "smart" refrigerator was, and only 7% had considered buying a smart refrigerator (Figure 4.7). The definition of a smart refrigerator is "An internet **refrigerator** (also known as **Smart refrigerator**) is a **refrigerator** which has been programmed to sense what kinds of products are being stored inside it and keep a track of the stock through barcode or RFID scanning".

It is clear that respondents would appreciate feedback that would help with stock control of the food in their refrigerator (Figure 4.8). Fifty eight percent would value feedback on food condition.

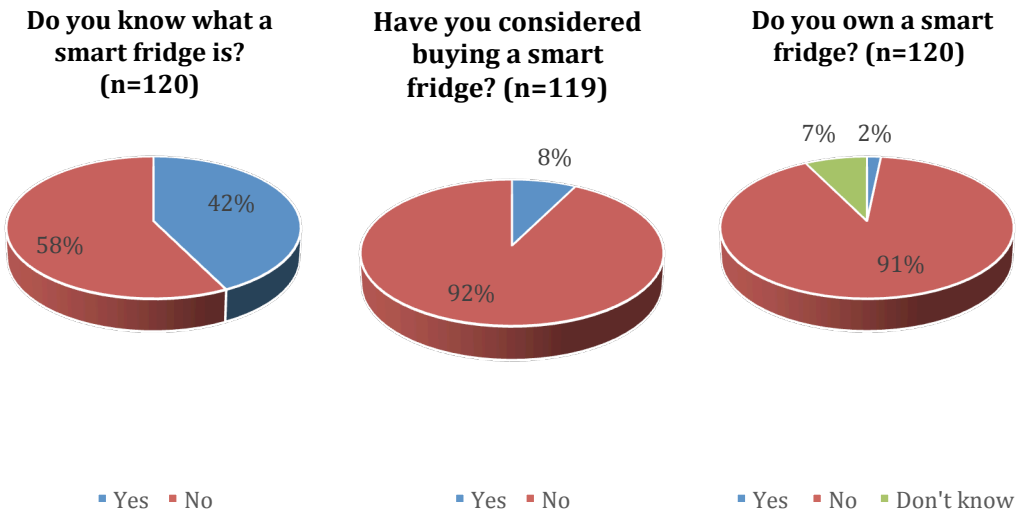


Figure 4.7. Respondents' answers to questions on smart refrigerators.

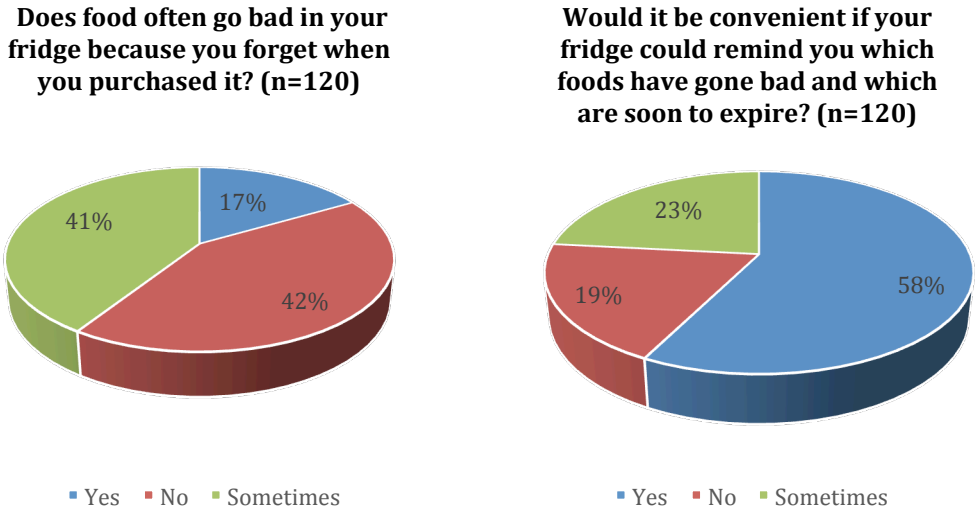


Figure 4.8. Respondents' answers to questions on food waste.

Some respondents' comments were of particular interest, as they provide us important information about the future thoughts/development of smart refrigerators. Below are some of the respondents' comments below:

Comment: *"There is a big danger that SMART refrigerators could create a dependency that stops people being able to think for themselves and truly understanding issues around food safety. I think increased education around food safety, etc., is a better option. Reminders and information about stock levels, food expiry, menu choices, etc., don't just apply to food in the refrigerator, so you're only going to get part of the information that you need to make these decisions, which I would find particularly annoying, so I'll continue*

to rely on good old fashioned lists, either on paper or in my phone and, of course, my ever diminishing brain power."

Comment: *"A refrigerator that can talk and remind would be great - a ROBO REFRIGERATOR"*

Comment: *"It would concern me that the more refrigerator gadgets I had, the more could go wrong with it. The first refrigerator we had lasted for over 20 years."*

4.2 Refrigerator performance survey

4.2.1 Temperature distribution plots

Full temperature plots of the refrigerators surveyed can be found in Appendix C. Of the **32** refrigerators surveyed so far:

- Only 6 fridges (18%) kept the mean temperature of the refrigerator below 5°C in all areas monitored (i.e. top shelf, bottom shelf, and door).
- If the door is excluded the above value rises to 11 fridges (34%).
- The warmest mean temperatures were recorded in the door area in the majority of the fridges (53%). While the top shelf and bottom shelf positions were the warmest (on average) in 31% and 15% of the fridges, respectively.
- The coldest mean temperatures were recorded in the bottom shelf area in the majority of the fridges (75%). While the top shelf and door positions were the coldest (on average) in only 19% and 6% of the fridges, respectively.
- The analysis on the current data provided very useful outcomes in terms of controller performance evaluation. However, it is necessary to examine a higher number of fridges (and their data) to have a clearer assessment on the control performance of different types of refrigerators and/or whether newer fridge control performance is better compared to older fridges.

Figure 4.9 presents the temperature distribution of the overall number of (en masse) refrigerators in the study. The temperature location contribution per temperature range is shown by the different coloured slices for the Top, Bottom and Door locations. It is worth noting that the bin width is 2 units, i.e. for a temperature centre of 2°C the bin edges extend from 1 to 3°C (similarly for other centre temperatures). In addition, the figure presents the fitted normal distribution curve with mean=5.26°C and standard deviation=3.62°C. The normal(-ish) distribution profile is not an unexpected result given the overall sample number and nature of expected temperature profile in a refrigerator. The result in this figure can be compared to James & Evans (1992) mean temperature profiles in refrigerators from the 1991 MAFF study.

In the much larger MAFF study the overall average temperature was 6°C. The data so far analysed indicates a small 0.74°C improvement. However, it still indicates that over 50% of the food in a domestic refrigerator is held at a temperature above the recommended 5°C maximum.

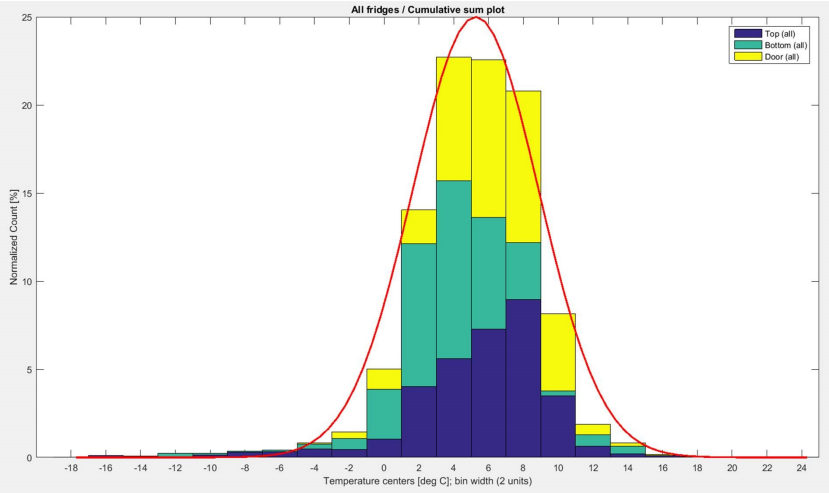


Figure 4.9 Temperature distribution (all refrigerators) with temp location cumulative sum contribution

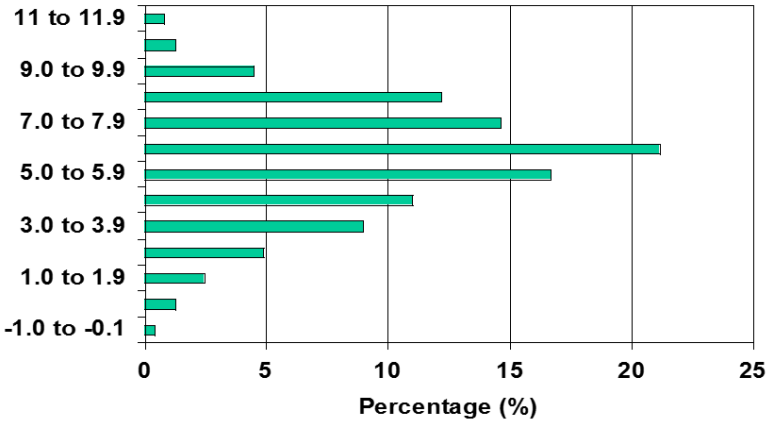


Figure 4.10 Temperature distribution from the 1991 MAFF study (James & Evans, 1992) (y-axis: Temperature [°C])

4.3 Assessing individual refrigerator performance

From the point of view of the food safety, it is clear that the control performance of refrigerators needs to be studied in more detail. Figure 4.11 shows that when all data are averaged domestic refrigerator temperature is over the 5 degree control band for considerable periods. However, this amalgamation of data hides the impact of specific refrigerators which may be performing very poorly, and could be above the 5 degree control band for the majority or all of the time. These refrigerators are of significant concern as poor temperature control over

sustained periods is likely to have food safety implications. Poor temperature control is also likely to increase food waste, and the rate of spoilage.

Figure 4.13, 4.14 and 4.15 show three examples of refrigerators with different characteristics (these are Excel figures listing the date/time). Refrigerator 4 is a refrigerator with low variation in temperature but large stratification (i.e. variance in temperature within a fridge (between top, bottom and door) and a steady control. Refrigerator 25 is a refrigerator with high temperature and large stratification, and required 4 days to recover to the setting point. It shows a very bad control of the temperature and energy. Refrigerator 17 is a refrigerator with a higher than desired temperature but generally good control.

All refrigerators survey plots are shown in the Appendix C. The data shows very mixed characteristics and some of the refrigerators are of concern. Some refrigerators seem to be "little more than an electric storage cupboard", such as refrigerator 1 (esp. Top temperature). It shows urgent need to carefully investigate refrigerator controls or settings.

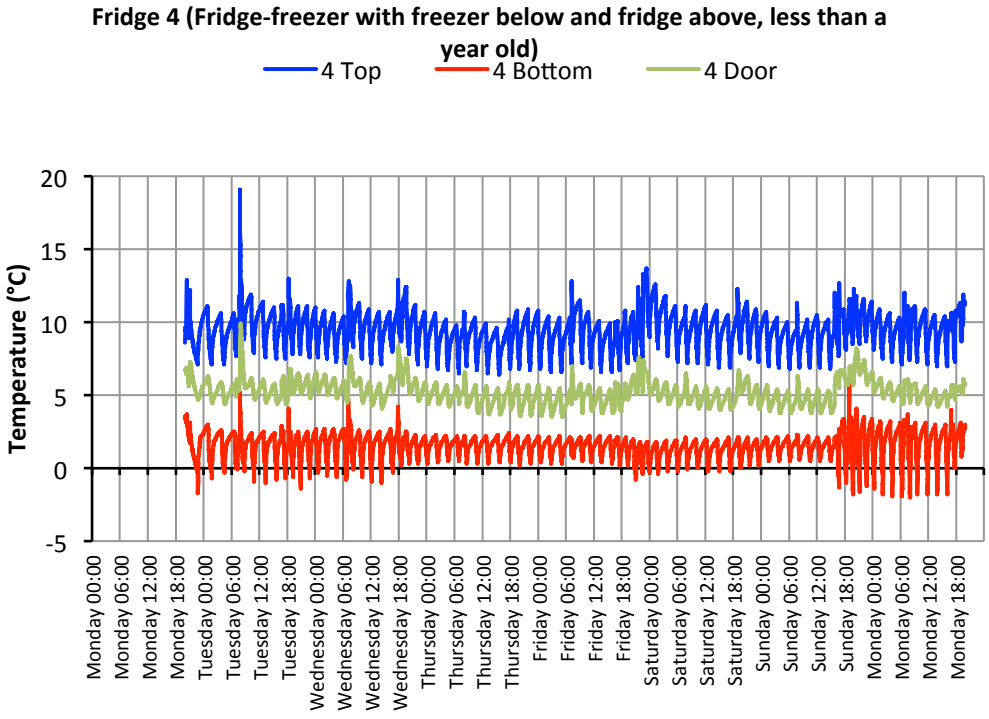


Figure 4.11. Example of a refrigerator with low variation in temperatures, but a large stratification in temperatures

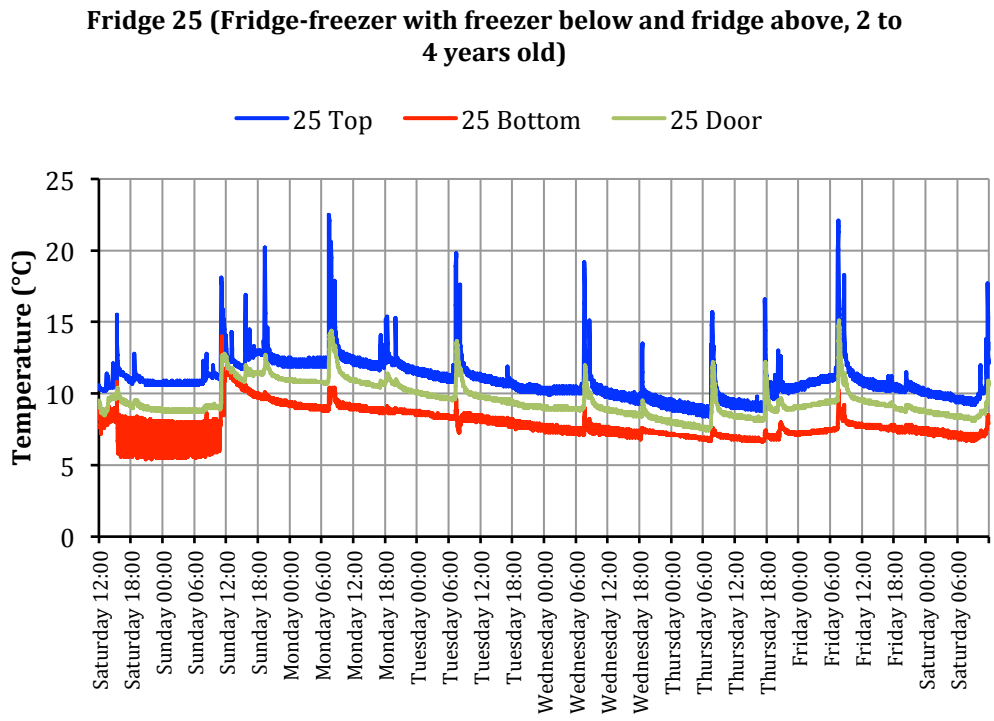


Figure 4.12. Example of a refrigerator with too high temperatures, too much stratification, and unable to recover control during week

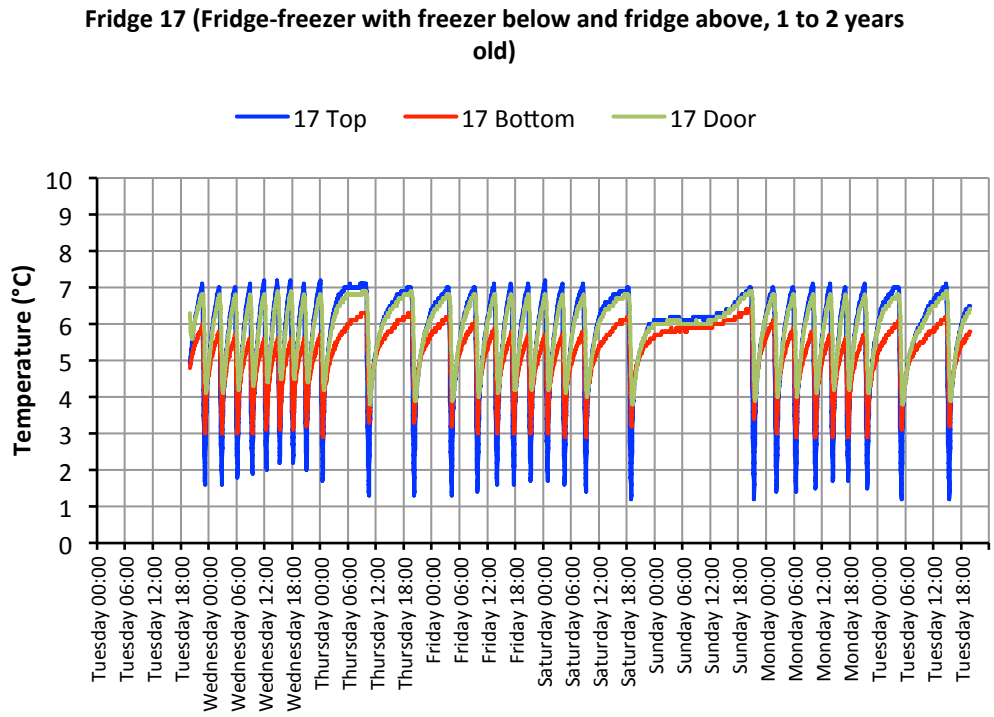


Figure 4.13. Example of a refrigerator with generally good control, but running a little bit high

The performance of all the refrigerators surveyed is summarised in Figures 4.16 to 20. The box plot in Figure 4.16 emphasises the difference in performances between refrigerators, for example Fridge 9 has minimal variance around the mean and 5 degree threshold, whilst fridge 25 never attained a temperature close to the threshold. Fridge 25 would be a very concerning refrigerator. The mean temperature for the top of all fridges was 5.5°C.

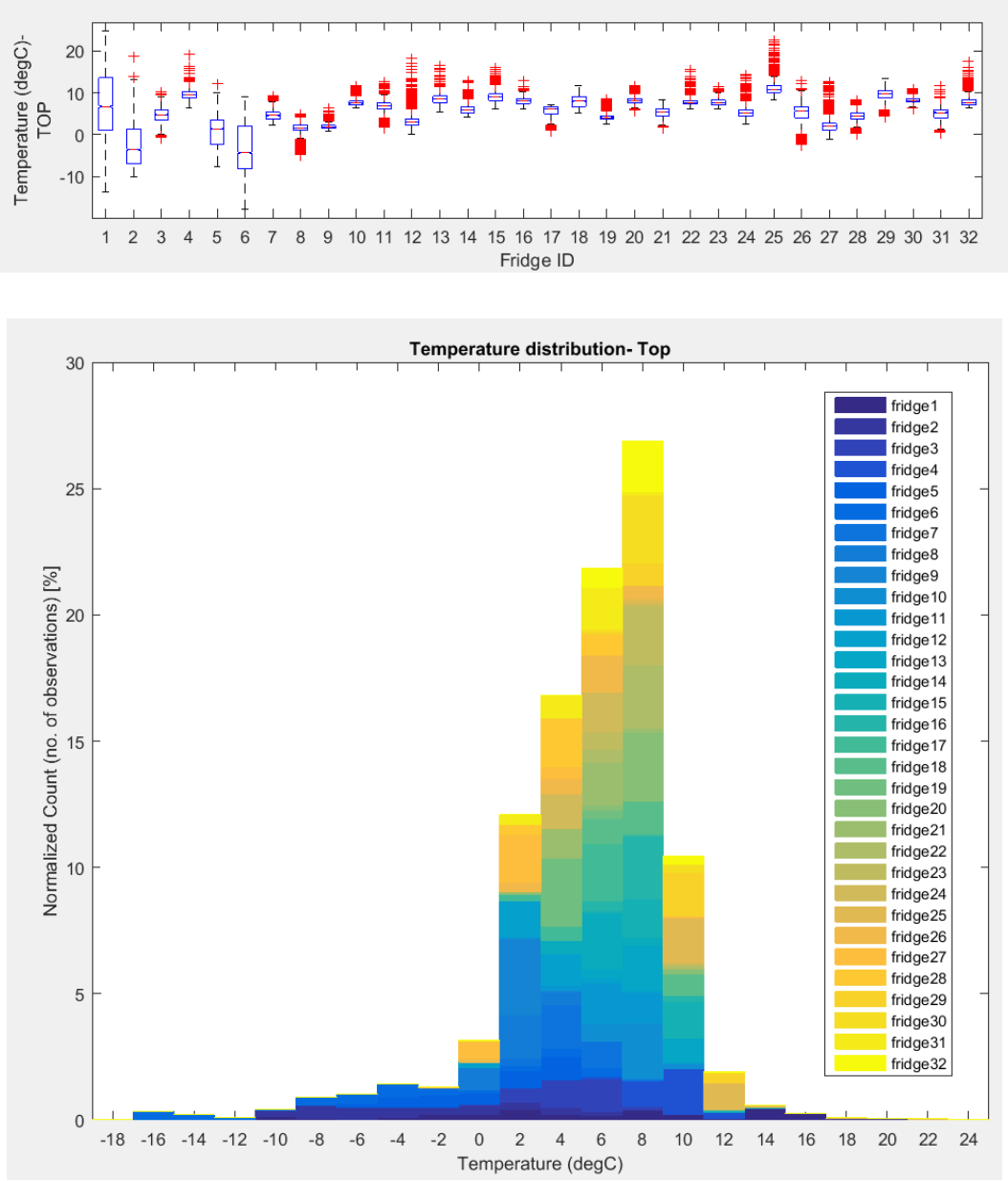


Figure 4.14 Boxplot and cumulative sum contribution for temperature distribution of top location with refrigerator identifier

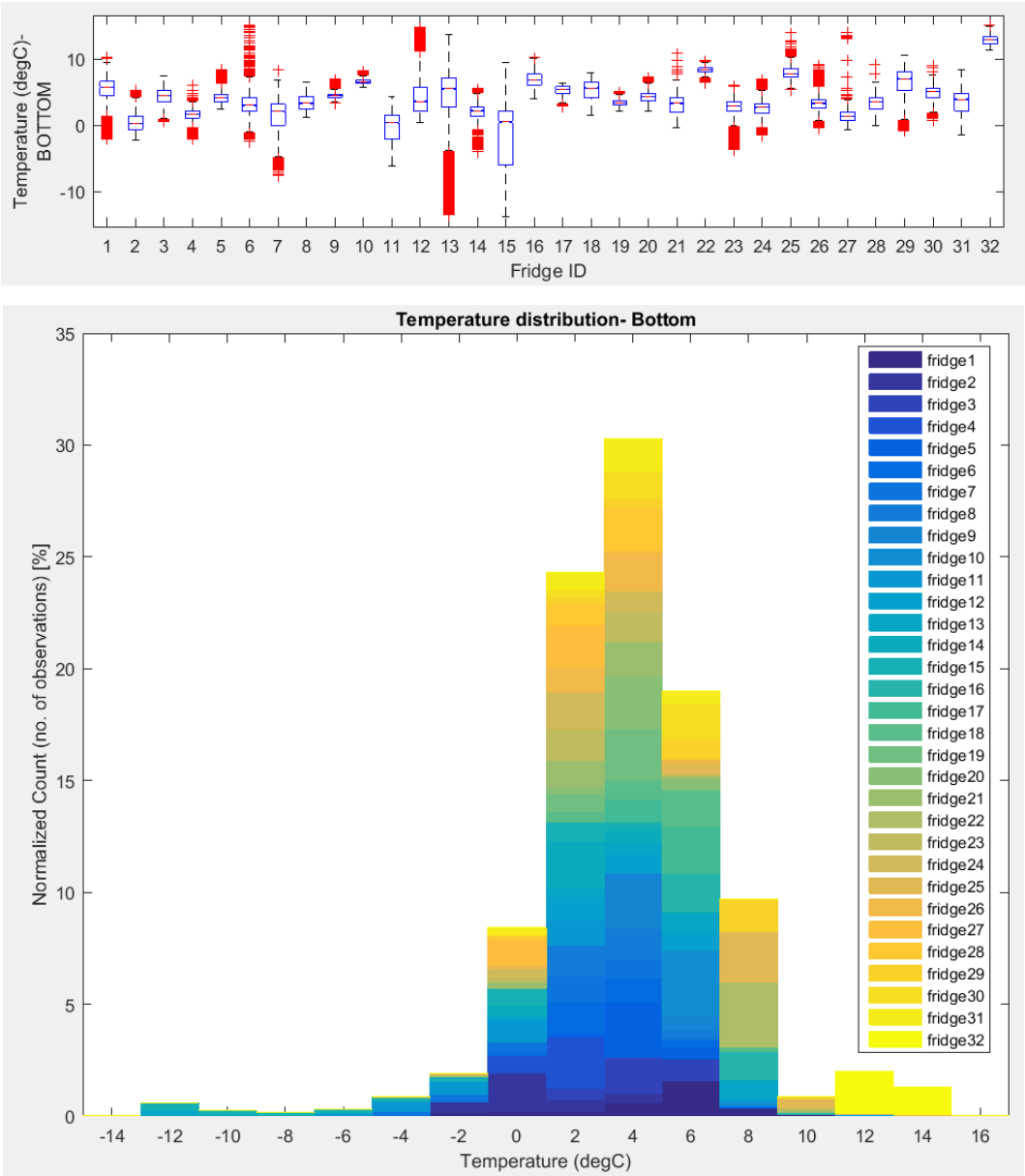


Figure 4.15 Boxplot and cumulative sum contribution for temperature distribution of bottom location with refrigerator identifier

Figure 4.17 shows that the bottom of the refrigerators tended to be cooler than the top, with an average temperature of 4.0^{o}C recorded. However, again there were notable exceptions, note fridge 32 where the mean was over 10 degrees. For fridge 13 there were a large number of freezing (sub -10^{o}) exceptional temperatures recorded.

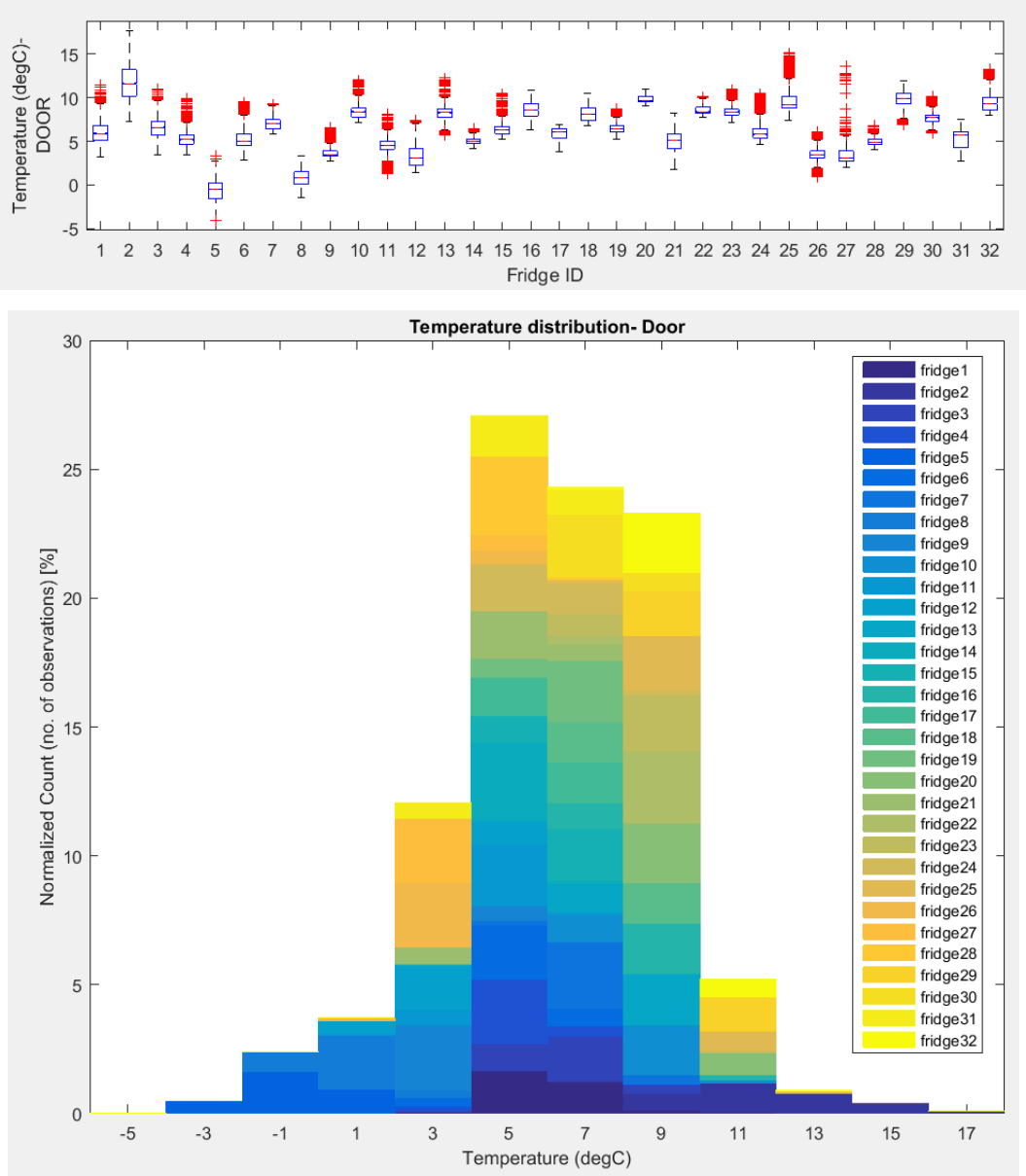


Figure 4.16 Boxplot and cumulative sum contribution for temperature distribution of door location with refrigerator identifier.

Figure 4.18 shows the door temperature profiles, across the survey the mean door temperatire was 6.0^{o}C so this tended to be warmest area of the fridge, probably reflecting the thermal transfer from the external room through the door. Again there were large variances in individual refrigerator performance, for example fridge 2 was consistently above 10 ^{o}C. These variations in mean temperature across the units are further summarised in Fig 4.19 and 4.20. These show and confirm considerable difference between different refrigerators, and a number of units (25 and 32) were operating at means of > 9^{o}C. These refrigerators would be of concern in terms of food safety and spoilage. It is not though clear how many refrigerators are of concern across the country. If we consider that there are 26m households within the UK, each with in average 1.5 fridges (total 39m refrigerators in the UK), there could be many multiple thousand which are poorly performing with an increased food

safety and spoilage risk. Identifying these poorly performing refrigerators could be a key benefit of the IoT, there is also a clear need to improve the design standards of refrigerators and to identify how there performance changes with time.

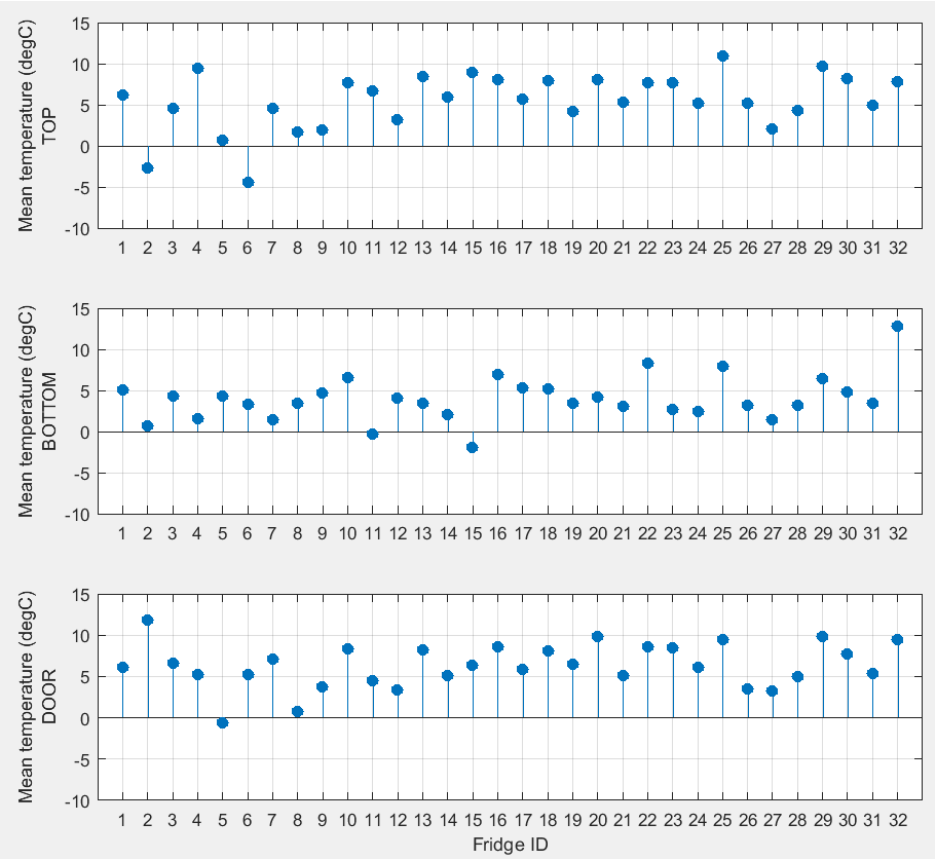


Figure 4.17 Mean temperatures per refrigerator per location

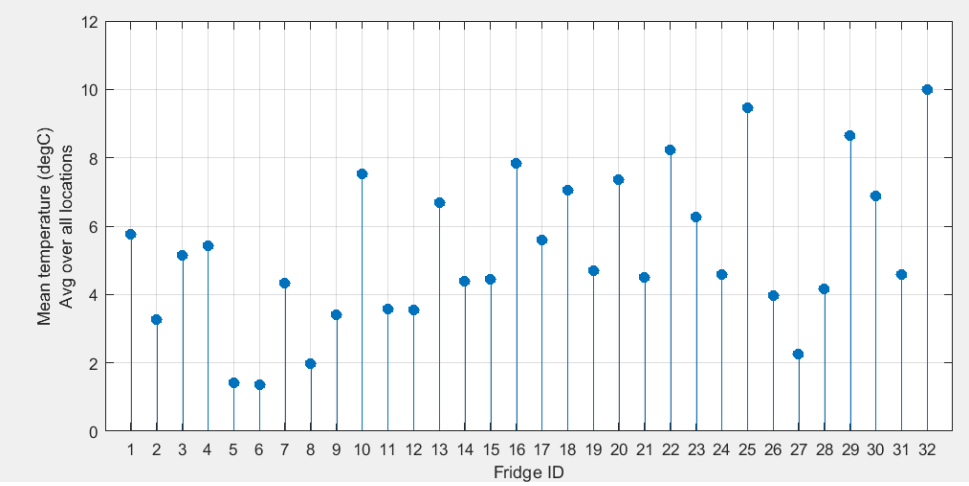


Figure 4.18 Average mean temperatures per refrigerator over all locations

Moreover, Appendix D presents the results on temperature distributions – presented in to - separated in relation to the individual refrigerators for completeness. In Appendix E we also present the detailed Temperature distribution plots per refrigerator per day in a cumulative sum plot format, with the coloured slices referring to the different temperature location contribution in the observations.

4.3.1 Clustering refrigerator controller performance

To explore the data in further detail, we applied a dynamic assessment of refrigerator performance, this approach has been applied in many engineering applications, and a number of approaches can be followed (an example from the area of railway control engineering can be seen in the paper by Goodall et al., 2000). In all dynamic control performance analyses a number of signal-related metrics are used (Skogestad & Postlethwaite, 2007), e.g. the 1-norm (or Sum of Absolute of signal values, or in estimation problems is referred to as Sum of Absolute Difference between target values and estimated ones), the Euclidean-norm (relates to the Root Mean Square, etc.) This also illustrates the multidisciplinary application nature of control systems and signal analysis.

For this study, we applied this approach to analyse the dynamic performance of the refrigerator controllers (from the refrigerators that were monitored in the study) as listed below:

a. Variation/Stratification level around refrigerator's mean temperature:
   This is performed per refrigerator. In this context, a typical control profile for a refrigerator is shown in Fig 4.21. An RMS (root-mean-square) calculation is performed with the mean of the temperature data removed (i.e. emphasizing stratification). The RMS nature of the metric will also emphasize time samples with extreme values of temperature variation with respect to the individual refrigerator mean. Larger RMS values will indicate higher variation of the refrigerator controller response around its temperature mean, lower

values refer to smoother control profiles around the mean.

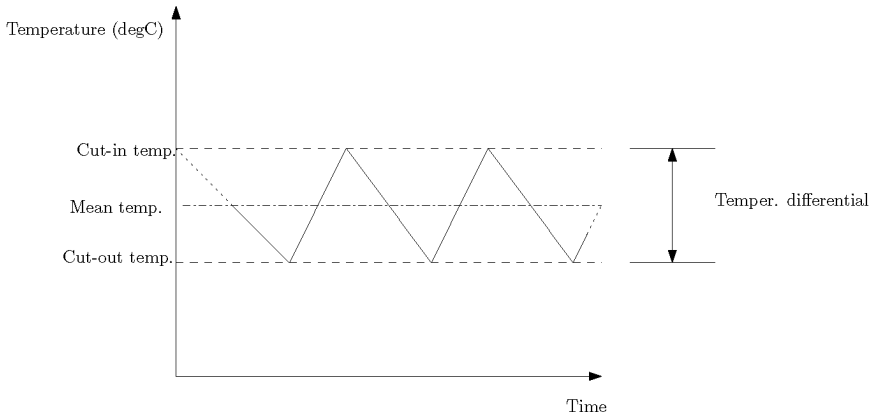


Figure 4.21 Typical switching control profile for a refrigerator

b. Variation/Distance above a set threshold temperature: A threshold temperature of 5°C is used and RMS calculation is performed on the extracted temperature data contribution above the threshold temperature (addressing a typical threshold for potential food safety concern, if this threshold temperature was violated by the refrigerator control system for a substantial range of samples). An example on the quantity assessed is shown in Fig 4.22. It is worth noting that the set threshold temperature is not necessarily associated to the actual mean temperature of the investigated refrigerator. This assessment intends to assist in identifying possible cases of high temperature set points (hence potentially jeopardising food safety) and possible concerning refrigerator controller performance. Larger values indicate that the refrigerator controller response tend to violate the threshold temperature for a larger period. The RMS nature of the metric will also emphasize time samples with high values of temperature violation.

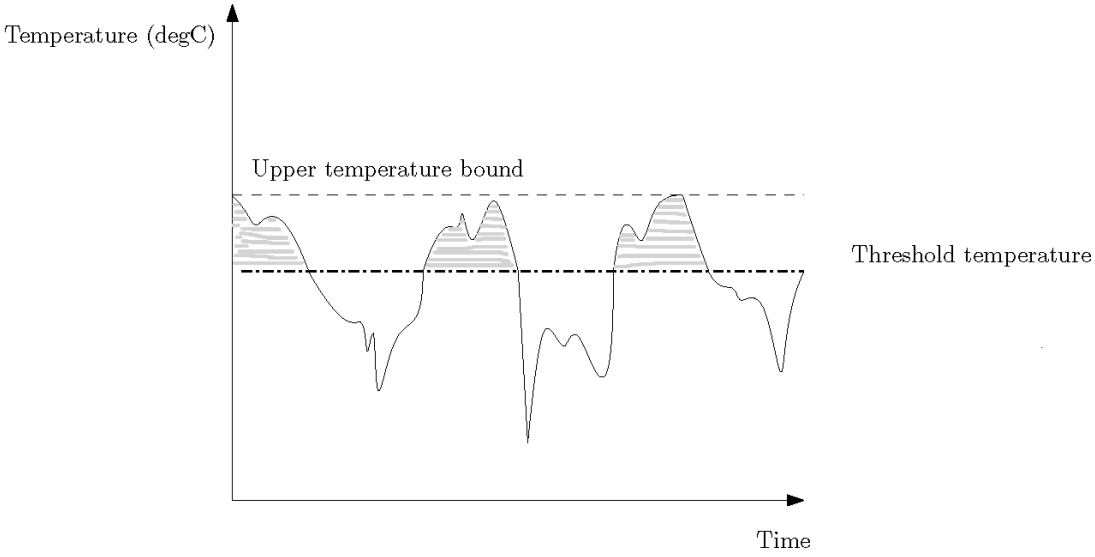


Figure 4.22 Illustrating violation area above a given threshold temperature for a refrigerator control system

We also performed a clustering exercise to classify refrigerator performance against specific groups (for example, refrigerators performing well, with large variations in temperature control around the threshold etc). Although classification/clustering of the refrigerator controllers could be performed manually for a sufficiently small number of refrigerators, for a large number of refrigerators it can be a time consuming exercise and in many cases can require a level of familiarity of refrigerator control operation and identification cluster centres empirically. In this section a fuzzy c-means clustering approach was followed to identify four clusters of refrigerator controller performance. In clustering theory one can set different number of clusters for a given data set (i.e. the number of clusters is not unique), albeit a set of 4 clusters is employed here attempting to indicate possible cases of:

(i) Refrigerator controllers performing close to an ideal temperature control profile.

(ii) Refrigerator controllers performing far from the ideal temperature control profile with concerning violations of the threshold temperature.

(iii) Refrigerator controllers with large fluctuations around their relevant mean temperature.

(iv) Refrigerator controllers performing in an intermediate manner, with some violations or the threshold temperature and some fluctuations around the mean.

Fuzzy c-means (FCM) is a clustering methodology (Bezdek et al., 1984; Bobrowski & Bezdek, 1991), within data clustering, that allows each data point

of a given dataset to belong to multiple clusters with varying degrees of membership (a form of group weighting/belonging). It follows an iterative process to minimising a weighted least-squares objective (cost function which relates the given data points and information on the number of clusters/groupings). Hence, the process effectively attempts to find the "best" cluster/grouping centres that will be, distance-wise, close to encompassing a particular group of data points.

From an analytical point of view the following steps are performed by the FCM approach to minimize the following objective function

$$J_{opt} = \sum_{i=1}^{D_p} \sum_{j=1}^{N_c} \mu_{ij}^{m} \left\| x_i - c_j \right\|^2$$

Where $D_p$is the number of points in the data, N_c is the number of clusters, *m* (a parameter > 1) is an exponent for controlling the degree of fuzzy overlap (i.e. how crisp or fuzzy the boundaries between clusters can be), x_i is the i-th data point, c_j is the center of the j-th cluster, μ_{ij} is the membership degree of the i-th data point in the j-th cluster (i.e. a measure of a data point "belonging" in the cluster).

The FCM process proceeds as follows:

Step 1: (randomly) initialise the cluster membership values μ_{ij}

Step 2: calculate the centres of clusters according to:

$$c_j = \frac{\left(\sum_{i=1}^{D_p} \mu_{ij}^{m} x_i\right)}{\left(\sum_{i=1}^{D_p} \mu_{ij}^{m}\right)}$$

Step 3: update the cluster membership values μ_{ij} according to:

$$\mu_{ij} = \frac{1}{\sum_{k=1}^{N_c} \left(\frac{\left\| x_i - c_j \right\|}{\left\| x_i - c_k \right\|} \right)^{\frac{2}{m-1}}}$$

Step 4: calculate the obj. function J_{opt}

Step 5: if specified max number of iterations is not reached or if the improvement of the value of J_{opt} is greater than the specified tolerance, GO TO Step 2.

Step 6: Stop, return the cluster centers *c* and fuzzy partition matrix *U*.

For the purposes of the refrigerator study in this work, given the required four clusters for the refrigerator data the Fuzzy c-means algorithm attempts to obtain the optimised four clustered sets for the set of points with coordinates (metric of Variation/Stratification level around refrigerator's mean temperature,

metric of Variation/Distance above a set threshold temperature) as presented above, for the different refrigerators.

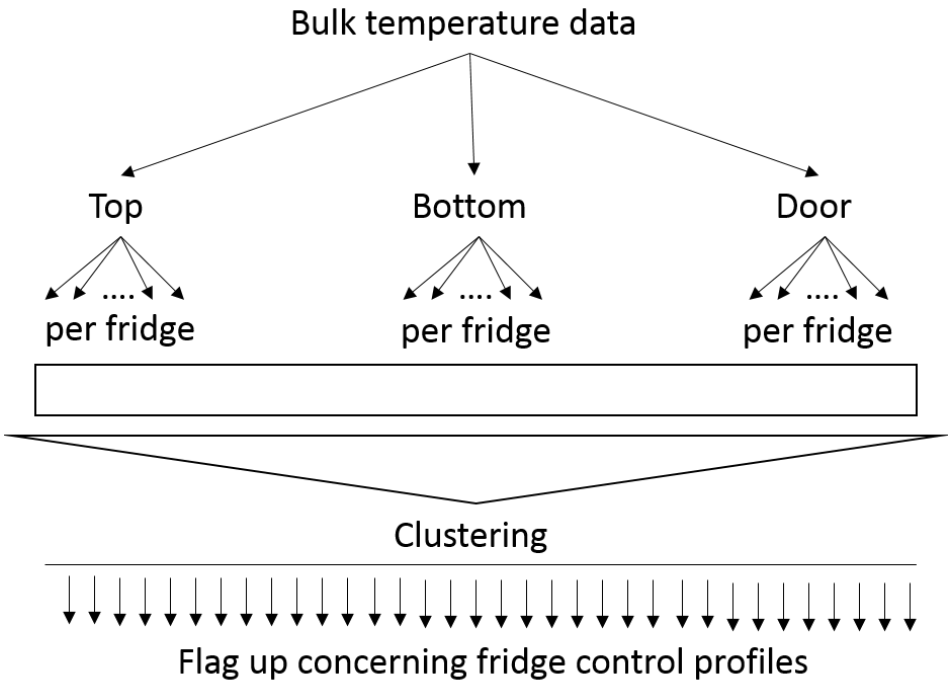


Figure 4.23 From en-masse refrigerator data to detailed contributions per refrigerator, clustering to flag up refrigerator controller performance issues

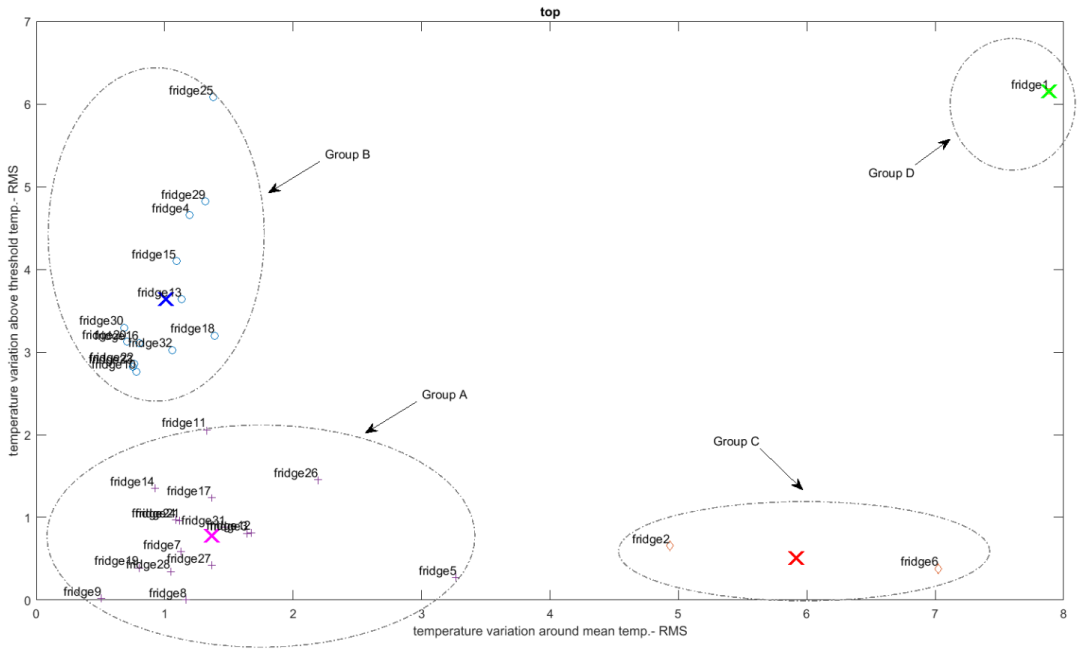
In addition, the proposed clustering approach (and clustering methods of similar nature) can be a useful tool within the context of IoT refrigerator monitoring. In particular, it will/could form a helpful decision mechanism to identify refrigerator controller performance levels, raise awareness of food safety (especially in cases of household with at risk population), and many more. An example (e.g. for the refrigerator controller performance) is shown in Fig 4.23.

4.3.3 Clustering

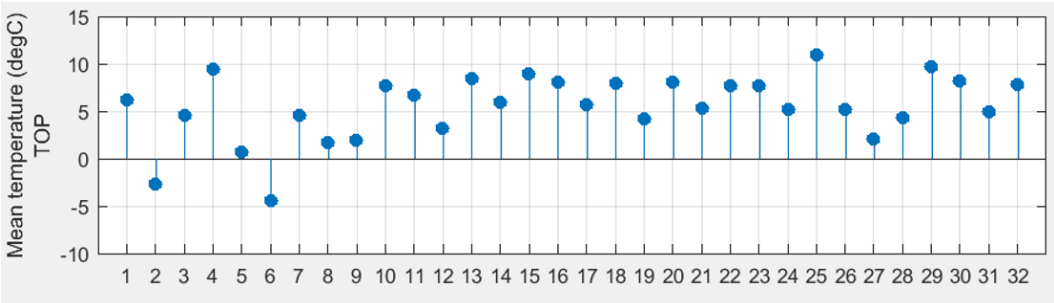
Figure 4.19 illustrates the results, with the four clusters (groups) identified for the top of the refrigerators accordingly, i.e.

- Group A are refrigerators with temperature control profiles performing very well.

- Group B are refrigerators with temperature control profiles that may require investigation as they consistently violate the threshold temperature (otherwise working smoothly around their individual mean temperature)
- Group C are refrigerators with low levels of threshold temperature violation but large stratification around mean.
- Group D are refrigerators with a very concerning temperature control profile (as captured by the sensor), i.e. having both large stratification around its mean temperature and large values of threshold temperature violation.



(a) Refrigerator control performance Clustering- for TOP location



(b) TOP Mean temperature per refrigerator id (x-axis)

Figure 4.19 Top temperature location clustering (a) Clusters (b) Mean temperature per refrigerator

Note that Figure 4.19 also includes the plot of mean temperature per refrigerator for a more direct assessment relative to the clusters.

For illustration we will refer to examples of refrigerator performance as identified from the clustering exercise above and referring to the TOP temperature location. The refrigerator temperature data to visualise are: Refrigerator 1, Refrigerator 25 Refrigerator 9, and Refrigerator 2.

Refrigerator 1 was identified as a concerning case in Group D. Refrigerator 25 as a concerning case in Group B, while Refrigerator 2 and Refrigerator 9 related to characteristics of Group C and Group A respectively. Temperature data plots for these units are shown in Figure 4.20 and Figure 4.21. In particular, temperature violations above the threshold temperature are depicted by the red areas.

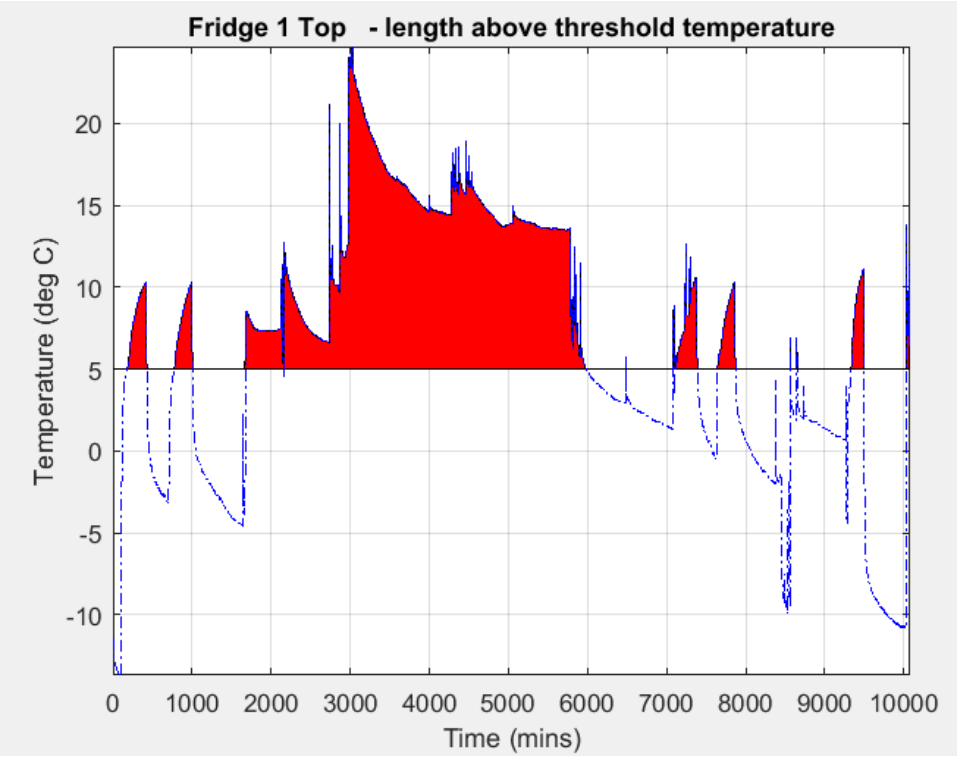


Figure 4.20 Refrigerator id 1 temperature control performance

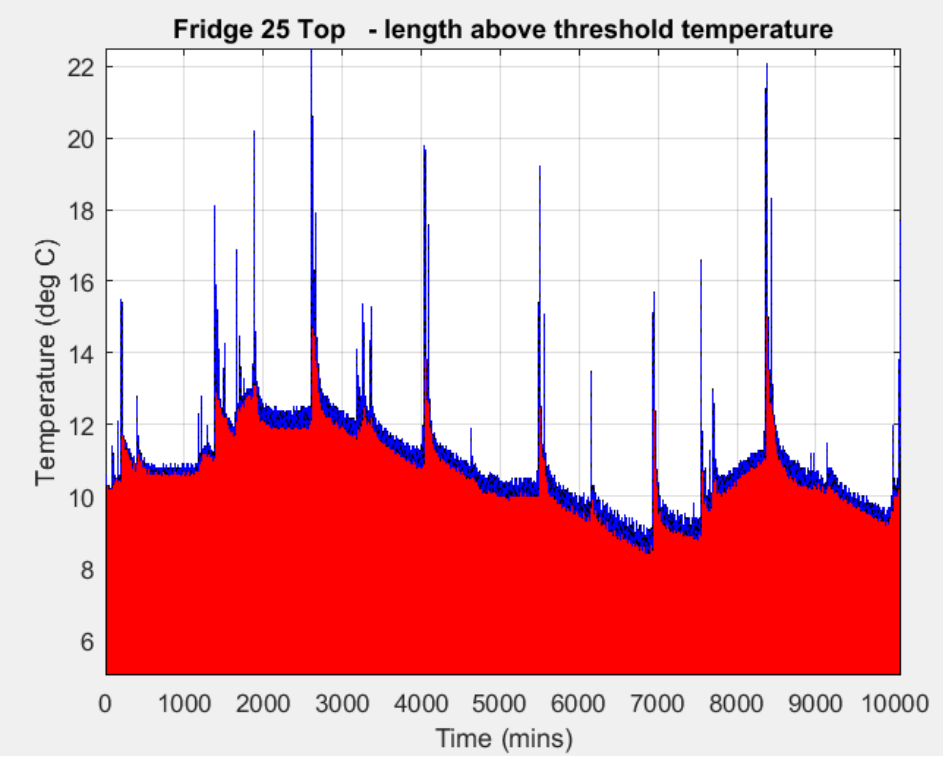


Figure 4.21 Refrigerator id 25 temperature control performance

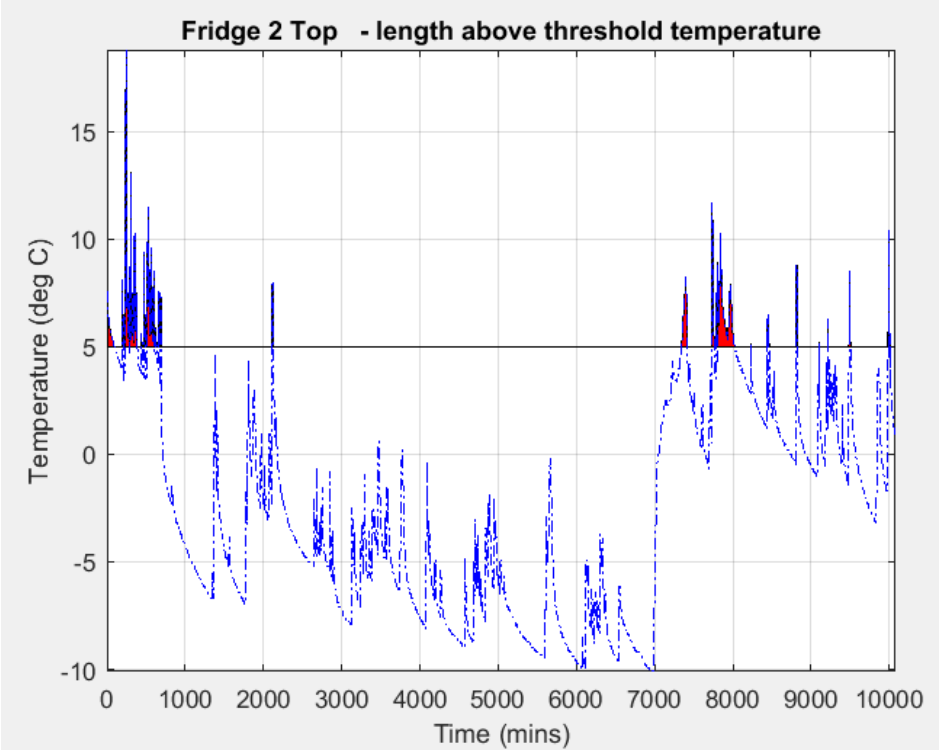


Figure 4.22 Refrigerator id 2 temperature control performance

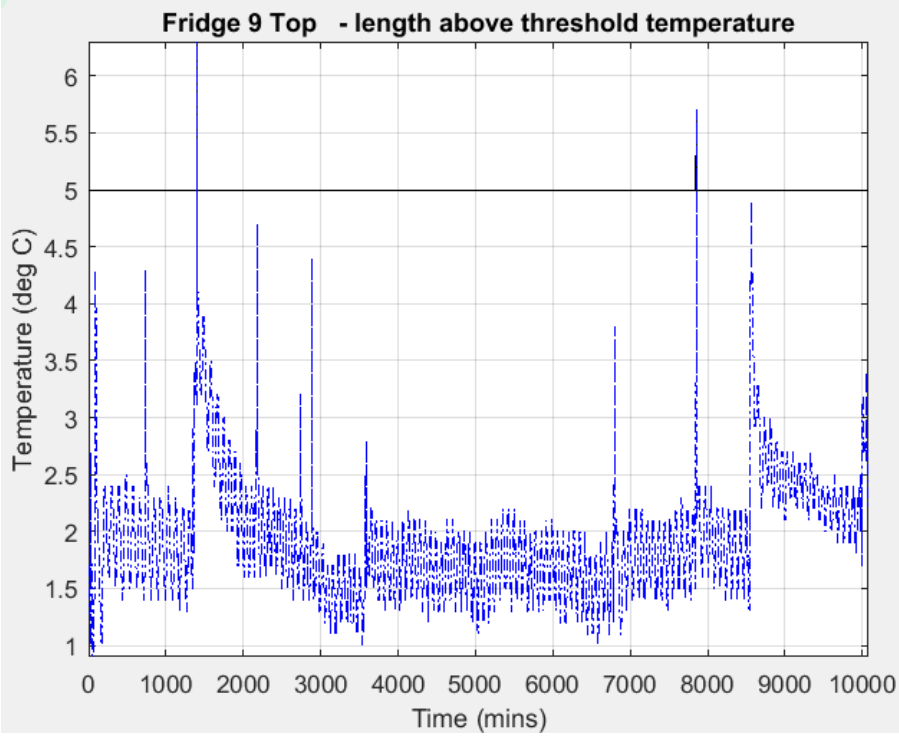


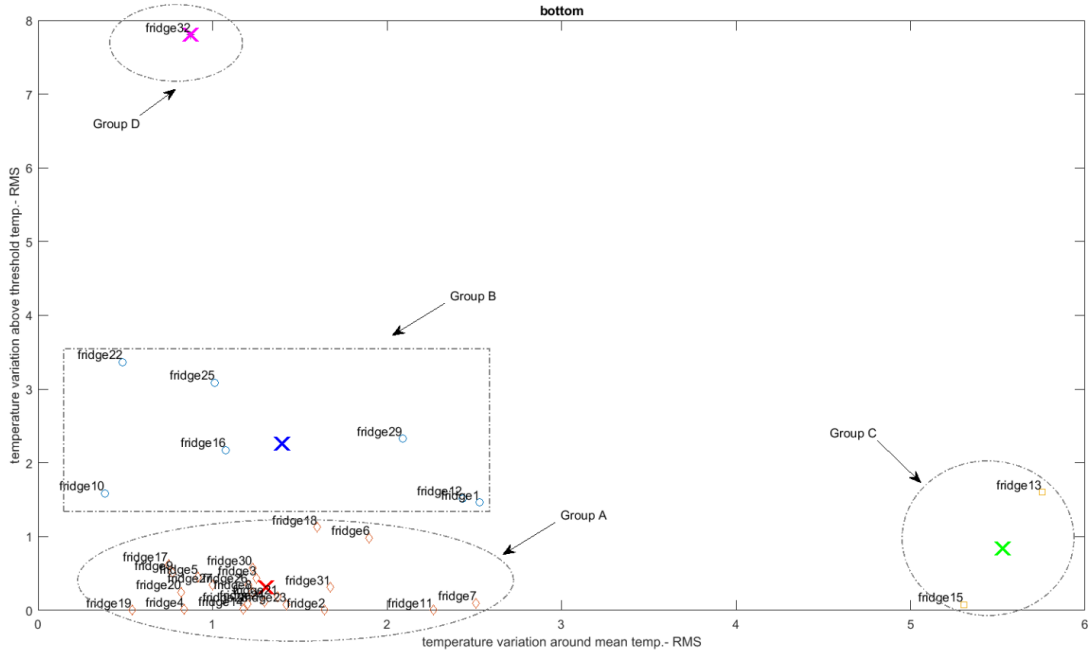
Figure 4.23 Refrigerator id 9 temperature control performance

The clustering exercise was repeated for the BOTTOM temperature locations (Figure 4.24). This showed with the four clusters (groups) identified accordingly, i.e.

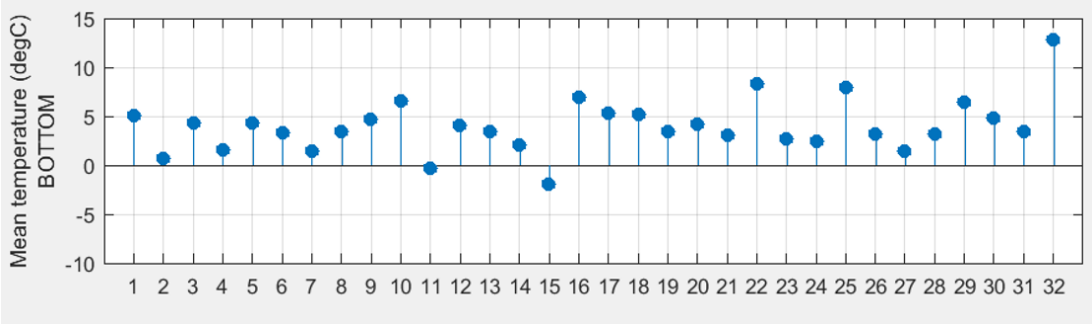
- Again, Group A are refrigerators with temperature control profiles performing very well.
- Group B are refrigerators with temperature control profiles that seem to behave in an intermediate manner (some violation of threshold temperature and a smooth-ish variation around their individual mean temperature).
- Group C are refrigerators with clearly large stratification around mean.
- Group D is clearly a refrigerator with large values of threshold temperature violation.

Note that Figure 4.24 also includes the plot of mean temperature per refrigerator for a more direct assessment relative to the clusters.

For illustration will refer to examples of refrigerator performance as identified from the clustering exercise above and referring to the BOTTOM temperature location. The refrigerator ids temperature data to visualise are: Refrigerator 32, Refrigerator 16, and Refrigerator 13. Figure 4.25 to Figure 4.27 present exactly what is expected from the clustering (seen Figure 4.24). Again, the range of violations is shown by the red areas on the time-series plots.



(a) Refrigerator control performance Clustering- for BOTTOM location



(b) BOTTOM Mean temperature per refrigerator id (x-axis)

Figure 4.24 Bottom temperature location clustering (a) Clusters (b) Mean temperature per refrigerator

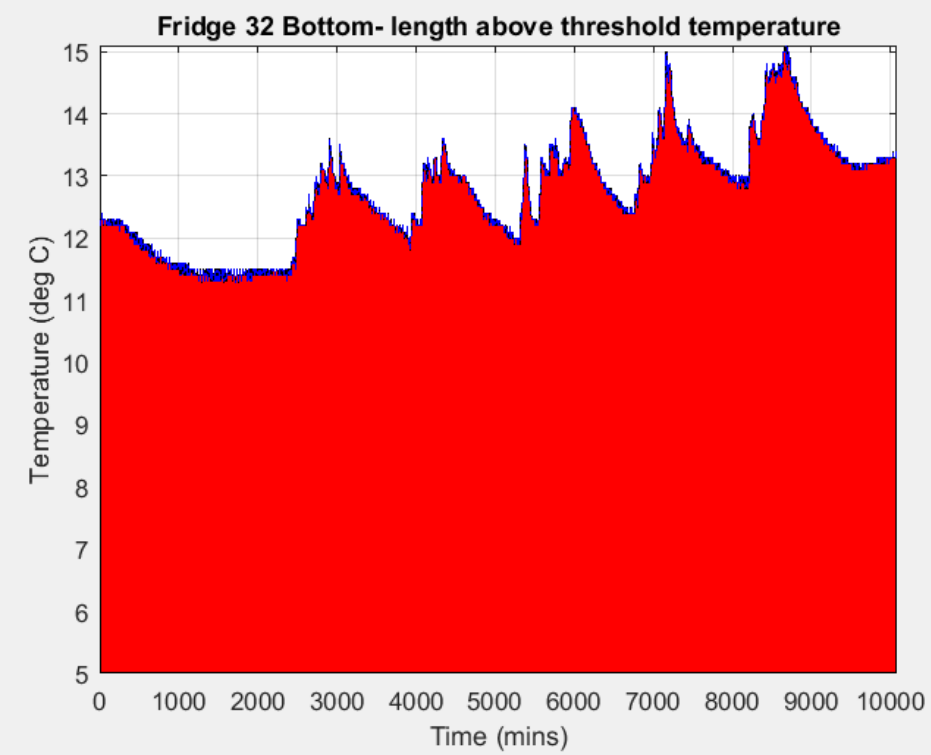


Figure 4.25 Refrigerator id 32 temperature control performance

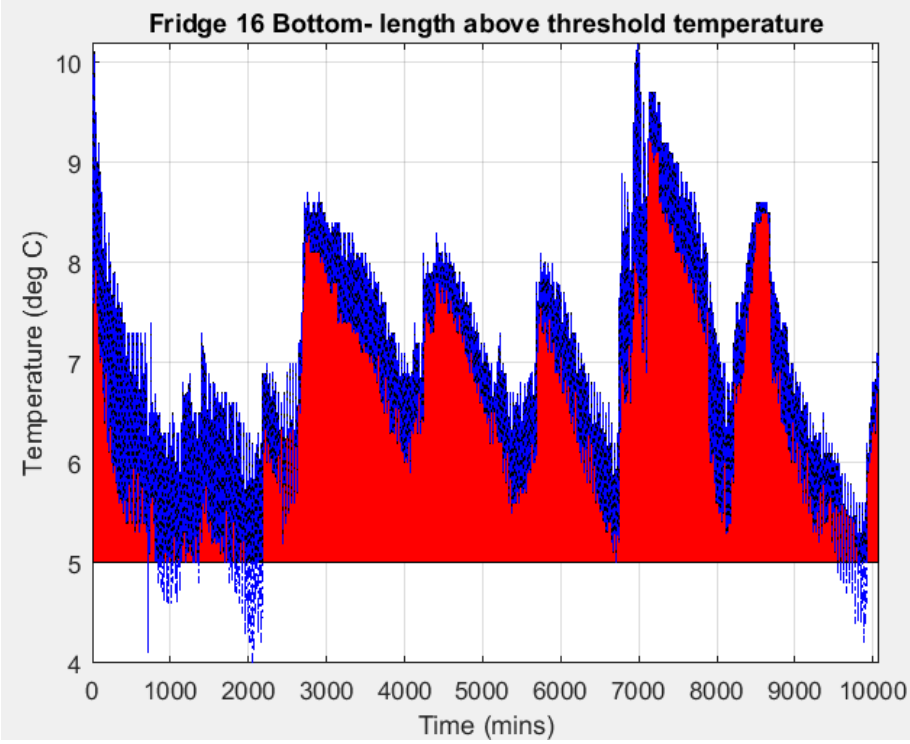


Figure 4.26 Refrigerator id 16 temperature control performance

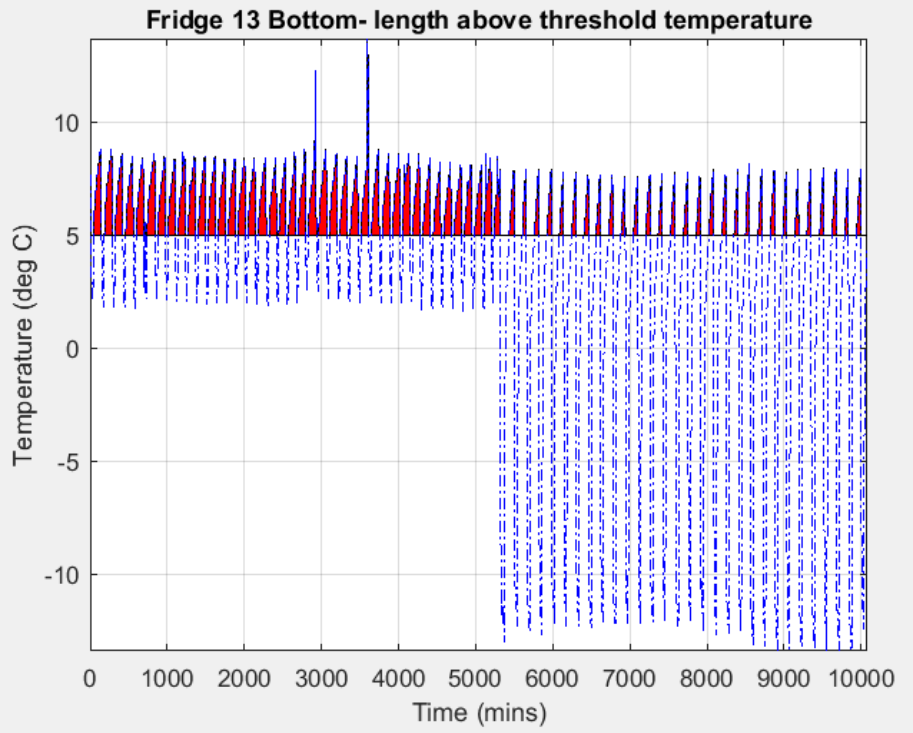
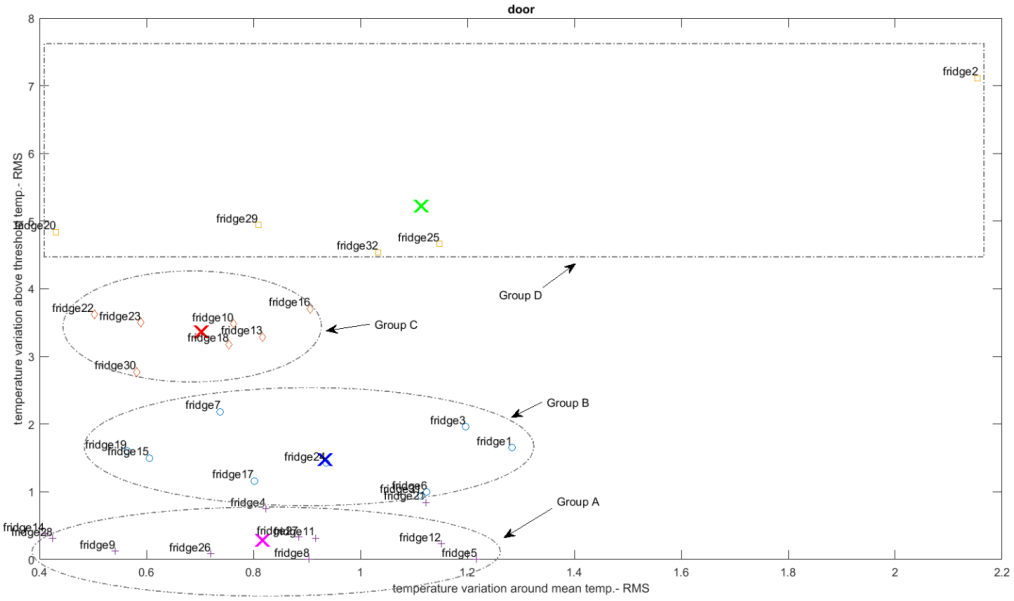


Figure 4.27 Refrigerator id 13 temperature control performance

Figure 4.33 shows the clustering exercise for the DOOR temperature locations.

- Again, Group A are refrigerators with temperature control profiles performing very well.
- Group B are refrigerators with temperature control profiles that seem to behave in an intermediate manner (some violation of threshold temperature and a smooth-ish variation around their individual mean temperature).
- Group C are refrigerators with control profiles that may indicate some concern on violation of the threshold temperature.
- Group D are clearly refrigerators with large values of threshold temperature violation (but may include some with large values of stratification around their mean temp.).

The refrigerators of note are 2, 15 and 19. (see Figure 4.29 to Figure 4.31).



(a) Refrigerator control performance Clustering- for DOOR location

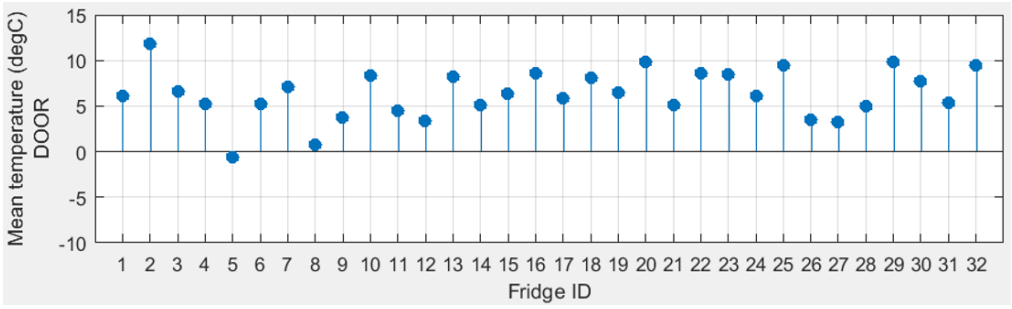


Figure 4.28 Door temperature location clustering (a) Clusters (b) Mean temperature per refrigerator

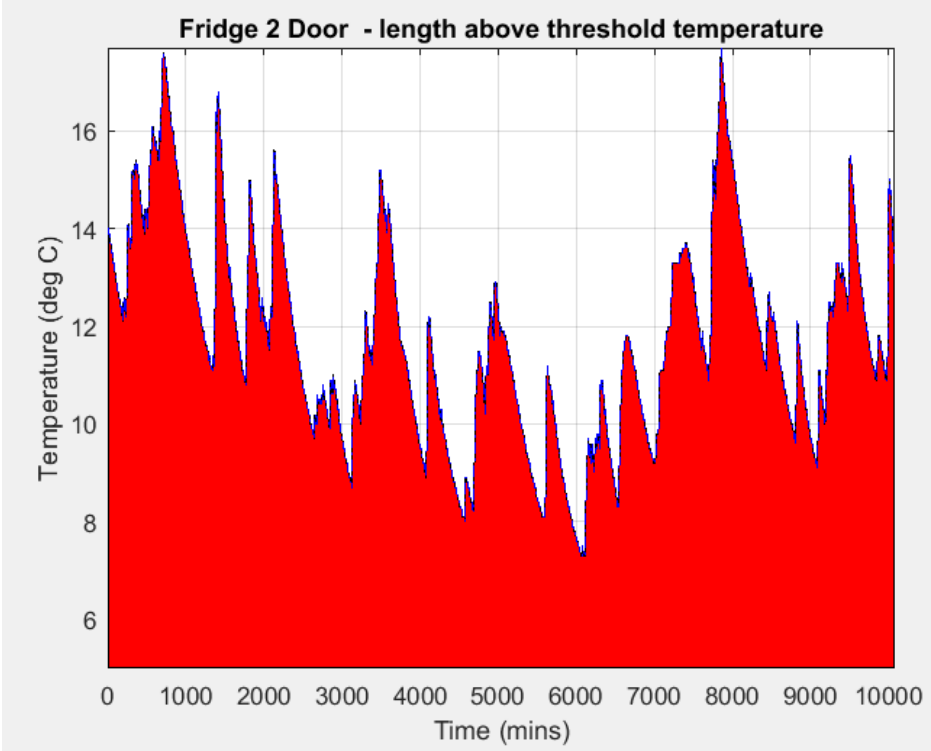


Figure 4.29 Refrigerator id 2 temperature control performance

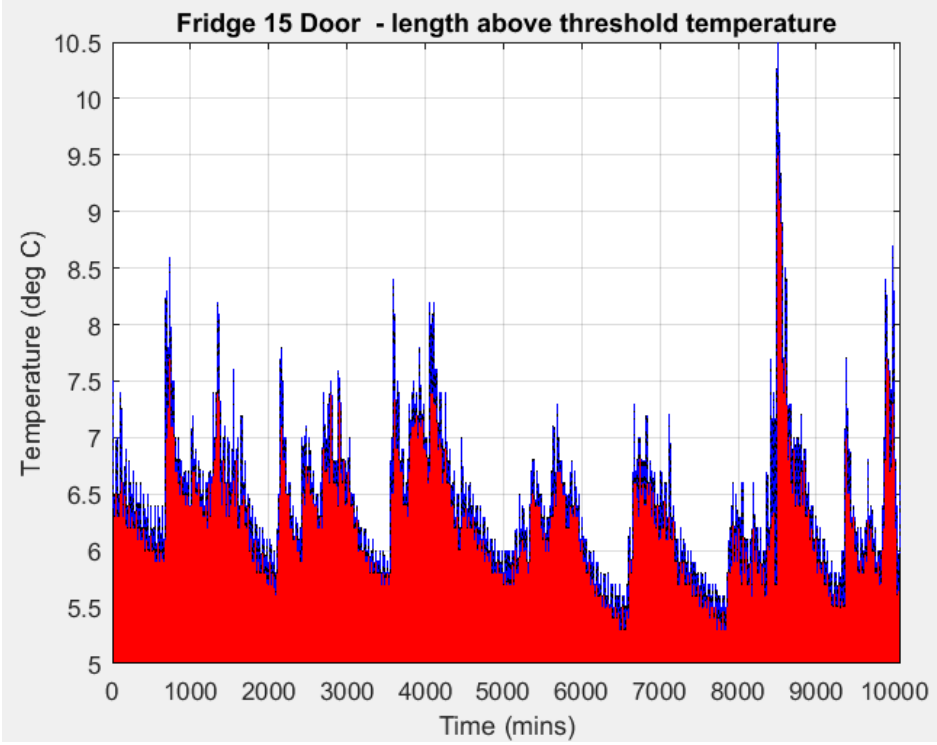


Figure 4.30 Refrigerator id 16 temperature control performance

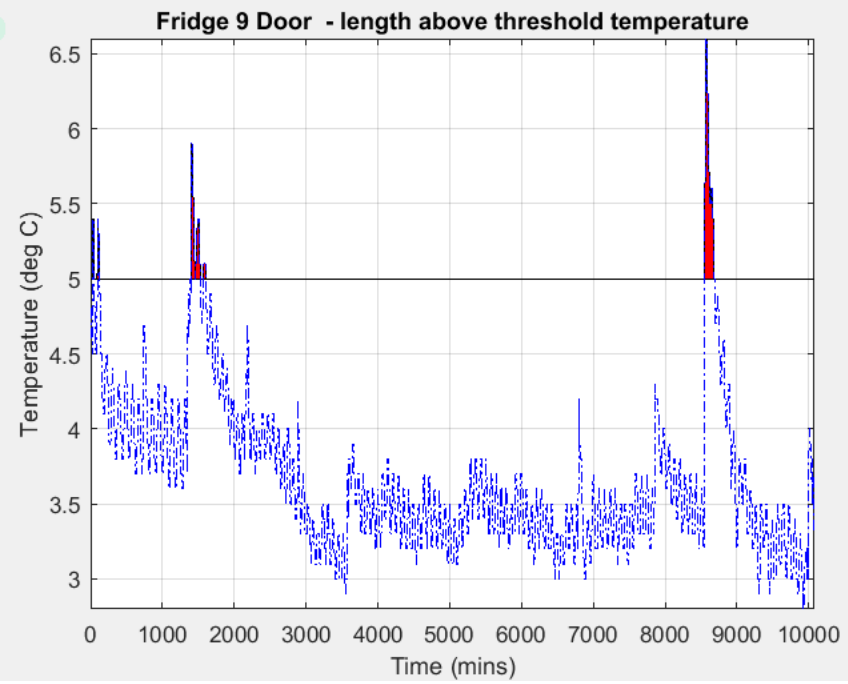


Figure 4.31 Refrigerator id 13 temperature control performance

4.4 Overall discussion and conclusions

The results of the various surveys reported here indicate that their has not been a marked advance in consumer knowledge or understanding of the relationship between temperature and food safety or the importance of maintaining a low <5°C temperature in a domestic refrigerator since at least 1991. Of particular concern only 7% of respondents (n=699) had a fridge temperature sensor and only 15% of refrigerators had an internal digital temperature display. The vast majority of respondents took for granted that the fridge was controlled as the food "felt cold".

The initial results of the refrigerator temperature measurement work indicates that there may have been a small <1°C improvement in the average temperature of a domestic refrigerator in 25 years. However, over half of the domestic refrigerators surveyed have average temperatures over 5°C. Many of those with average temperatures at or below 5°C contain areas well above this temperature. So very few temperatures achieve the FSA guidance of keeping chilled food below 5°C during domestic storage.

However, the aggregation of data into means across different refrigerators masks the potential impact of individual units operational performance on food safety and spoilage. Here we have used a clustering approach that can clearly identify "at risk" refrigerators, i.e. those are significantly higher than the threshold temperature of 5°C or have large control variances around the threshold temperature. Our survey showed at least two refrigerators (of 32 surveyed) which showed a very concerning temperature control profile. We estimate though they there are in the order of 39m domestic refrigerators in the UK. Of these 39m it is not clear how many (likely to many tens of thousands) have a higher "risk" (food safety and spoilage) temperature control performance.

The IoT (via online streaming of temperature data) may offer a genuine opportunity to help consumers understand how well their refrigerators are performing. The IoT could help change consumer behaviours towards a domestic appliance which is clearly taken for granted by many households. It could indicate when they should change the control settings (especially with changes in ambient temperature), how location in an individual fridge impacts performance, whether a unit needs maintenance or disposal etc. It could also show how an individual persons fridge is operating compared to those used by larger groups of consumers.

"SMART" fridges are already available on the market and these enables consumers to monitor stock levels within a fridge and support food purchasing behaviour. Our surveys showed an interest in these devices, and they may

develop within the market. We believe however that the smart fridge is a safe fridge and this could be underpinned by temperature data streaming through the IoT.

Given the now widely acknowledged consumer behaviours towards domestic refrigeration, we believe that there is a clear social case for change in policy which would require manufacturers to fit all new appliances with internal temperature displays. This would directly help consumers to understand the performance of their refrigerator and underpin the safe handling and storage of food within the home. It will also have an impact on food waste and storage.

Figure 4.32. Examples of gadgets available to add "smart" capabilities to existing refrigerators

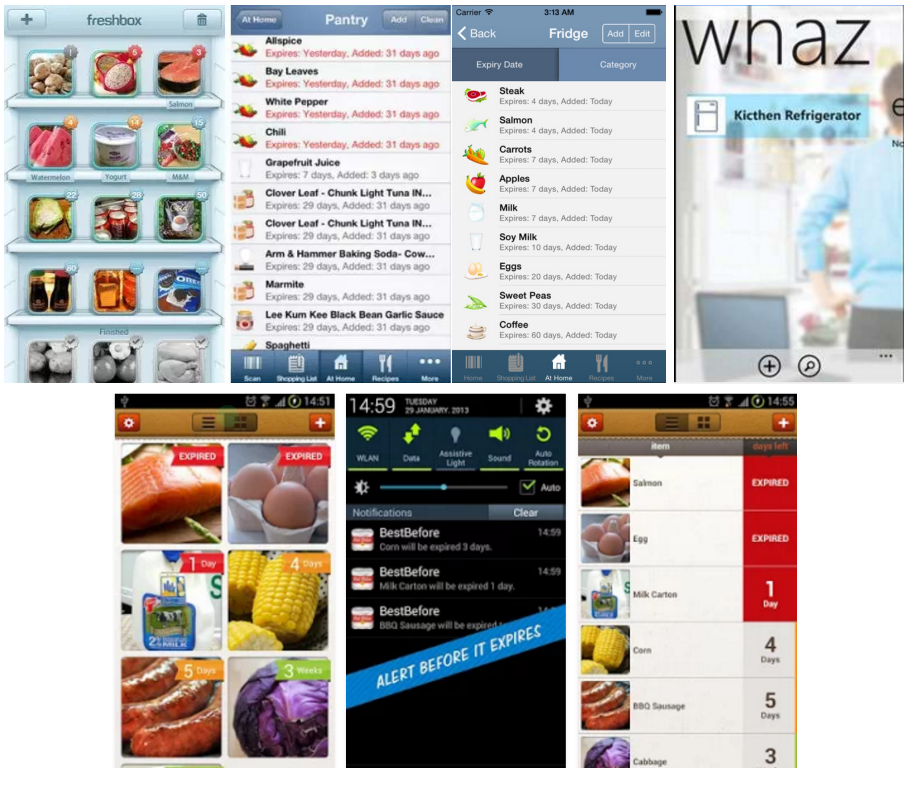


Figure 4.33. Examples of inventory and stock control apps for managing food storage in domestic refrigerators

5 Engagement, impact and dissemination

- The results of this feasibility work show substantial impact on food safety concern and food control, and at least two publications are expected and are under preparation at the moment.
- We wish to support any further activity in terms of design standards and policy of domestic refrigeration systems. There is a clear social argument that all domestic refrigeration systems should be sold with at least one internal digital temperature display. This will show consumers the real temperature at which their refrigerator is performing and help improve the behavioural understanding of the link between temperature food safety and spoilage. The location of the thermometer in the refrigerator will need consideration in terms of stratification between different systems.
- There is an opportunity to develop the necessary IoT infra structure for data streaming from refrigerators. This will include necessary sensors and big data handling systems. We wish to engage with and support potential actors within this segment.
- There is a clear need to educate consumers on how they use their refrigerators, the lack of persons who monitor fridge temperature is low, and we have showed even in a survey of 32 units some very concerning operational performances.

6 Funding strategy for future activity

With a clear alignment to food safety standards and the RCUK cross-council research theme of Digital Economy and including aspects of Energy and Big Data in the IoT, the outcomes of this feasibility study strongly support a larger Phase 2 project. We are engaging with the current industrial partner Tesco and also SMEs in the area of IoT towards such RCUK funding possibility. The key findings of this feasibility study, enhanced via a larger project study with a direct demonstration in the IoT framework, will be key drivers to provide policy makers and the public with guidance towards utilisation of big data of domestic fridges via IoT for better understanding of domestic refrigeration performance and the link to food safety, behaviour change in using domestic refrigeration, minimisation of food waste, and technological innovations in smart refrigeration with positive impact on public, the economy and the environment.

7 Glossary

EPSRC	Engineering and Physical Sciences Research Council
FSA	Food Standards Agency
ITaaU	IT as a Utility
IoT	Internet of Things
RFID	Radio-frequency Identification
RCUK	Research Councils UK
SD	Standard Deviation
UK	United Kingdom
WHO	World Health Organisation

8 References

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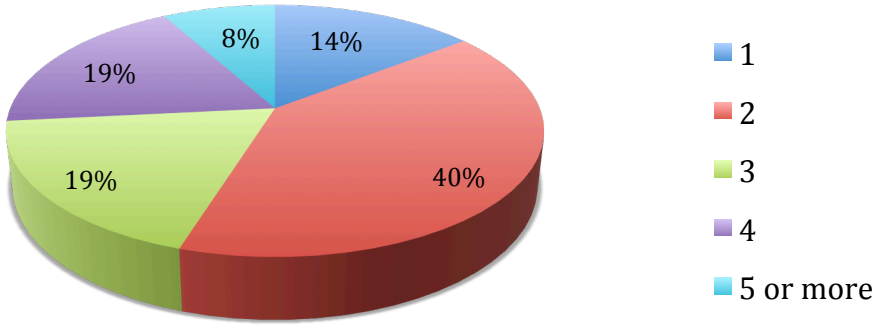
9 Appendix A: Technology review

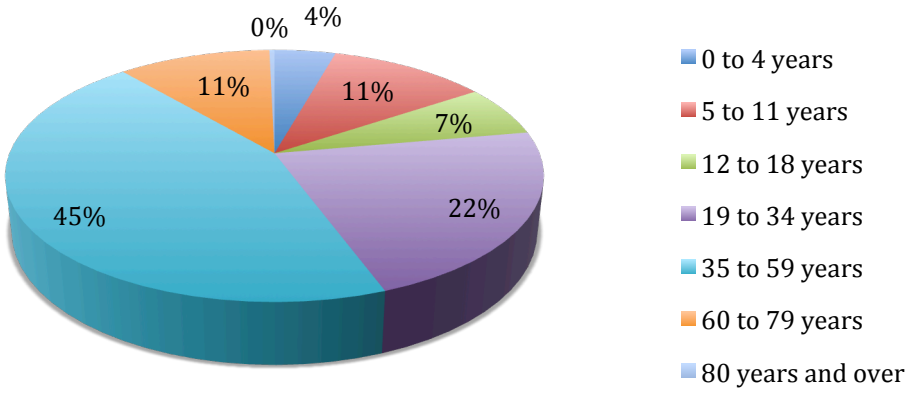
Technology	Description	Evaluation	Used in project?	Verdict
Datalogger				

10 Appendix B1: Complete questionnaire responses

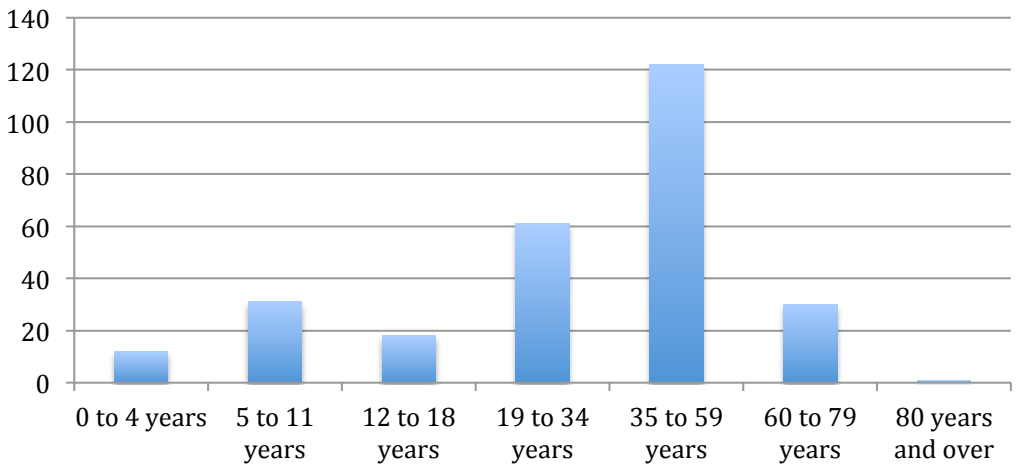
1.1 Number of occupants/persons living in your household? (n=124)



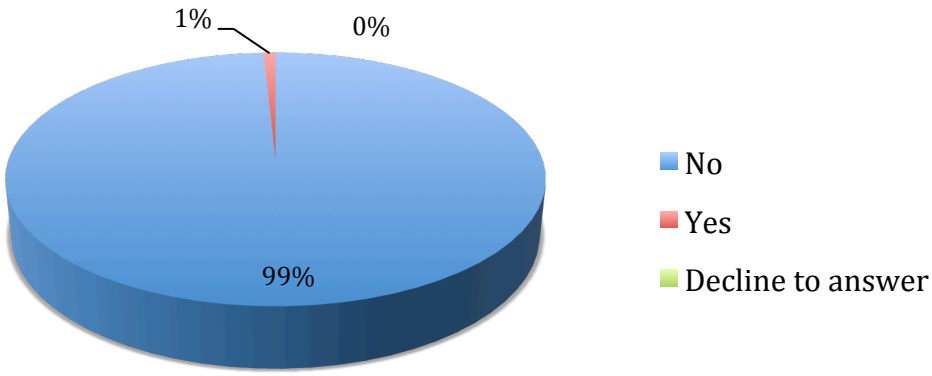
1.2 How many people in each of these age groups live in your household? (n=275)



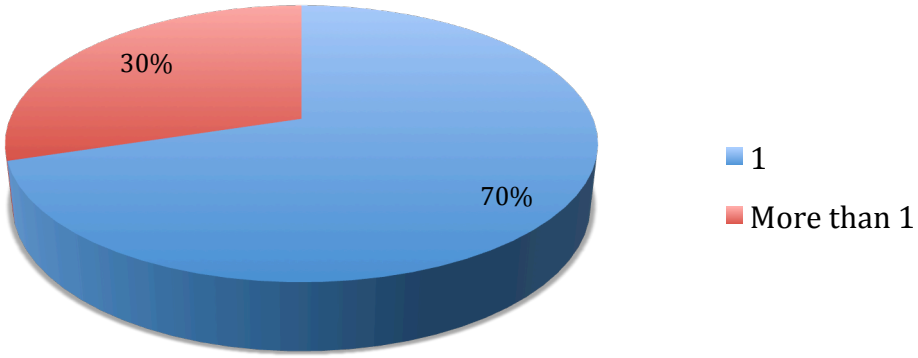
1.2 Age groups covered



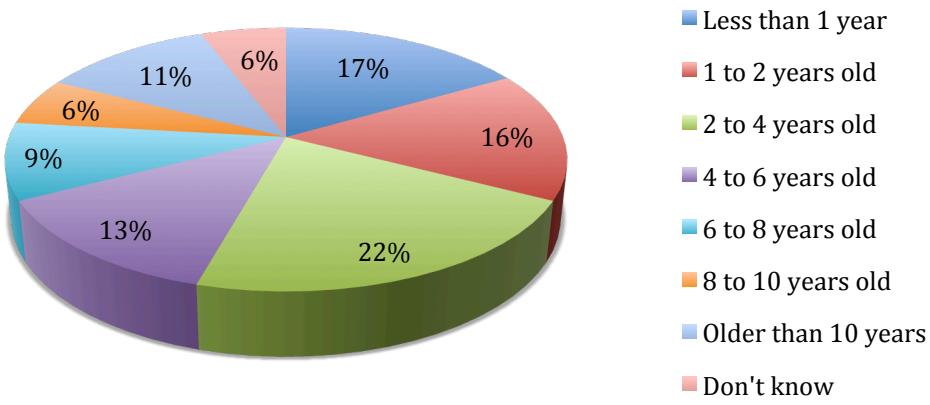
1.3 Is anyone in your household pregnant? (n=120)



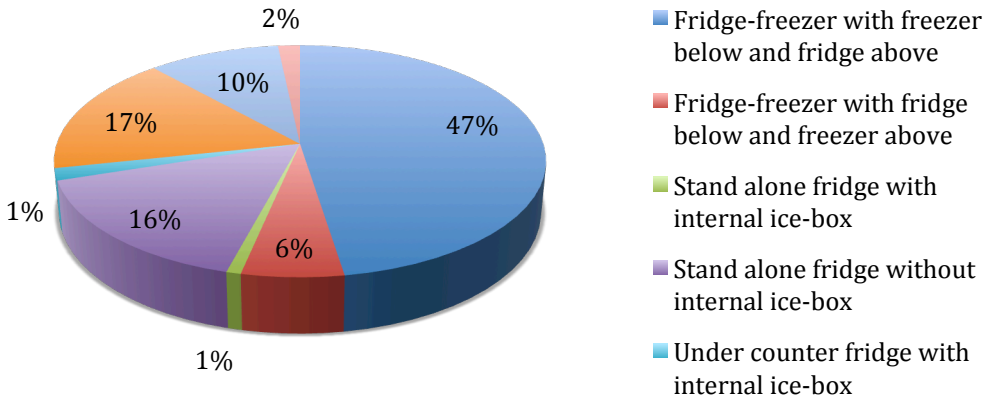
2.1 How many fridges do you have? (n=104)



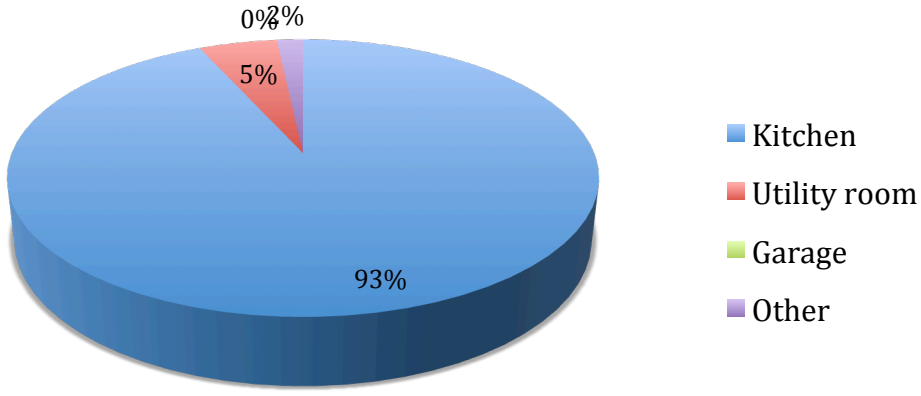
2.2 How old is your fridge? (n=138)



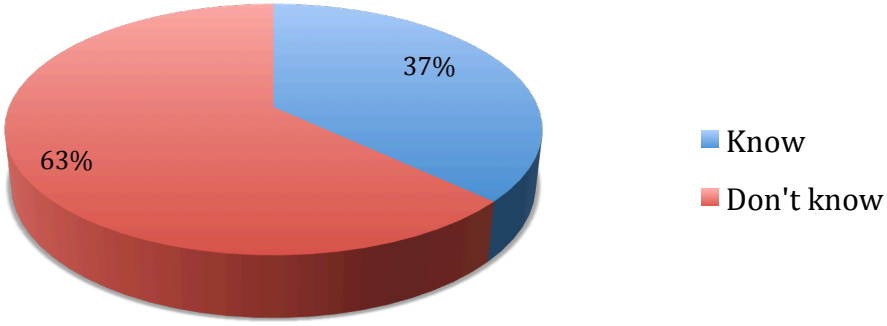
2.3 What type of fridge(s) do you have? (n=120)



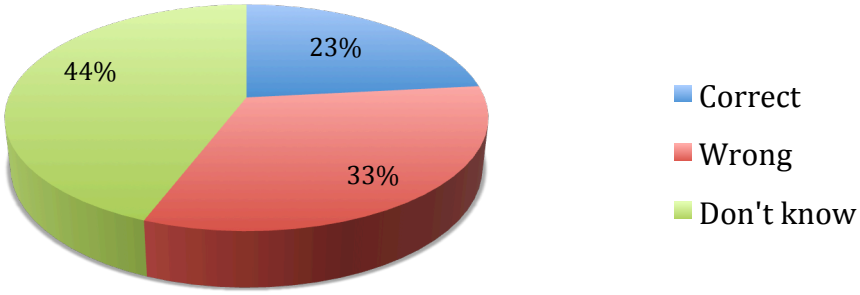
2.4 Where is your fridge(s)? (n=118)



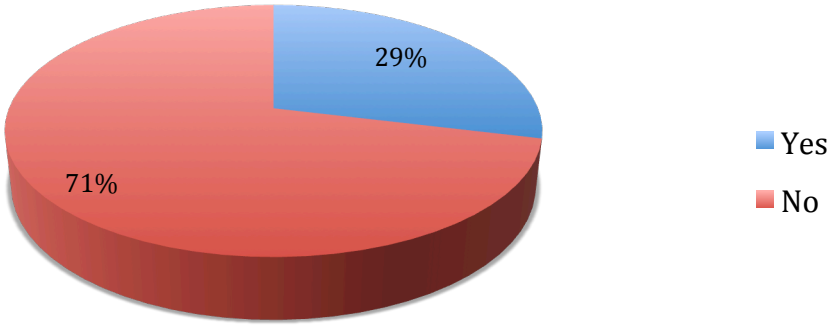
2.5 Do you know what temperature is your main fridge is running at? (n=119)



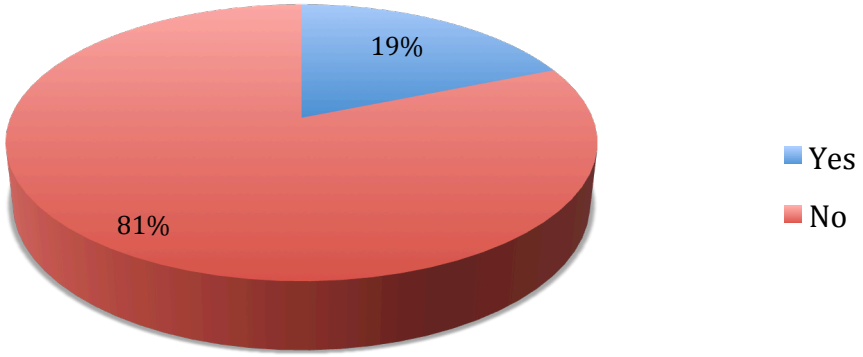
2.6 Do you know what the recommended maximum (highest) temperature that you should keep your fridge at is? (n=120)



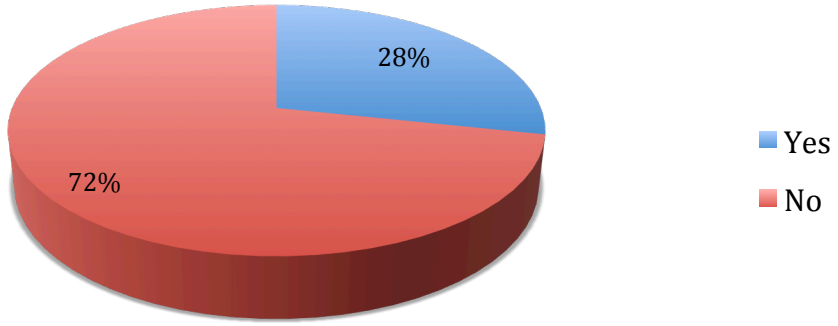
2.7 Does your refrigerator have an external/internal digital temperature display? (n=118)



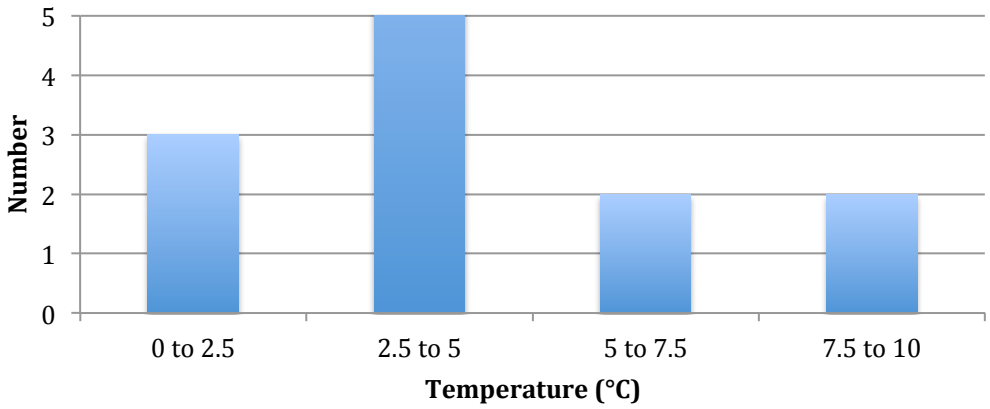
2.8 Do you have a fridge thermometer? (n=117)



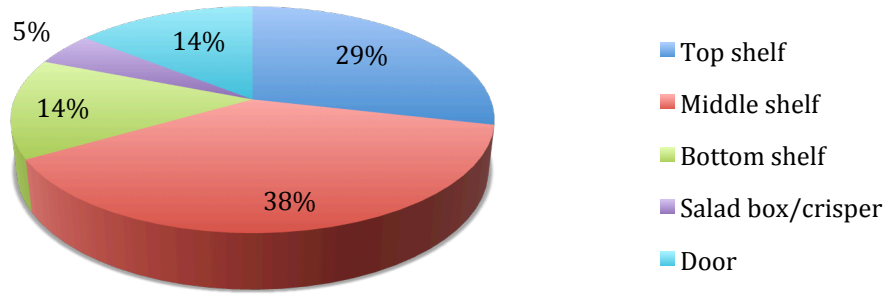
2.9 Do you regularly check the temperature of your fridge? (n=67)



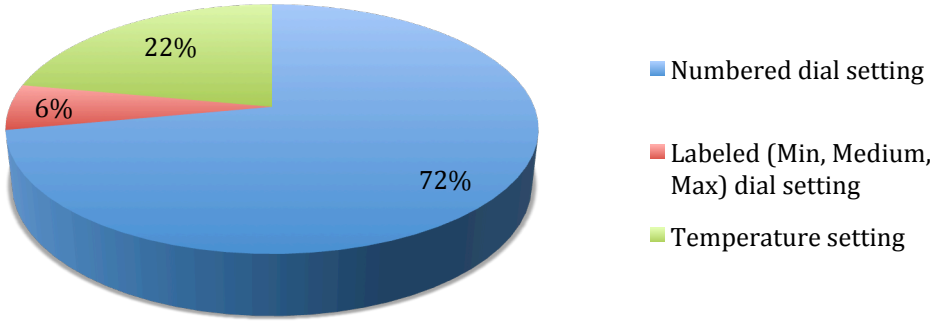
2.10 If a thermometer is present what temperature is it reading? (17 out of 120)



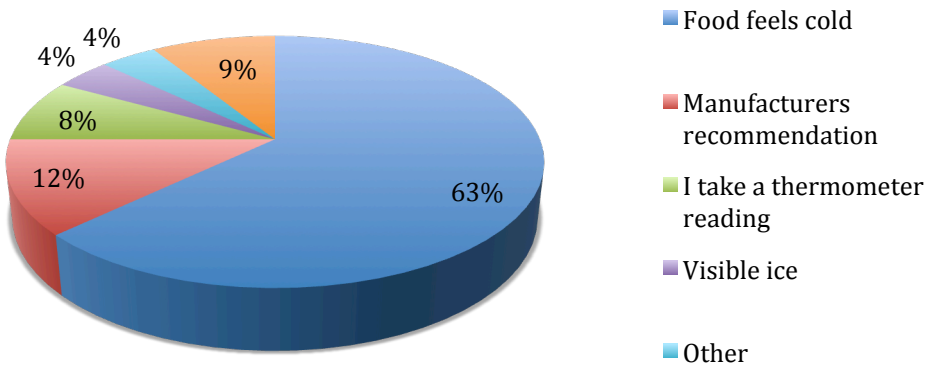
2.11 If you do have a fridge thermometer, in which part of the refrigerator is the thermometer kept? (21 out of 120)



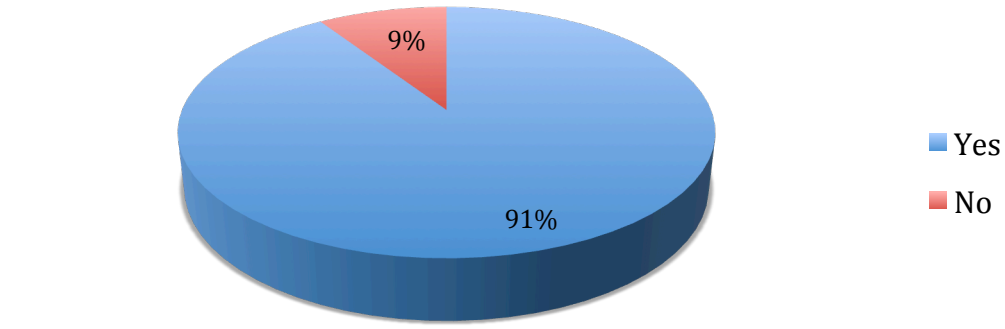
2.12 What is the current control setting on your refrigerator? (n=118)



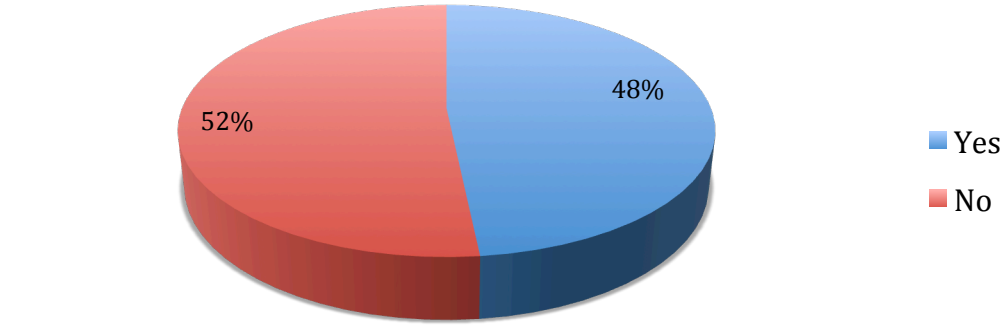
2.13 How do you know if your fridge is at the right temperature/cold enough? (n=124)



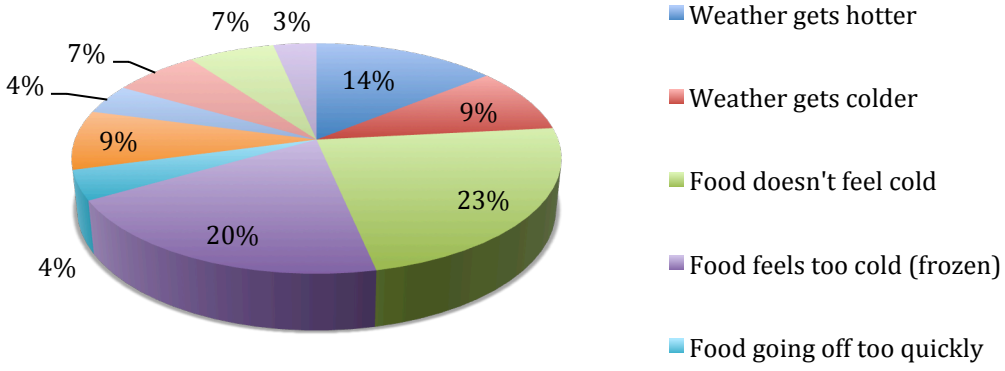
2.14 Do you know how to change your fridge settings/ temperature? (n=119)



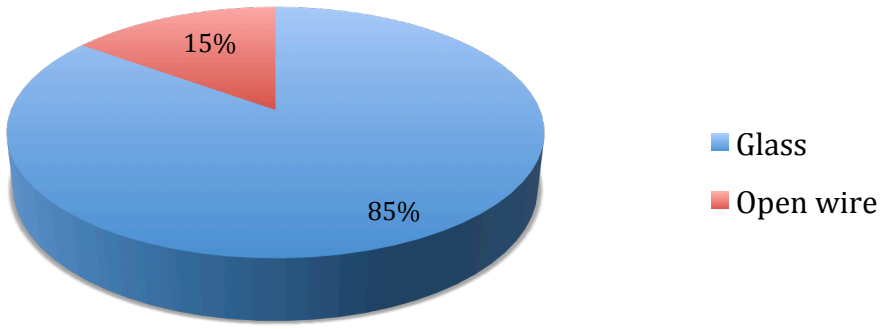
2.15 Do you change your fridge settings/temperature? (n=120)



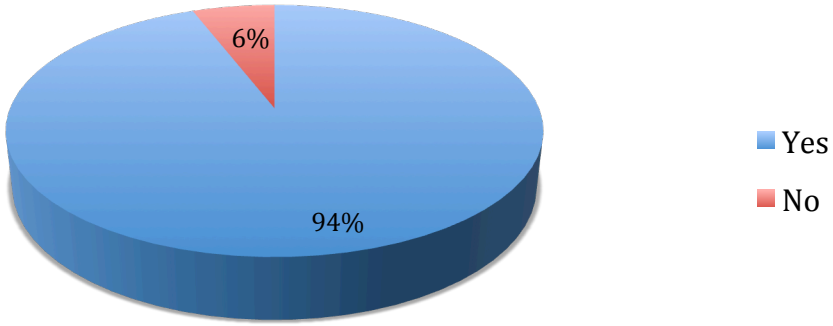
2.16 If yes, why do you change your fridge settings/ temperature? (n=120)



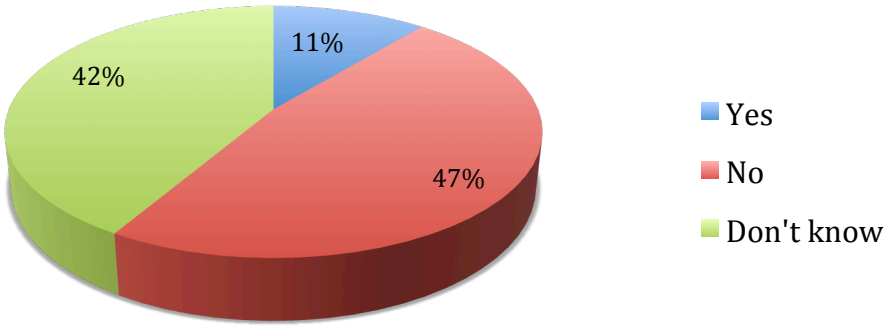
2.17 What type of shelving does your (main) fridge have? (n=120)



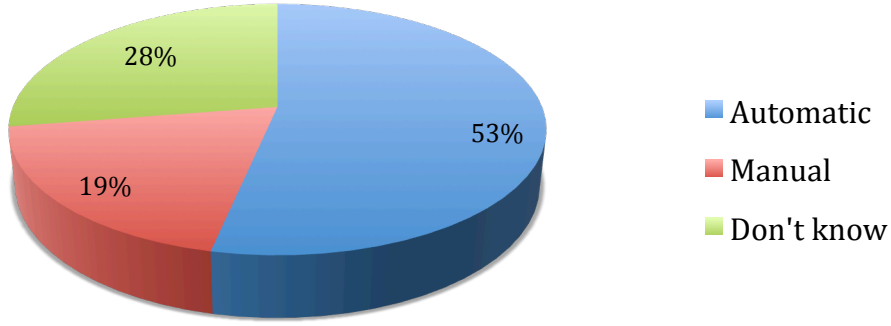
2.18 Does your (main) fridge have an inbuilt salad box / drawer? (n=119)



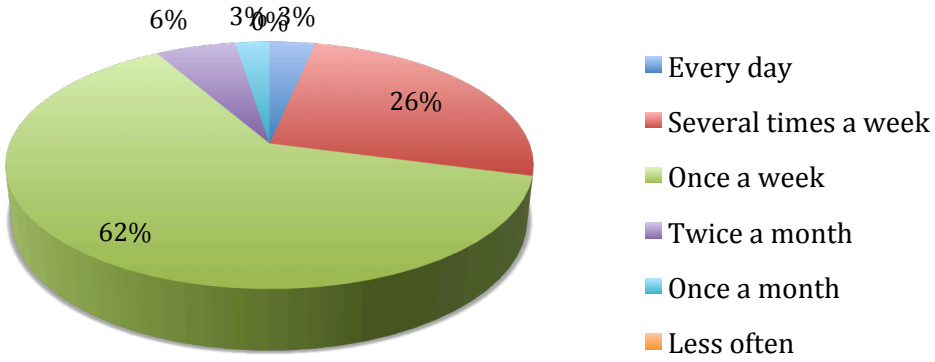
2.19 Does your (main) fridge have an internal fan? (n=118)



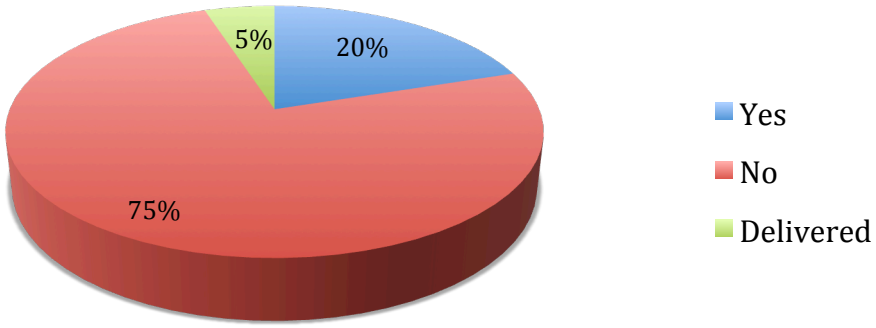
2.20 What type of defrosting system does your (main) fridge have? (n=120)



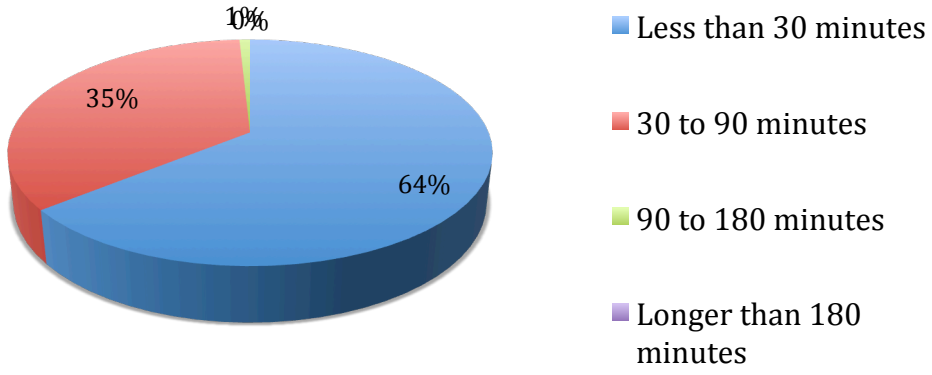
3.1 How often do you usually carry out your main food shopping for your household? (n=120)



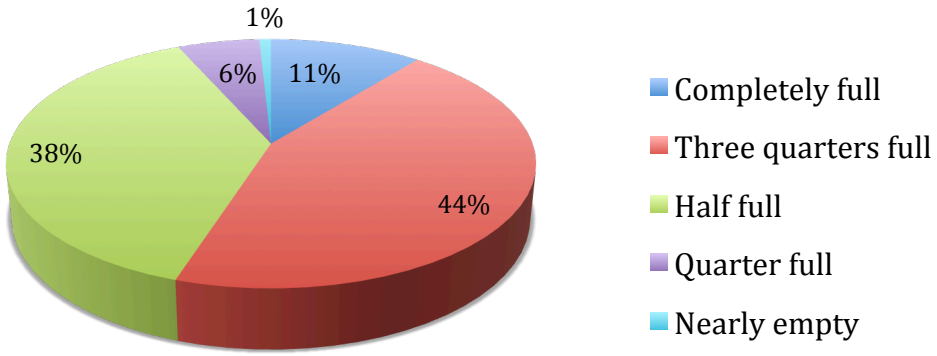
3.2 Do you use a cool bag/box to bring chilled food home? (n=114)



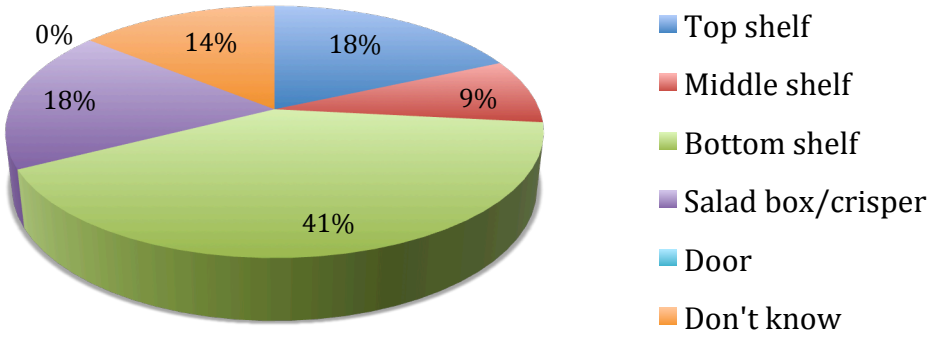
3.3 Thinking of the last time you went shopping for chilled food, how much time lapsed before it was stored in the refrigerator or freezer? (n=120)



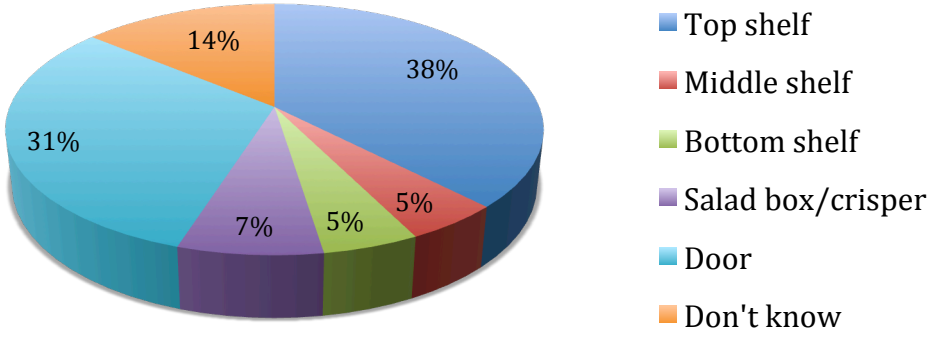
3.4 How full is you fridge usually kept? (n=119)



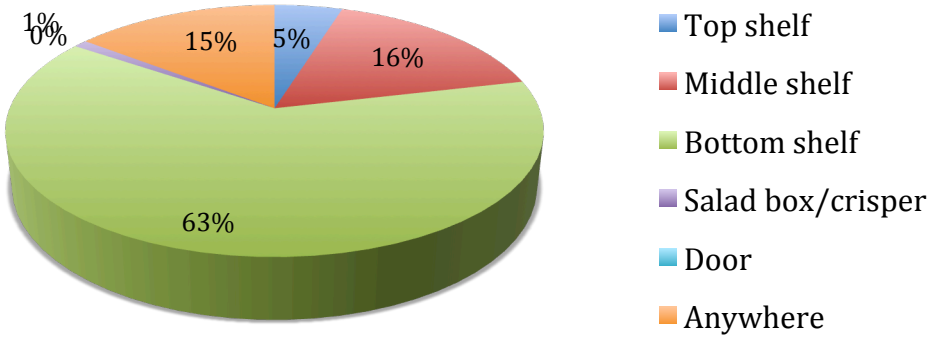
3.5 What area of your fridge do you think is the coldest? (n=120)



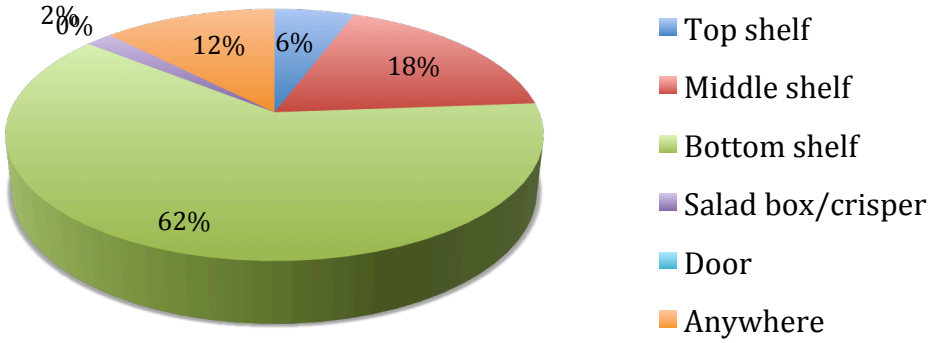
3.6 What area of your fridge do you think is the warmest? (n=122)



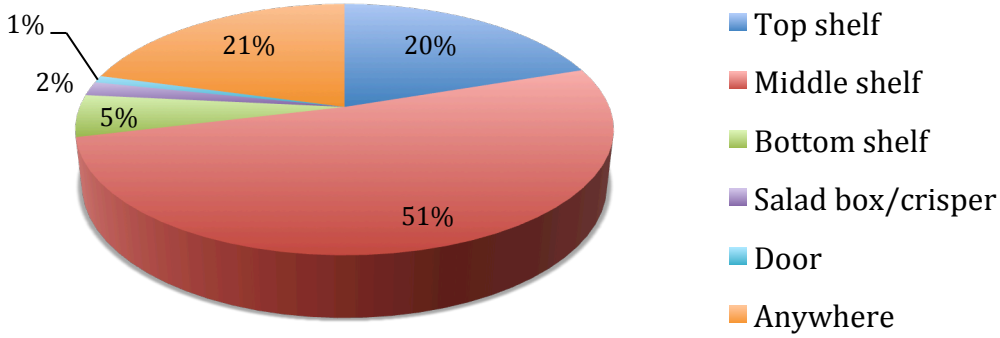
3.7.1 In what area of your fridge do you keep raw red meat? (n=103)



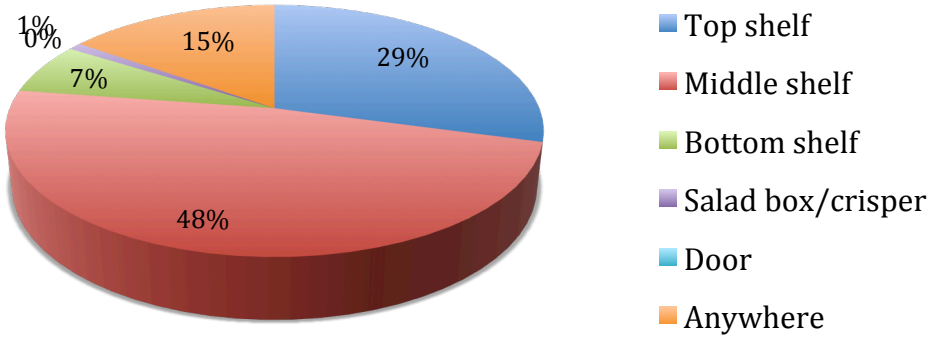
3.7.2 In what area of your fridge do you keep raw poultry meat? (n=105)



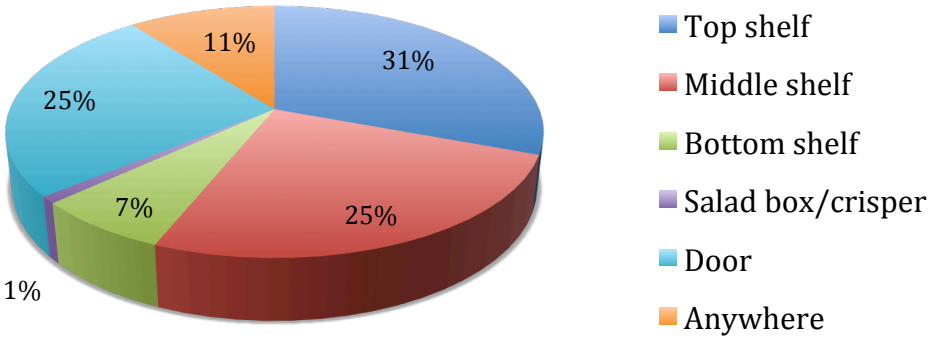
3.7.3 In what area of your fridge do you keep left overs? (n=111)



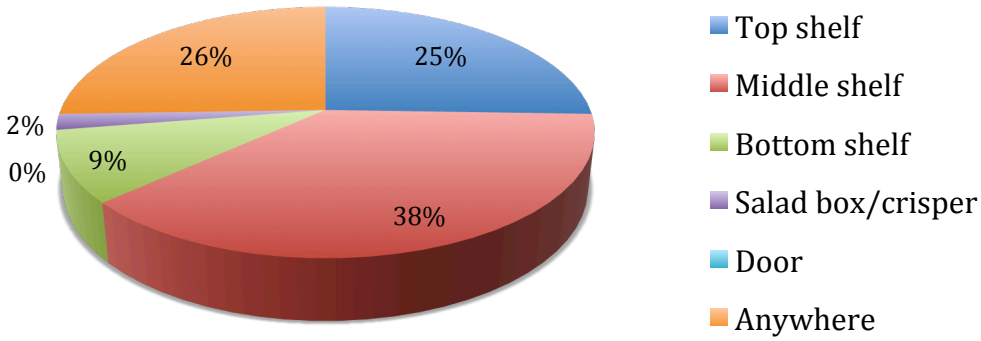
3.7.4 In what area of your fridge do you keep cooked sliced meats? (n=106)



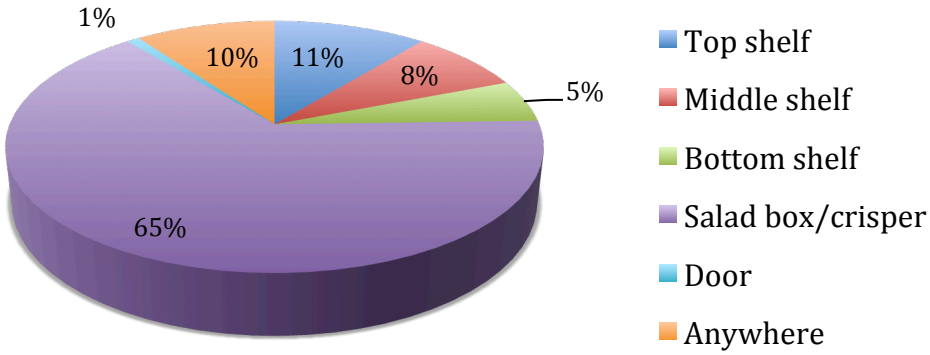
3.7.5 In what area of your fridge do you keep cheese? (n=114)



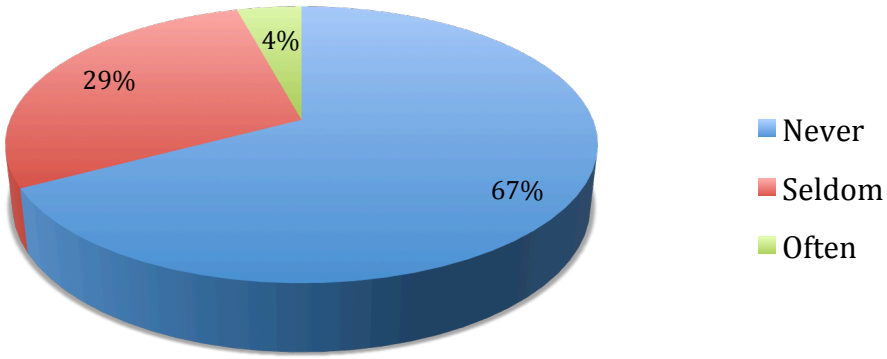
3.7.6 In what area of your fridge do you keep ready meals? (n=98)



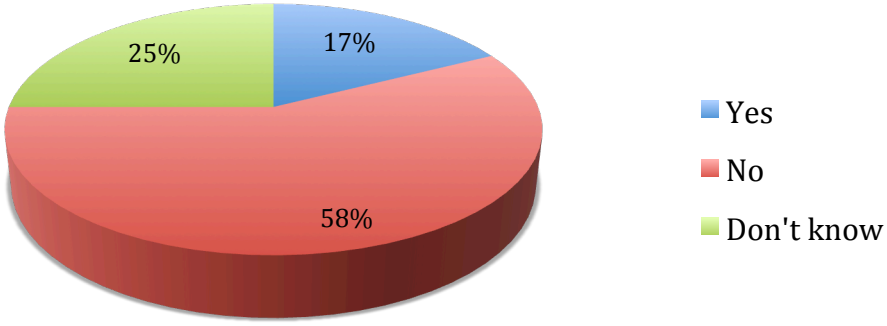
3.7.7 In what area of your fridge do you keep pre-packed salads? (n=110)



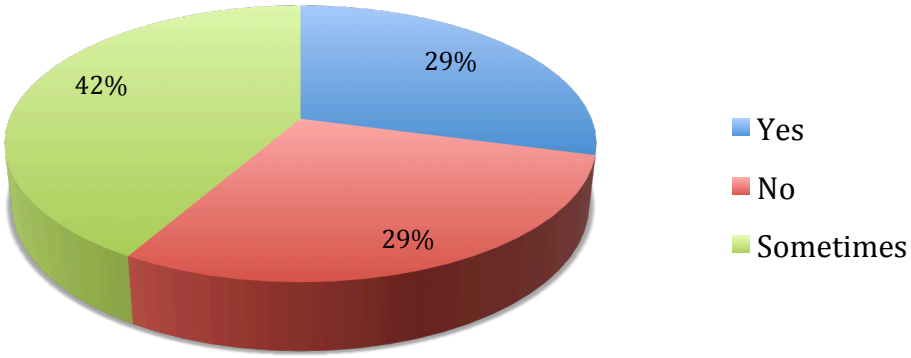
3.8 Do you put warm or hot foods in you fridge? (n=119)



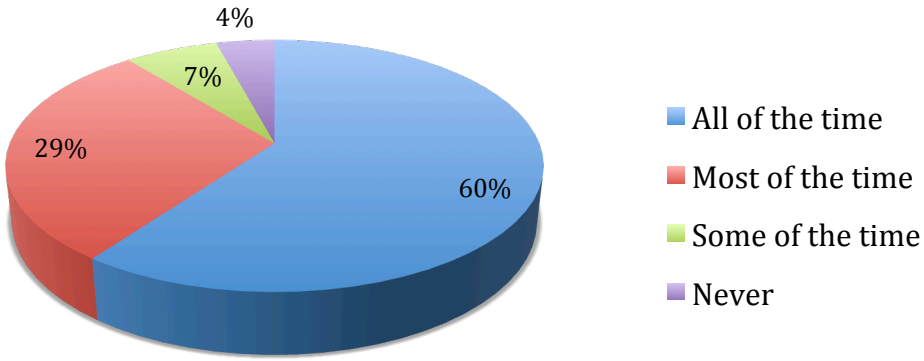
3.9 Does your fridge have a special rapid cooling or chilling function? (n=120)



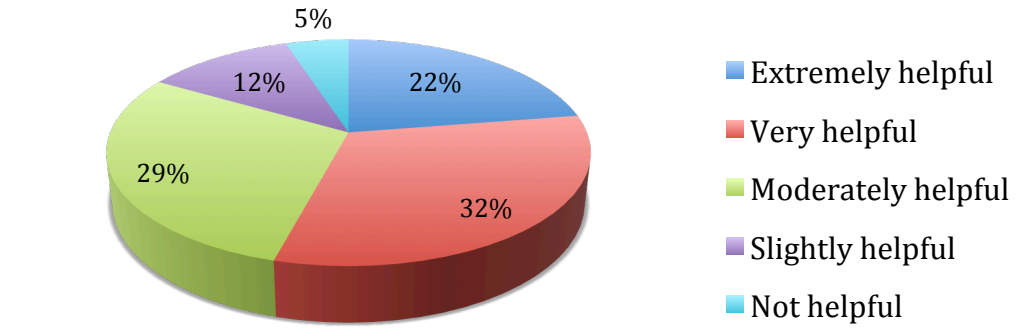
3.10 Do you defrost food in the fridge? (n=120)



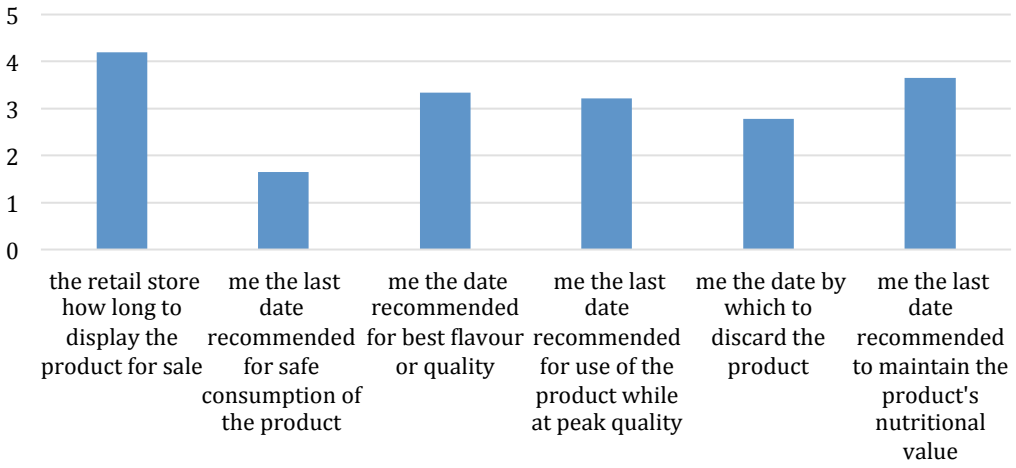
4.1 Do you follow storage advice, for example 'Keep refrigerated' given on packaged foods? (n=120)



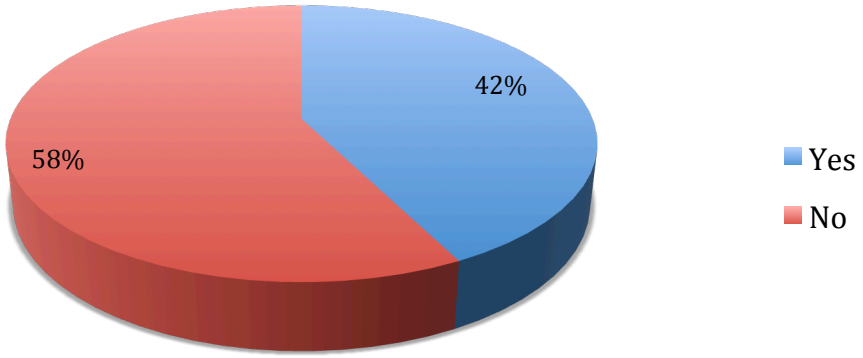
4.2 How helpful do you personally find the current methods, e.g. best before dates, of providing people with advice on when to eat food? (n=120)



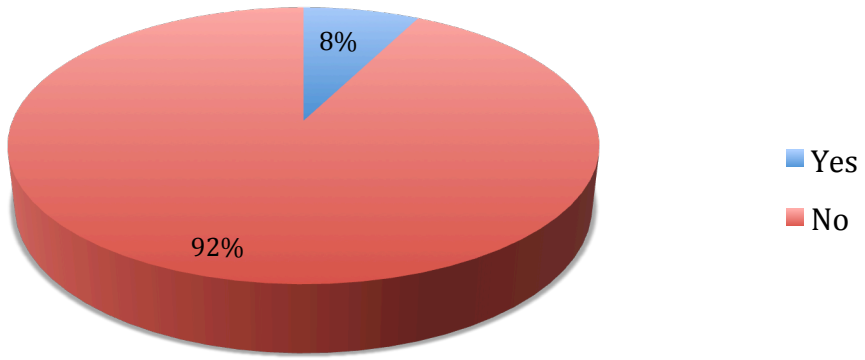
4.3 Which type of information is most useful to you? A product date that tells ... (rank in order of importance: 1=most important, 6=least important)



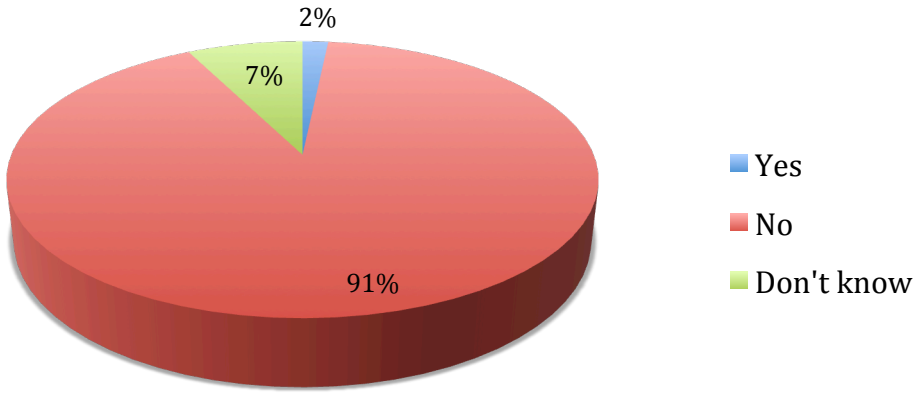
5.1 Do you know what a smart fridge is? (n=120)



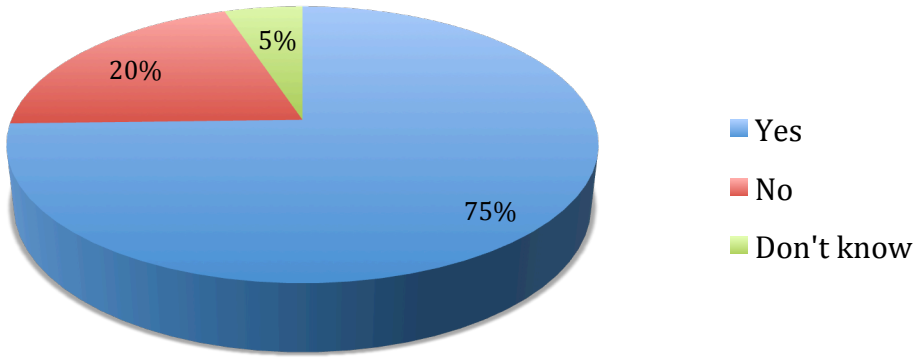
5.2 Have you considered buying a smart fridge? (n=119)



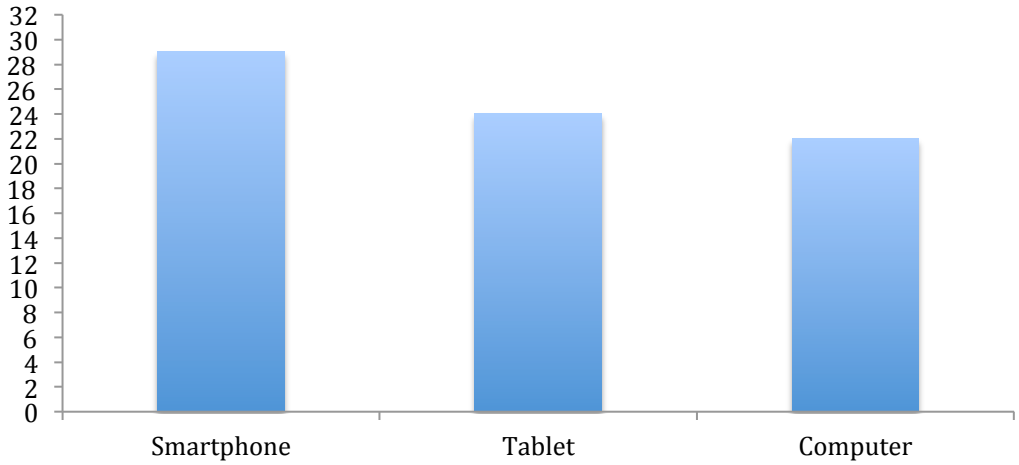
5.3 Do you own a smart fridge? (n=120)



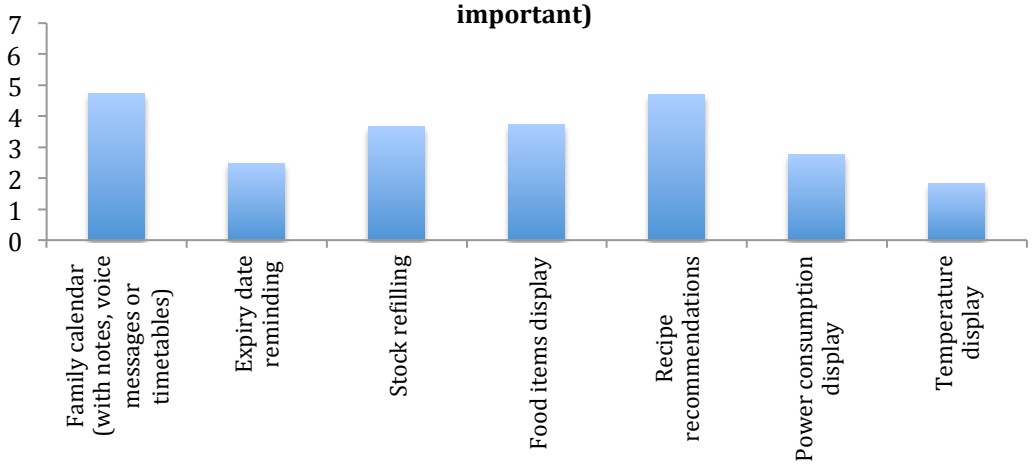
5.4 Do you own any smart devices? (n=118)



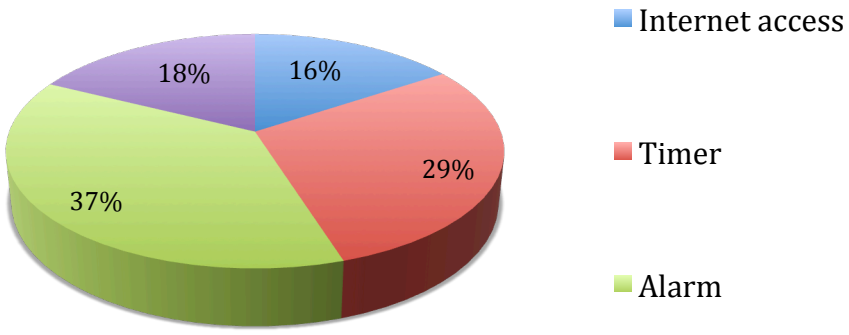
5.5 Do you own any of the following devices? (n=118)



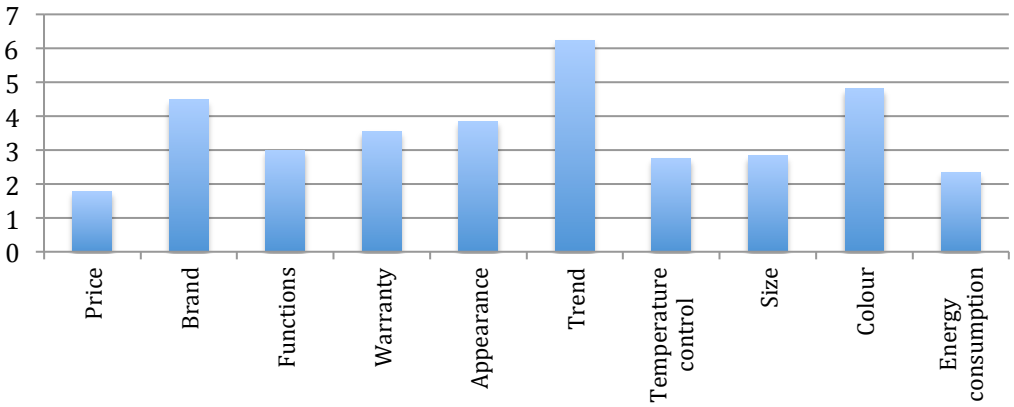
5.6 If you were considering buying a smart fridge, how would you rank the following features? (1 = most important, 7 = least important)



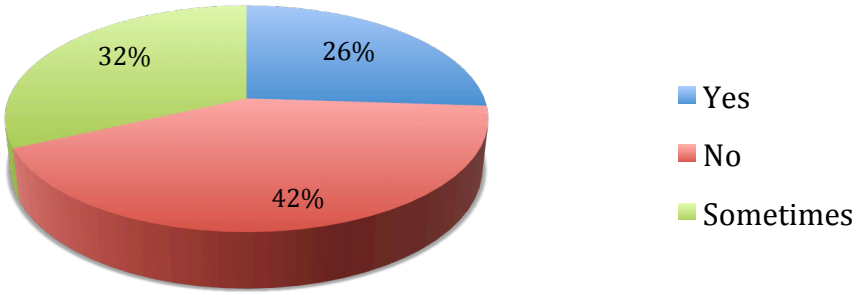
5.7 What other feature(s) would you want a smart fridge to include? (n=102)



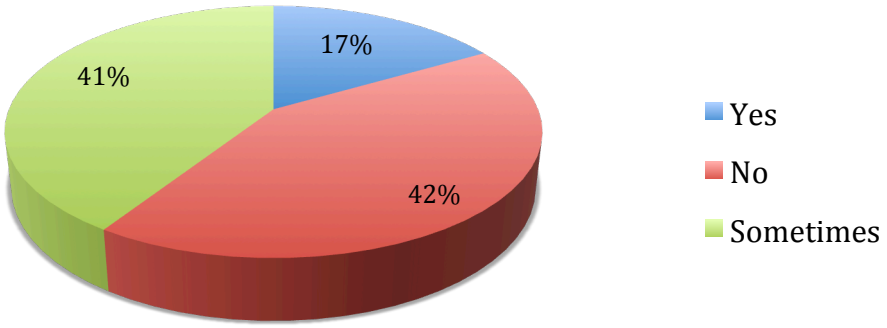
5.8 If you were considering buying a smart fridge, how would you rank the following features? (1 = most important, 10 = least important)



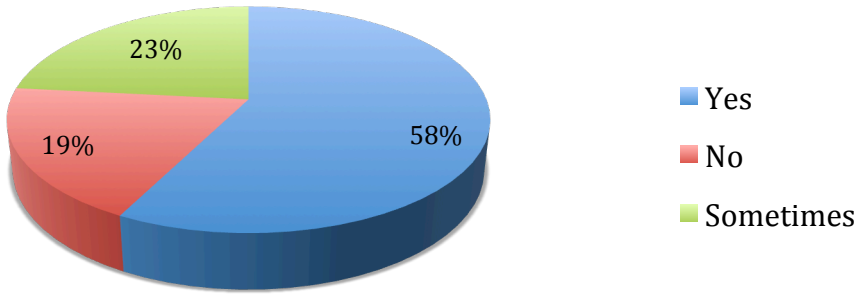
5.9 Would you eat more healthily if your fridge provided you with the nutrition facts of possible meal ideas and/ or snacks? (n=119)



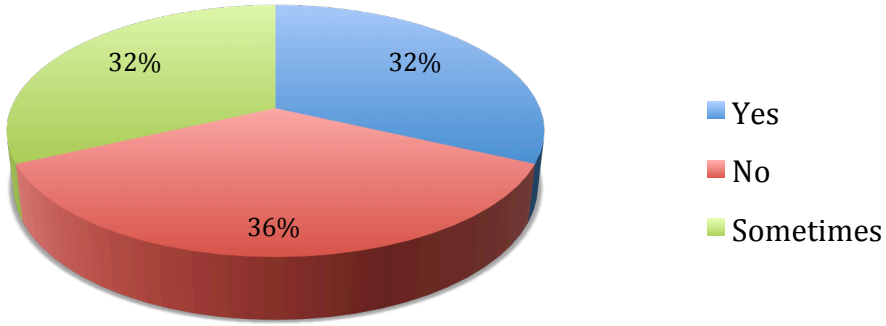
5.10 Does food often go bad in your fridge because you forget when you purchased it? (n=120)



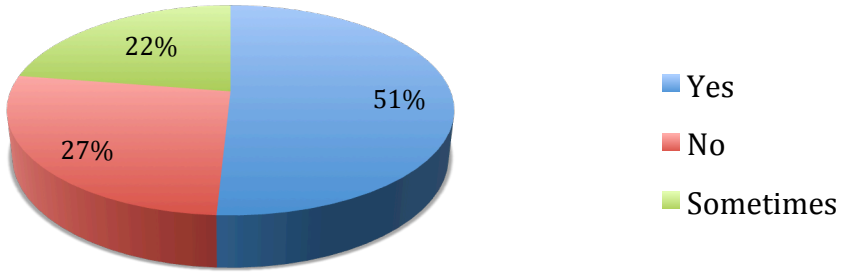
5.11 Would it be convenient if your fridge could remind you which foods have gone bad and which are soon to expire? (n=120)



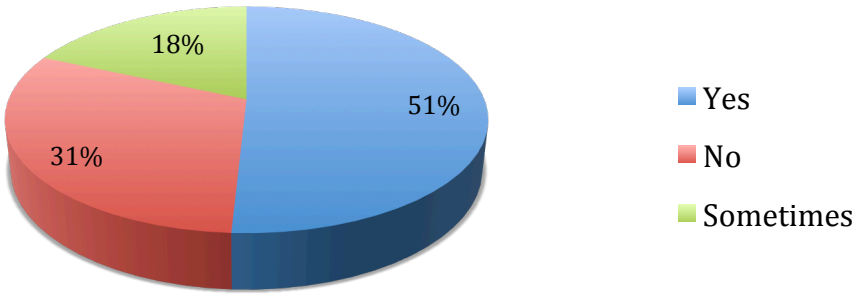
5.12 Do you often go to the grocery store and forget which groceries you need to purchase? (n=119)



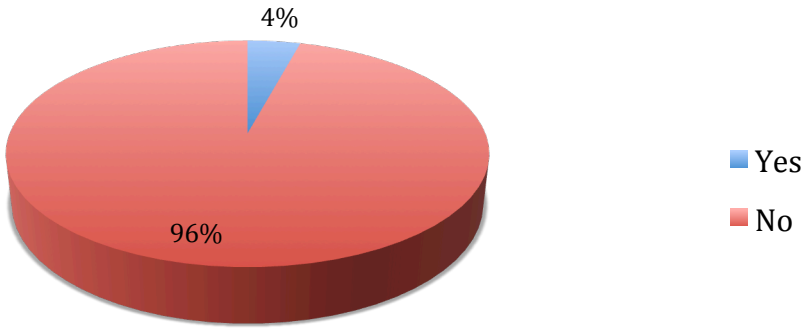
5.13 Would having a grocery inventory list that is transferable from your fridge to your mobile phone help you plan meal ideas before you get home or when you're at the grocery store? (n=120)



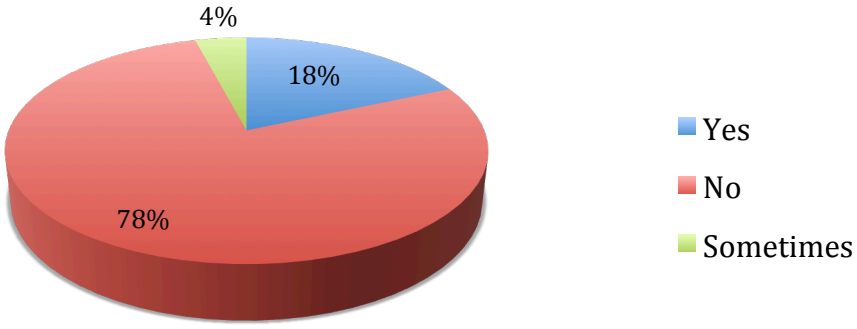
5.14 Would you find it a chore to scan barcodes on packaged foods as you first put the items into your fridge? (n=120)



5.15 Have you ever used a grocery inventory planning app on your mobile phone or tablet to help you keep stock of the food in your fridge? (n=119)

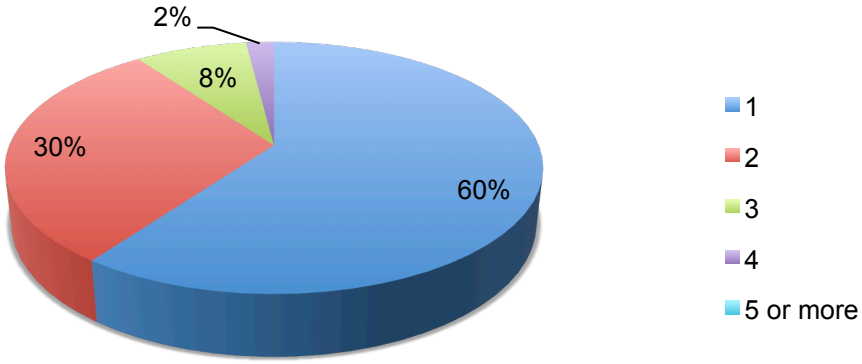


5.16 If you have ever used a grocery inventory planning app on your mobile phone or tablet, did you find it useful? (n=49)

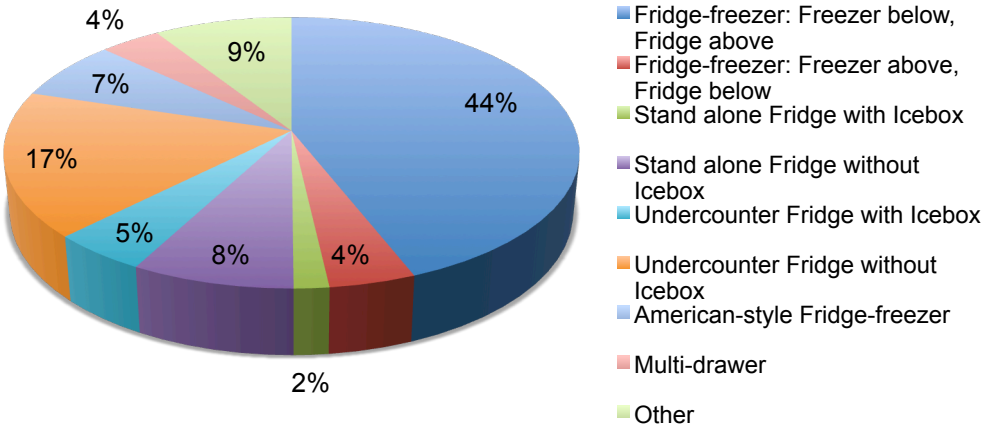


11 Appendix B2: Tesco Panellists Initial Questionnaire Responses.

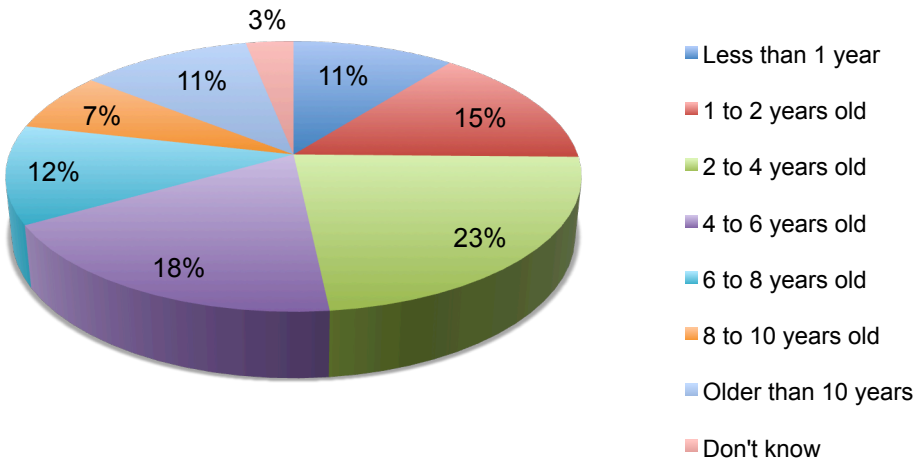
How many FRIDGE/FRIDGE-FREEZERS are there in your household? (n=710)



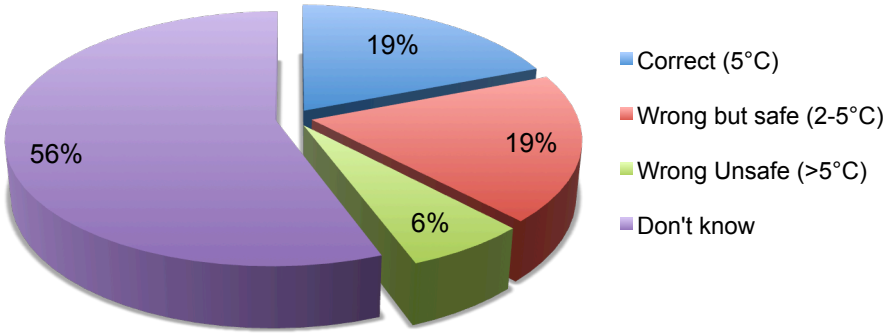
What type of fridge(s) do you have? (n=704)



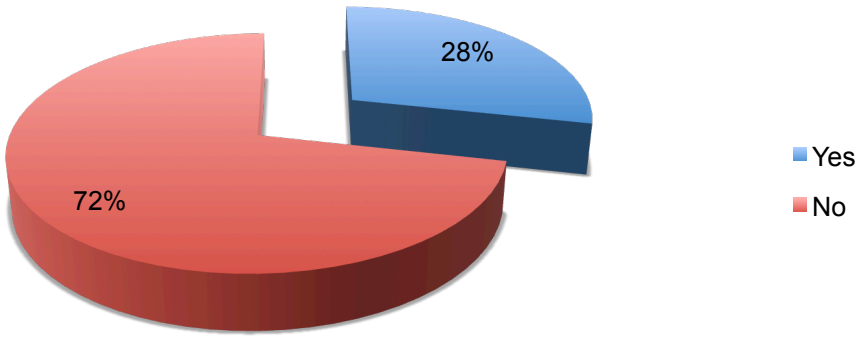
How old is your MAIN fridge? (n=704)



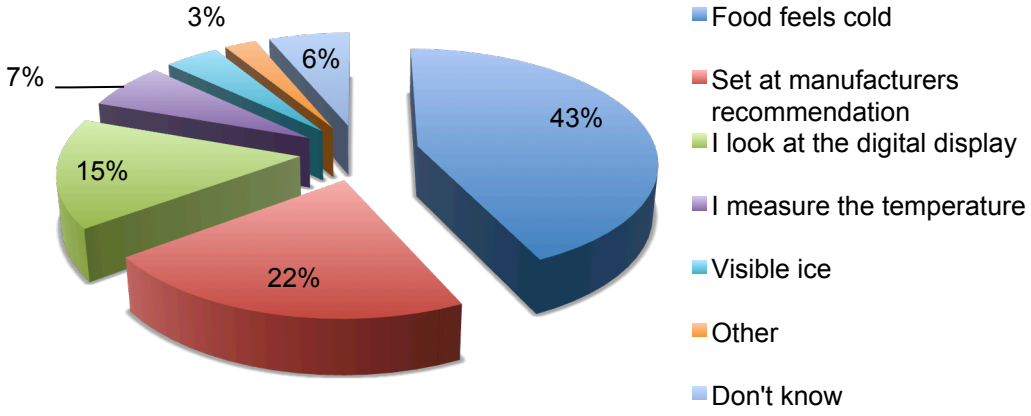
Do you know what the recommended maximum (highest) temperature that you should keep your fridge at is? (n=704)



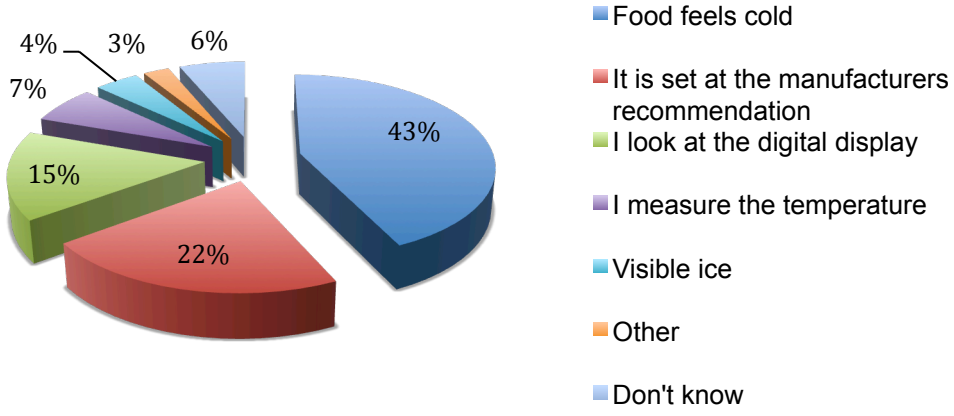
Do you have a Fridge Thermometer? (n=700)



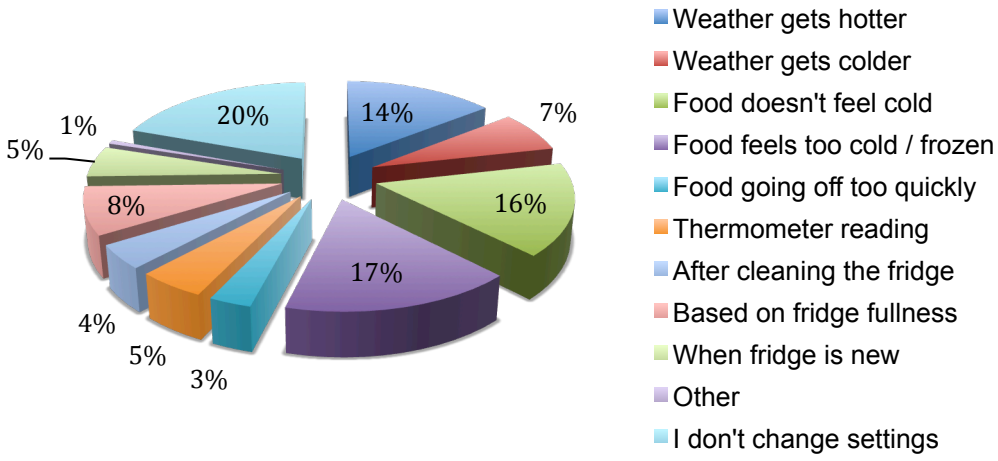
How do you know if your fridge is running at the right temperature? (n=699)



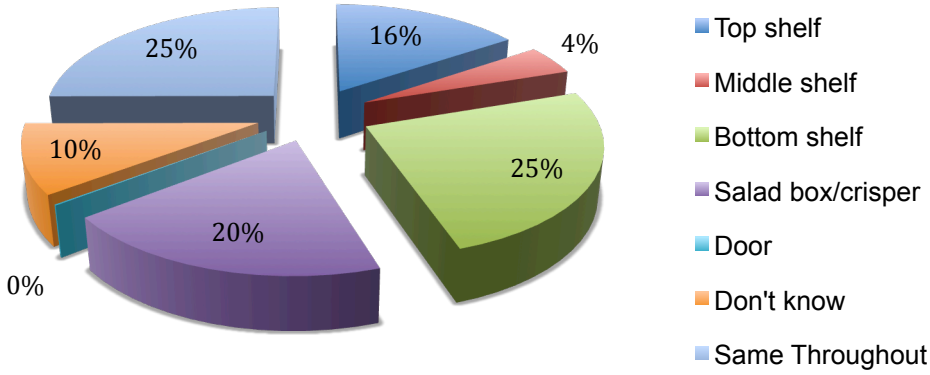
How do you know if your fridge is running at the right temperature? (n=699)



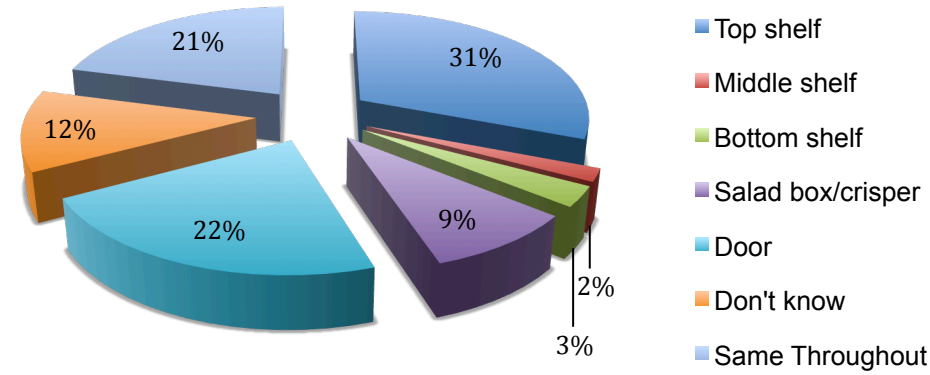
Do you change your fridge settings for any of these reasons? (n=699)



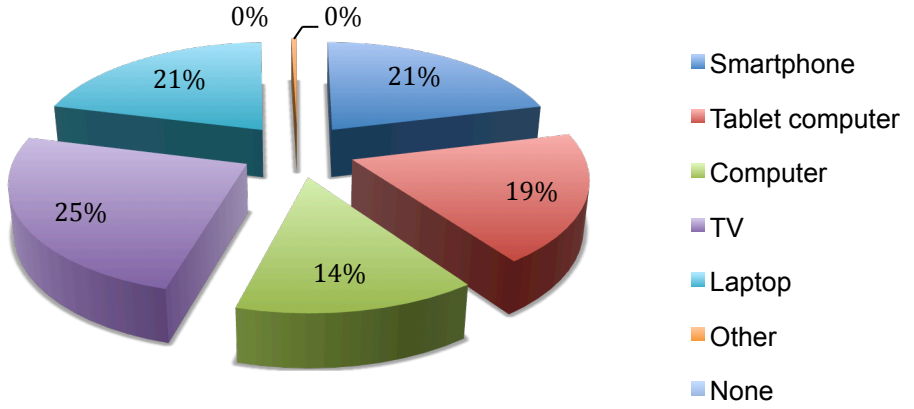
G. What area of your fridge do you think is the Coldest? (n=698)

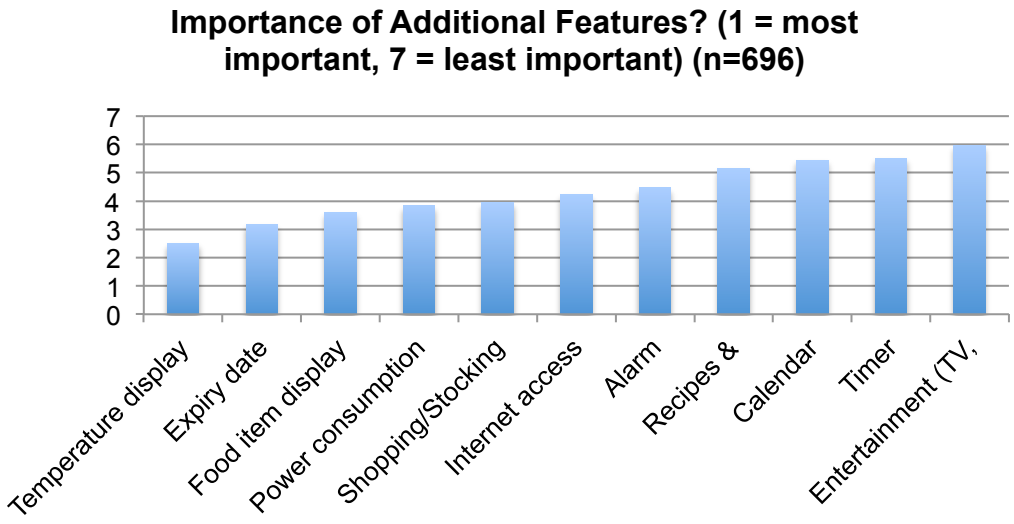


What area of your fridge do you think is the Warmest? (n=698)



Do you own/use any of the following devices? (n=698)

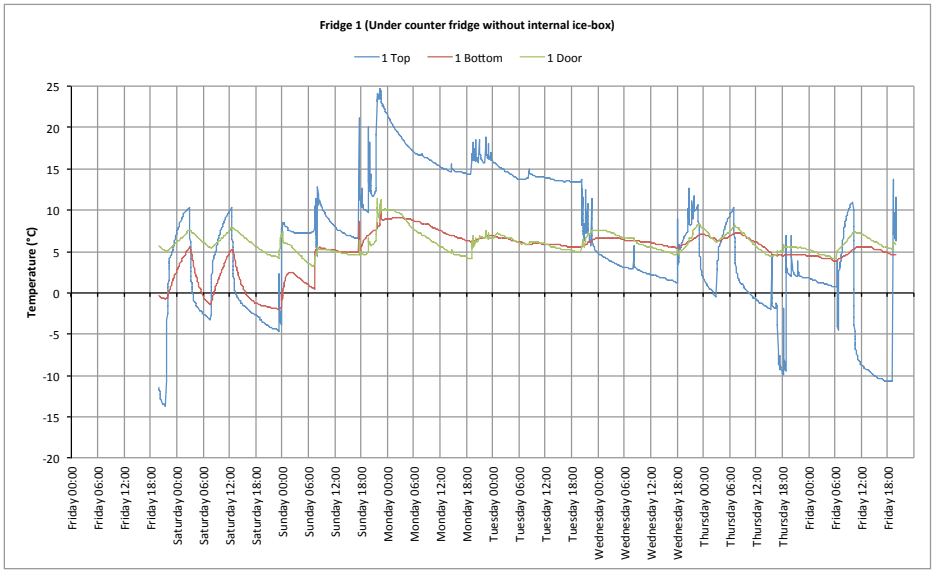


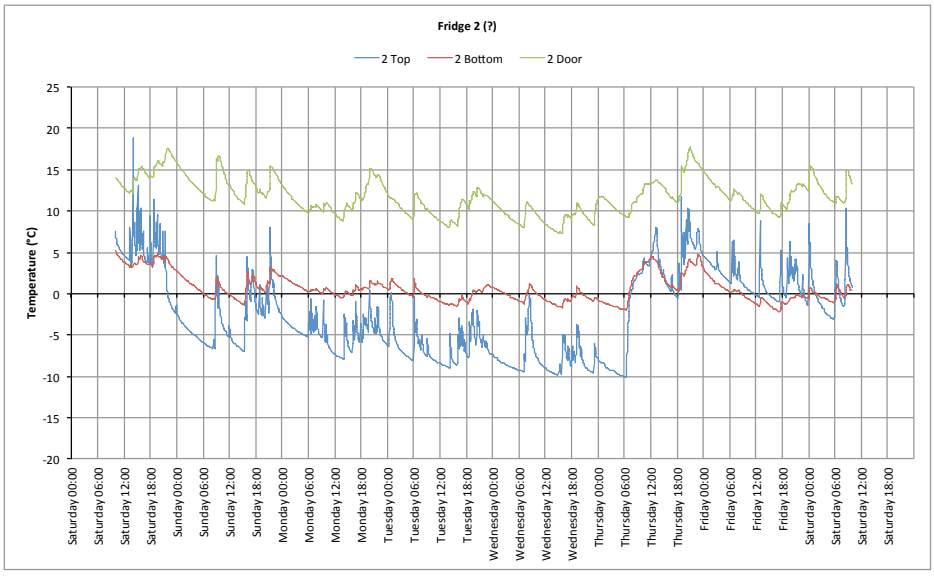

Importance of Additional Features? (1 = most important, 7 = least important) (n=696)
7
6
5
4
3
2
1
0
Temperature display
Expiry date
Food item display
Power consumption
Shopping/Stocking
Internet access
Alarm
Recipes &
Calendar
Timer
Entertainment (TV,

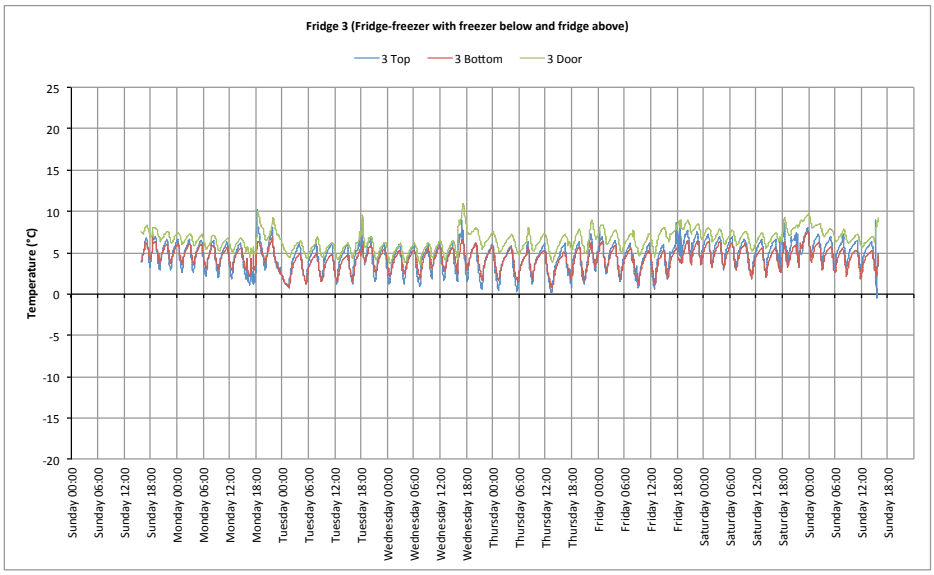
12 Appendix C: Refrigerator temperature survey

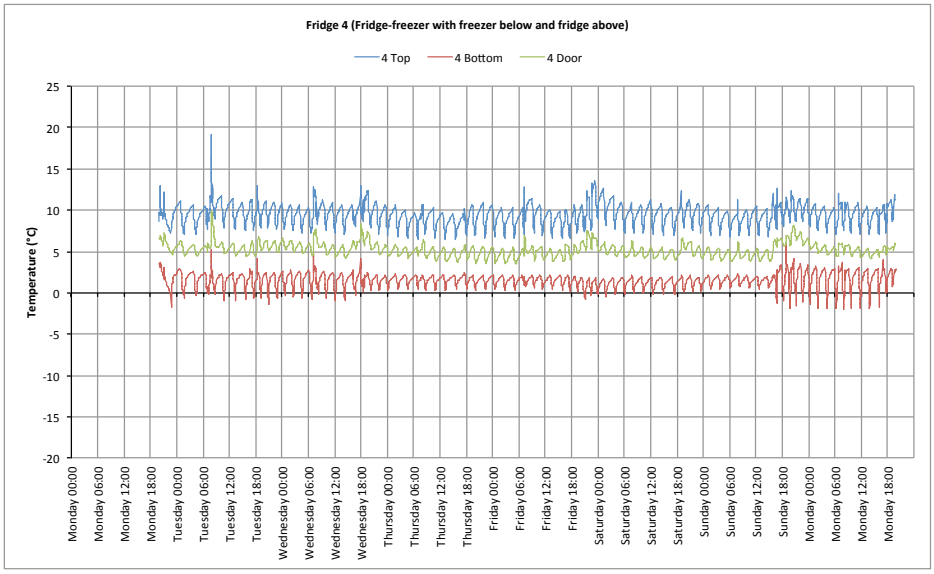
Refrigerator	Type	Age of refrigerator	Type of household (family with children, single, couple, elderly)
1	Under counter fridge without internal ice-box	4 to 6 years old	couple
2	Under counter fridge without internal ice-box	1 to 2 years old	family with children
3	Fridge-freezer with freezer below and fridge above	4 to 6 years old	family with children
4	Fridge-freezer with freezer below and fridge above	Less than 1 year	family
5	American style fridge-freezer	6 to 8 years old	family with children
6	American style fridge-freezer	Older than 10 years	family with children
7	Under counter fridge without internal ice-box	Less than 1 year	couple
8	Under counter fridge with internal ice-box	Older than 10 years	single
9	Under counter fridge with internal ice-box	Don’t know	couple
10	Under counter fridge without internal ice-box	1 to 2 years old	family with children
11	Stand-alone fridge without internal ice-box	1 to 2 years old	family with children
12	Under counter fridge without internal ice-box	2 to 4 years old	single
13	Under counter fridge without internal ice-box	Older than 10 years	family with children
14	Fridge-freezer with freezer below and fridge above	2 to 4 years old	single
15	Stand-alone fridge without internal ice-box	Less than 1 year	family with children
16	Fridge-freezer with freezer below and fridge above	1 to 2 years old	family
17	Fridge-freezer with freezer below and fridge above	1 to 2 years old	family
18	Fridge-freezer with freezer below and fridge above	2 to 4 years old	single
19	American style fridge-freezer	Older than 10 years	couple
20	Stand-alone fridge without internal ice-box	1 to 2 years old	family with children
21	Fridge-freezer with freezer below and fridge above	1 to 2 years old	couple
22	Fridge-freezer with freezer below and fridge above	1 to 2 years old	couple
23	Under counter fridge without internal ice-box	Older than 10 years	single
24	Fridge-freezer with freezer below and fridge above	Less than 1 year	family with children
25	Fridge-freezer with freezer below and fridge above	2 to 4 years old	couple
26	Fridge-freezer with freezer below and fridge above	Less than 1 year	couple
27	American style fridge-freezer	Older than 10 years	couple
28	Fridge-freezer with freezer below and fridge above	Less than 1 year	couple
29	Under counter fridge without internal ice-box	Older than 10 years	elderly
30	Stand-alone fridge without internal ice-box	2 to 4 years old	couple

31	Fridge-freezer with freezer below and fridge above	6 to 8 years old	couple
32	Fridge-freezer with freezer below and fridge above	Less than 1 year	elderly






Fridge 3 (Fridge-freezer with freezer below and fridge above)
3 Top
3 Bottom
3 Door
Temperature (°C)
25
20
15
10
5
0
-5
-10
-15
-20
Sunday 00:00
Sunday 06:00
Sunday 12:00
Sunday 18:00
Monday 00:00
Monday 06:00
Monday 12:00
Monday 18:00
Tuesday 00:00
Tuesday 06:00
Tuesday 12:00
Tuesday 18:00
Wednesday 00:00
Wednesday 06:00
Wednesday 12:00
Wednesday 18:00
Thursday 00:00
Thursday 06:00
Thursday 12:00
Thursday 18:00
Friday 00:00
Friday 06:00
Friday 12:00
Friday 18:00
Saturday 00:00
Saturday 06:00
Saturday 12:00
Saturday 18:00
Sunday 00:00
Sunday 06:00
Sunday 12:00
Sunday 18:00


Fridge 4 (Fridge-freezer with freezer below and fridge above)
4 Top
4 Bottom
4 Door
Temperature (°C)
25
20
15
10
5
0
-5
-10
-15
-20
Monday 00:00
Monday 06:00
Monday 12:00
Monday 18:00
Tuesday 00:00
Tuesday 06:00
Tuesday 12:00
Tuesday 18:00
Wednesday 00:00
Wednesday 06:00
Wednesday 12:00
Wednesday 18:00
Thursday 00:00
Thursday 06:00
Thursday 12:00
Thursday 18:00
Friday 00:00
Friday 06:00
Friday 12:00
Friday 18:00
Saturday 00:00
Saturday 06:00
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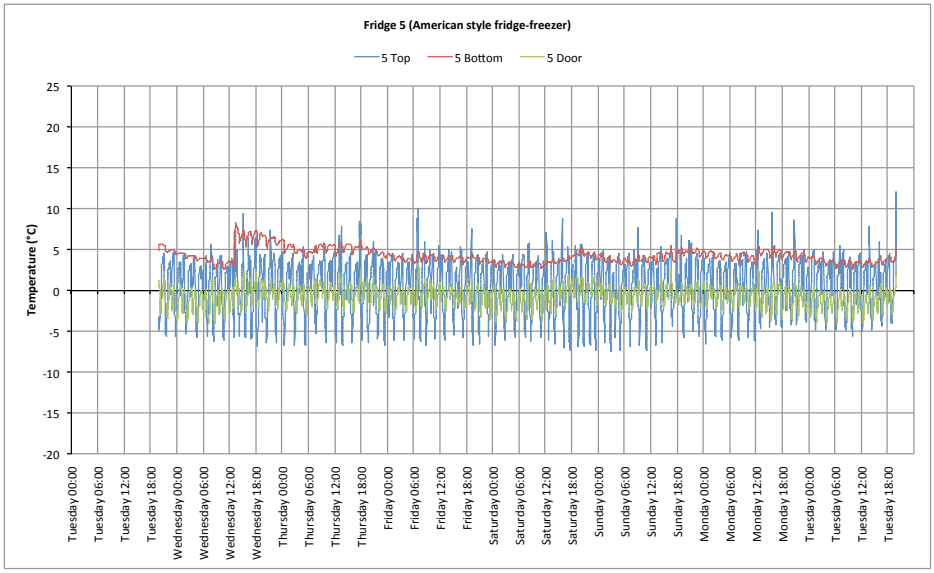
Sunday 00:00
Sunday 06:00
Sunday 12:00
Sunday 18:00
Monday 00:00
Monday 06:00
Monday 12:00
Monday 18:00


Fridge 5 (American style fridge-freezer)
5 Top
5 Bottom
5 Door
Temperature (°C)
25
20
15
10
5
0
-5
-10
-15
-20
Tuesday 00:00
Tuesday 06:00
Tuesday 12:00
Tuesday 18:00
Wednesday 00:00
Wednesday 06:00
Wednesday 12:00
Wednesday 18:00
Thursday 00:00
Thursday 06:00
Thursday 12:00
Thursday 18:00
Friday 00:00
Friday 06:00
Friday 12:00
Friday 18:00
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Saturday 06:00
Saturday 12:00
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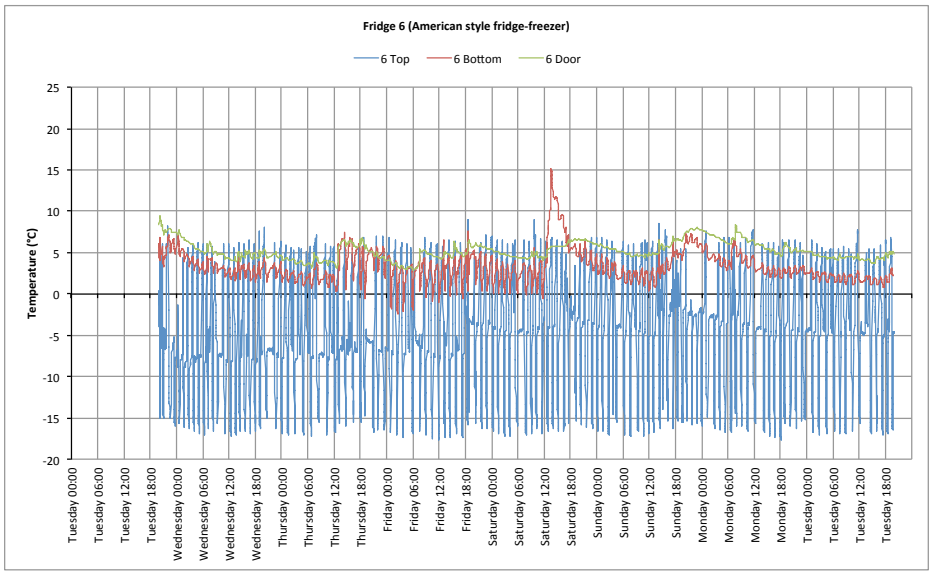
Monday 12:00
Monday 18:00
Tuesday 00:00
Tuesday 06:00
Tuesday 12:00
Tuesday 18:00


Fridge 6 (American style fridge-freezer)
6 Top
6 Bottom
6 Door
Temperature (°C)
25
20
15
10
5
0
-5
-10
-15
-20
Tuesday 00:00
Tuesday 06:00
Tuesday 12:00
Tuesday 18:00
Wednesday 00:00
Wednesday 06:00
Wednesday 12:00
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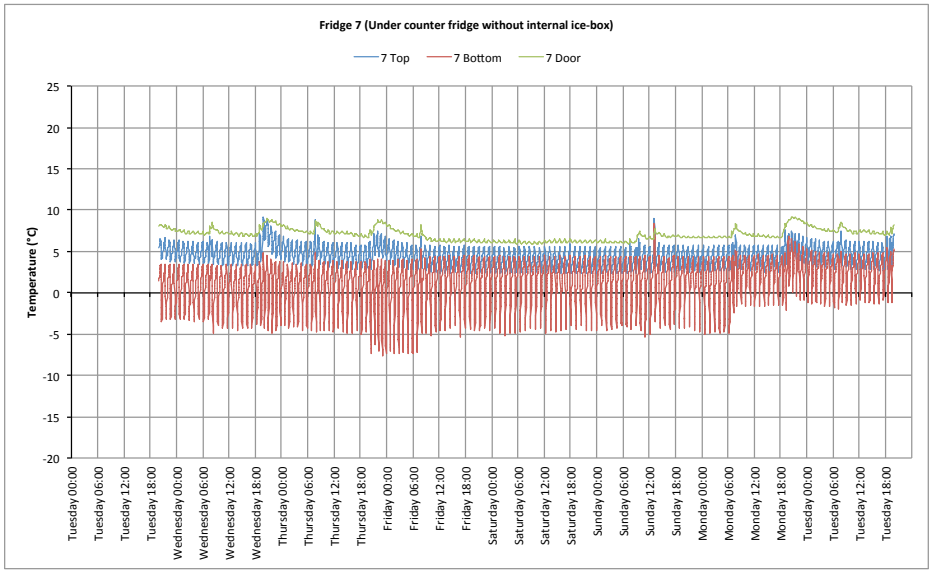
Fridge 7 (Under counter fridge without internal ice-box)
7 Top
7 Bottom
7 Door
Temperature (°C)
25
20
15
10
5
0
-5
-10
-15
-20
Tuesday 00:00
Tuesday 06:00
Tuesday 12:00
Tuesday 18:00
Wednesday 00:00
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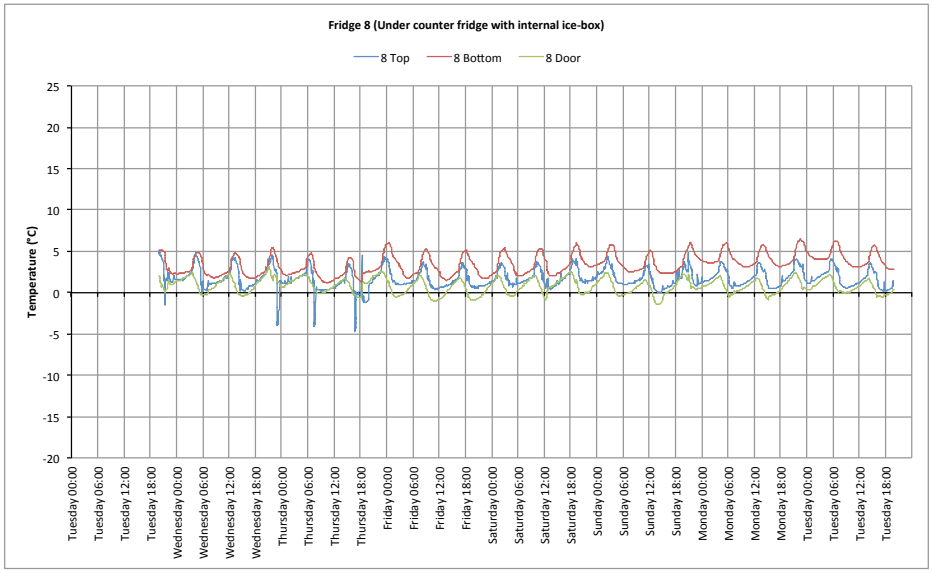
Fridge 8 (Under counter fridge with internal ice-box)
8 Top
8 Bottom
8 Door
Temperature (°C)
25
20
15
10
5
0
-5
-10
-15
-20
Tuesday 00:00
Tuesday 06:00
Tuesday 12:00
Tuesday 18:00
Wednesday 00:00
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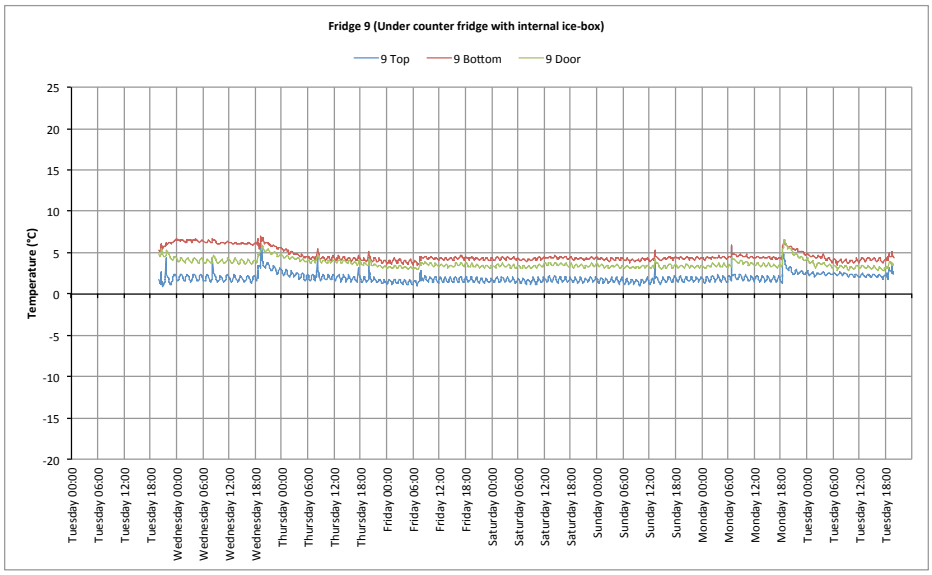
Fridge 9 (Under counter fridge with internal ice-box)
9 Top
9 Bottom
9 Door
Temperature (°C)
25
20
15
10
5
0
-5
-10
-15
-20
Tuesday 00:00
Tuesday 06:00
Tuesday 12:00
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Wednesday 00:00
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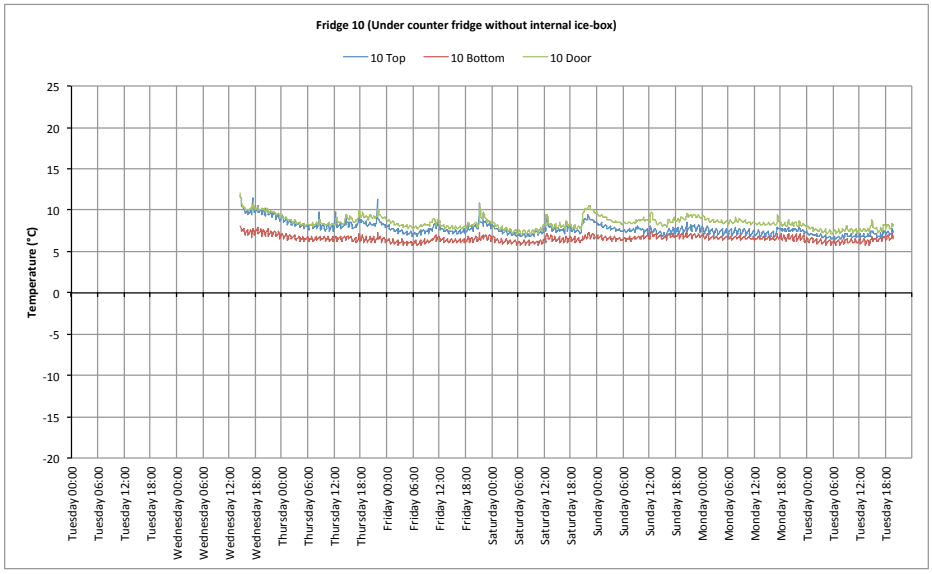
Fridge 10 (Under counter fridge without internal ice-box)
10 Top
10 Bottom
10 Door
Temperature (°C)
25
20
15
10
5
0
-5
-10
-15
-20
Tuesday 00:00
Tuesday 06:00
Tuesday 12:00
Tuesday 18:00
Wednesday 00:00
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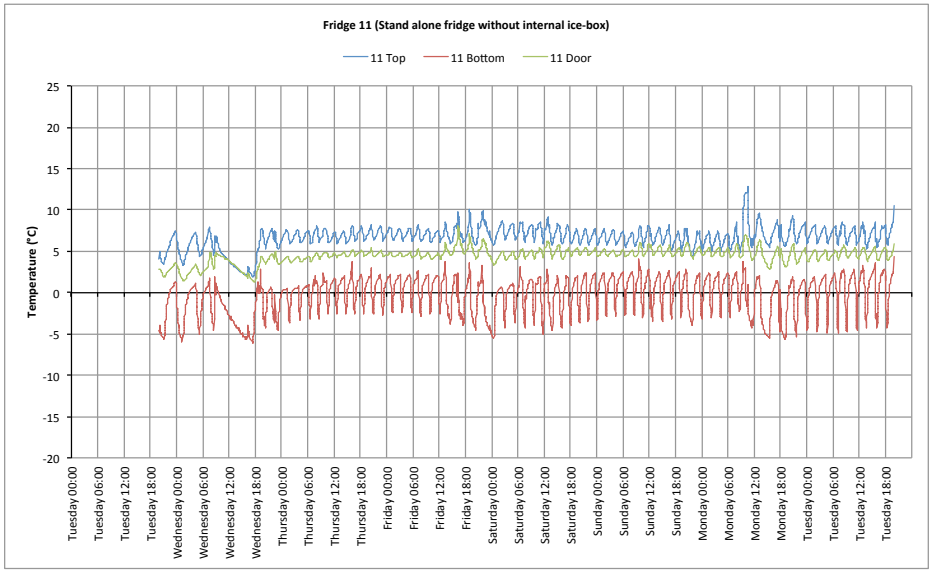
Fridge 11 (Stand alone fridge without internal ice-box)
11 Top
11 Bottom
11 Door
Temperature (°C)
25
20
15
10
5
0
-5
-10
-15
-20
Tuesday 00:00
Tuesday 06:00
Tuesday 12:00
Tuesday 18:00
Wednesday 00:00
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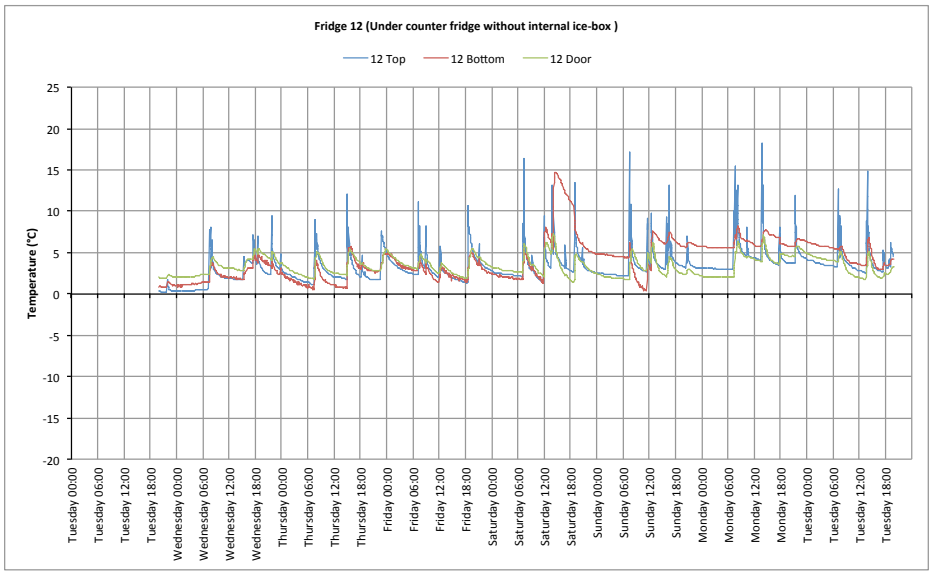
Fridge 12 (Under counter fridge without internal ice-box)
12 Top
12 Bottom
12 Door
Temperature (°C)
25
20
15
10
5
0
-5
-10
-15
-20
Tuesday 00:00
Tuesday 06:00
Tuesday 12:00
Tuesday 18:00
Wednesday 00:00
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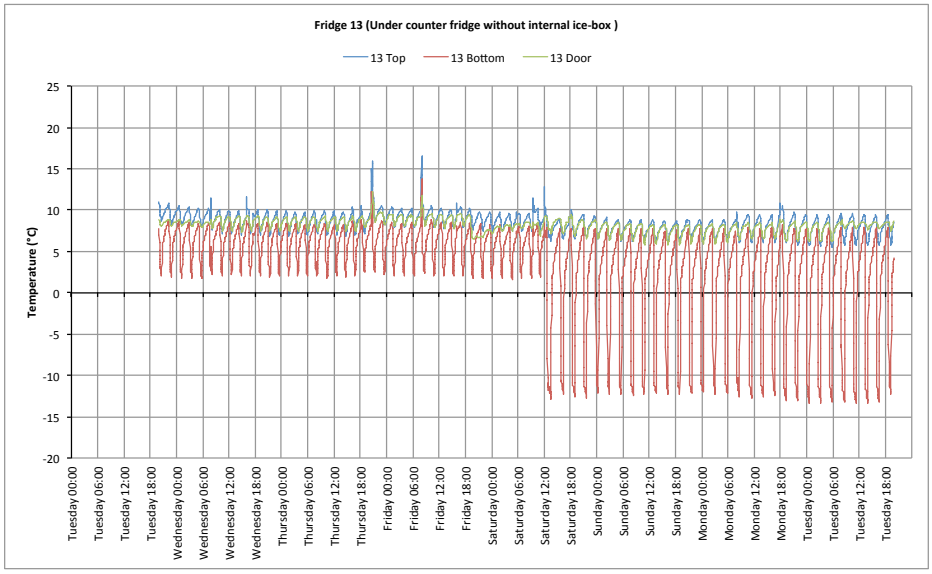
Fridge 13 (Under counter fridge without internal ice-box)
13 Top
13 Bottom
13 Door
Temperature (°C)
25
20
15
10
5
0
-5
-10
-15
-20
Tuesday 00:00
Tuesday 06:00
Tuesday 12:00
Tuesday 18:00
Wednesday 00:00
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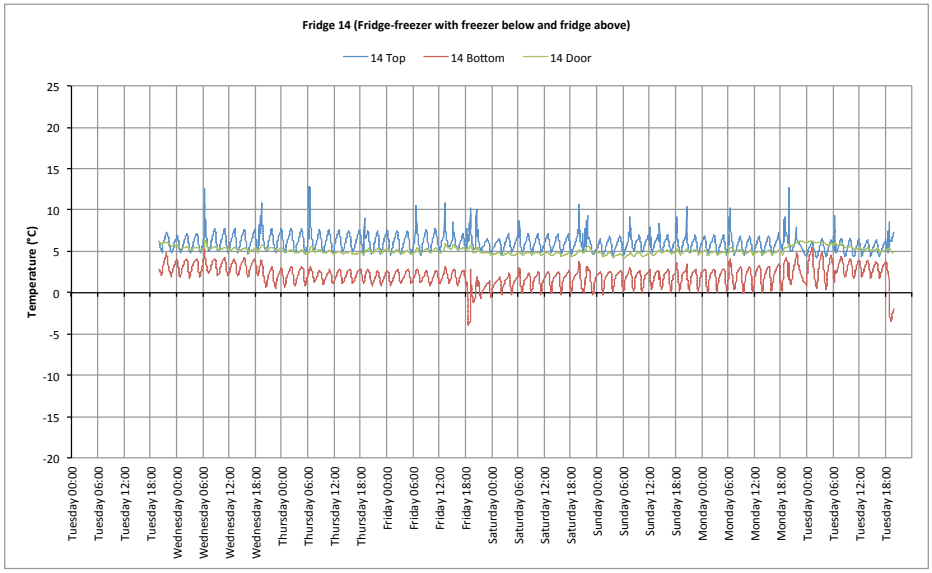
Fridge 14 (Fridge-freezer with freezer below and fridge above)
14 Top
14 Bottom
14 Door
Temperature (°C)
25
20
15
10
5
0
-5
-10
-15
-20
Tuesday 00:00
Tuesday 06:00
Tuesday 12:00
Tuesday 18:00
Wednesday 00:00
Wednesday 06:00
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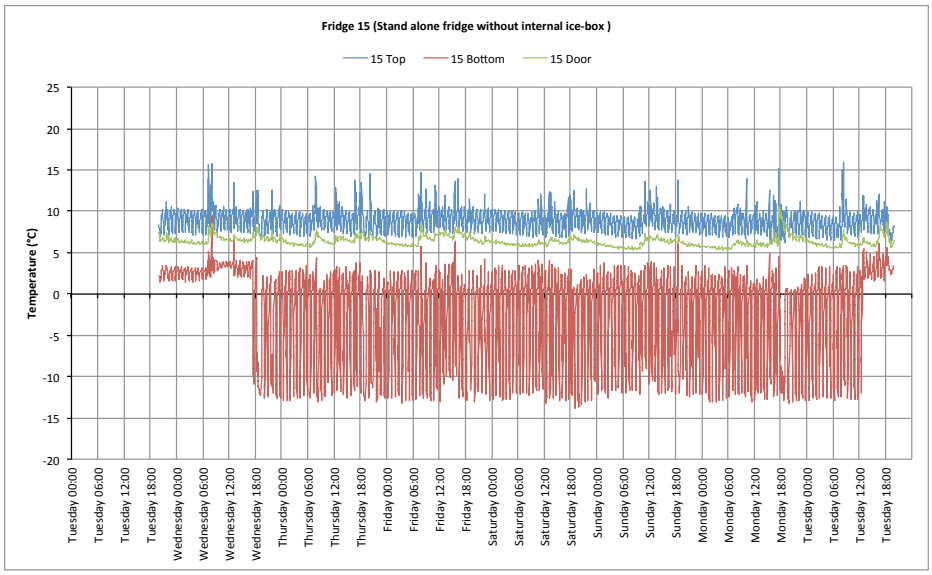
Fridge 15 (Stand alone fridge without internal ice-box)
15 Top
15 Bottom
15 Door
Temperature (°C)
25
20
15
10
5
0
-5
-10
-15
-20
Tuesday 00:00
Tuesday 06:00
Tuesday 12:00
Tuesday 18:00
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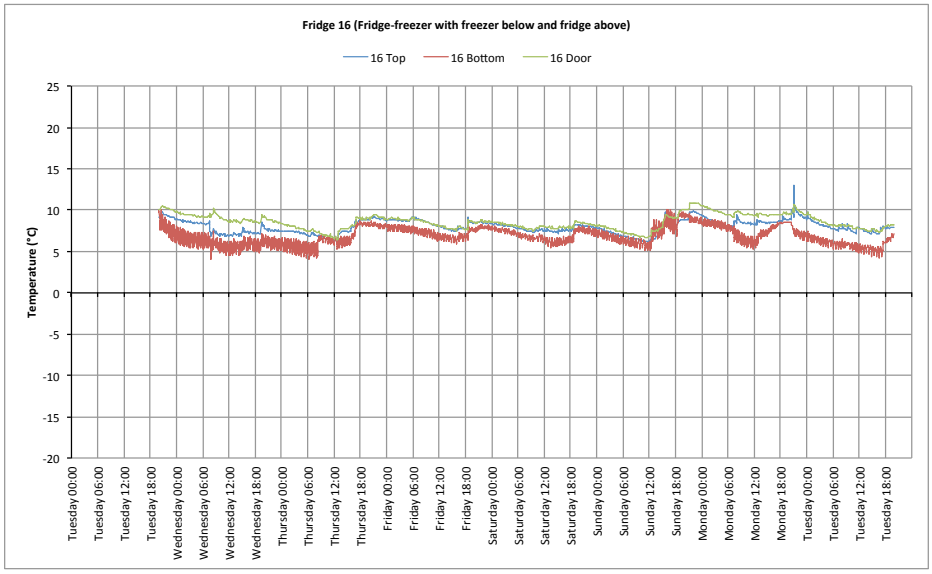
Fridge 16 (Fridge-freezer with freezer below and fridge above)
16 Top
16 Bottom
16 Door
Temperature (°C)
25
20
15
10
5
0
-5
-10
-15
-20
Tuesday 00:00
Tuesday 06:00
Tuesday 12:00
Tuesday 18:00
Wednesday 00:00
Wednesday 06:00
Wednesday 12:00
Wednesday 18:00
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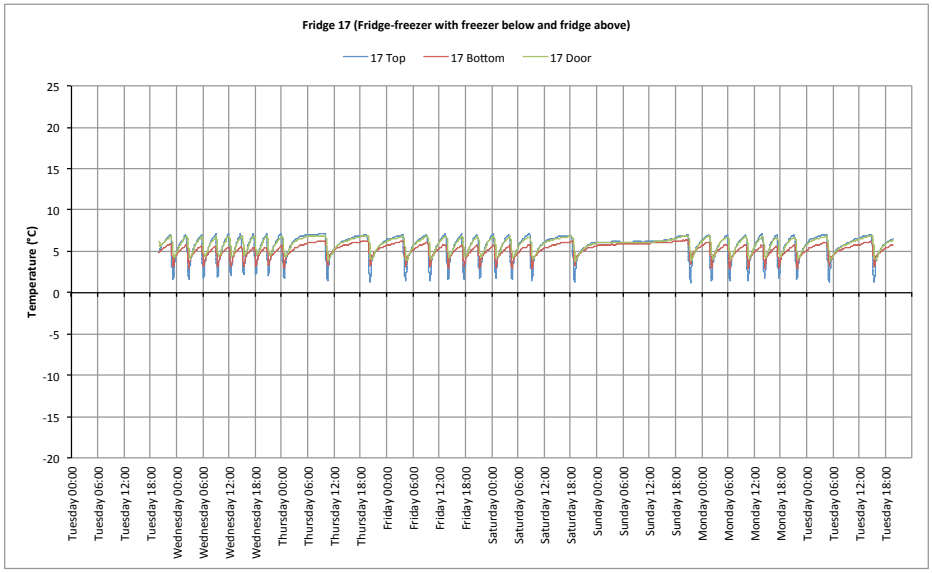
Tuesday 12:00
Tuesday 18:00


Fridge 17 (Fridge-freezer with freezer below and fridge above)
17 Top
17 Bottom
17 Door
Temperature (°C)
25
20
15
10
5
0
-5
-10
-15
-20
Tuesday 00:00
Tuesday 06:00
Tuesday 12:00
Tuesday 18:00
Wednesday 00:00
Wednesday 06:00
Wednesday 12:00
Wednesday 18:00
Thursday 00:00
Thursday 06:00
Thursday 12:00
Thursday 18:00
Friday 00:00
Friday 06:00
Friday 12:00
Friday 18:00
Saturday 00:00
Saturday 06:00
Saturday 12:00
Saturday 18:00
Sunday 00:00
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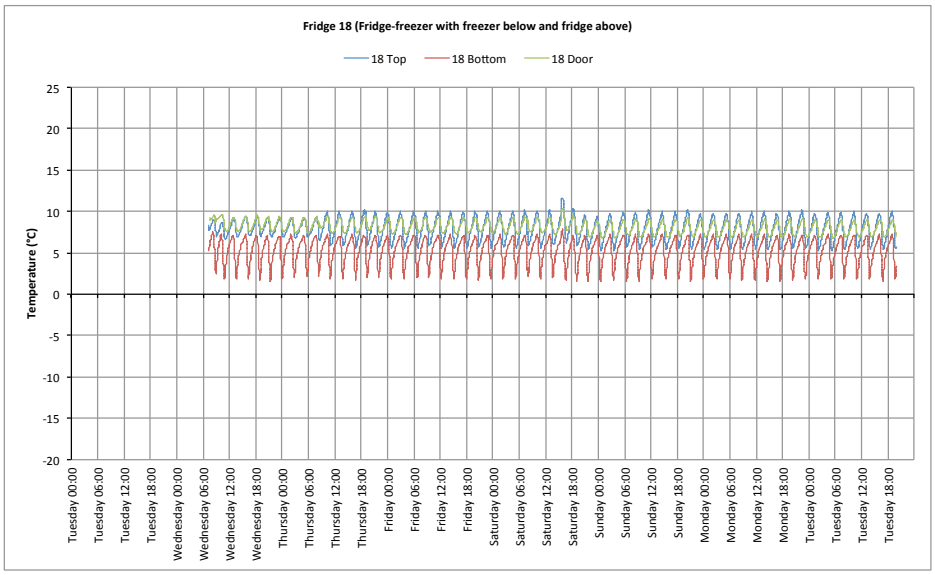
Sunday 12:00
Sunday 18:00
Monday 00:00
Monday 06:00
Monday 12:00
Monday 18:00
Tuesday 00:00
Tuesday 06:00
Tuesday 12:00
Tuesday 18:00


Fridge 18 (Fridge-freezer with freezer below and fridge above)
18 Top
18 Bottom
18 Door
Temperature (°C)
25
20
15
10
5
0
-5
-10
-15
-20
Tuesday 00:00
Tuesday 06:00
Tuesday 12:00
Tuesday 18:00
Wednesday 00:00
Wednesday 06:00
Wednesday 12:00
Wednesday 18:00
Thursday 00:00
Thursday 06:00
Thursday 12:00
Thursday 18:00
Friday 00:00
Friday 06:00
Friday 12:00
Friday 18:00
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Saturday 06:00
Saturday 12:00
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Sunday 06:00
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Monday 00:00
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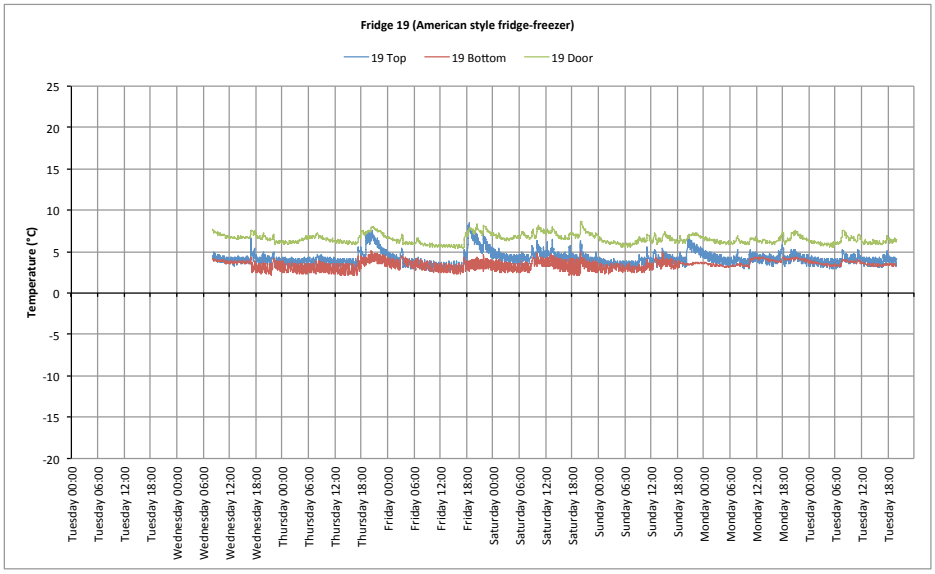
Monday 12:00
Monday 18:00
Tuesday 00:00
Tuesday 06:00
Tuesday 12:00
Tuesday 18:00


Fridge 19 (American style fridge-freezer)
19 Top
19 Bottom
19 Door
Temperature (°C)
25
20
15
10
5
0
-5
-10
-15
-20
Tuesday 00:00
Tuesday 06:00
Tuesday 12:00
Tuesday 18:00
Wednesday 00:00
Wednesday 06:00
Wednesday 12:00
Wednesday 18:00
Thursday 00:00
Thursday 06:00
Thursday 12:00
Thursday 18:00
Friday 00:00
Friday 06:00
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Saturday 06:00
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Sunday 06:00
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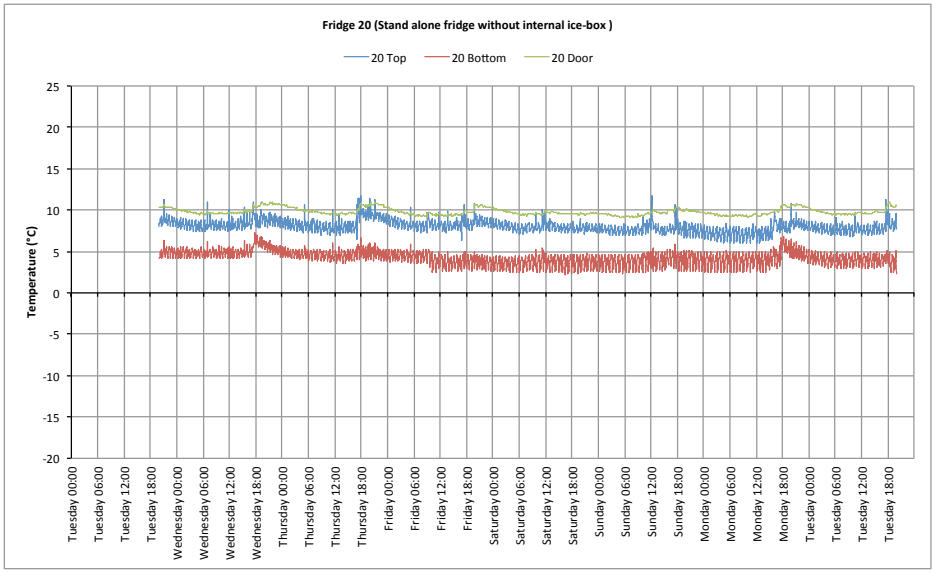
Sunday 18:00
Monday 00:00
Monday 06:00
Monday 12:00
Monday 18:00
Tuesday 00:00
Tuesday 06:00
Tuesday 12:00
Tuesday 18:00


Fridge 20 (Stand alone fridge without internal ice-box)
20 Top
20 Bottom
20 Door
Temperature (°C)
25
20
15
10
5
0
-5
-10
-15
-20
Tuesday 00:00
Tuesday 06:00
Tuesday 12:00
Tuesday 18:00
Wednesday 00:00
Wednesday 06:00
Wednesday 12:00
Wednesday 18:00
Thursday 00:00
Thursday 06:00
Thursday 12:00
Thursday 18:00
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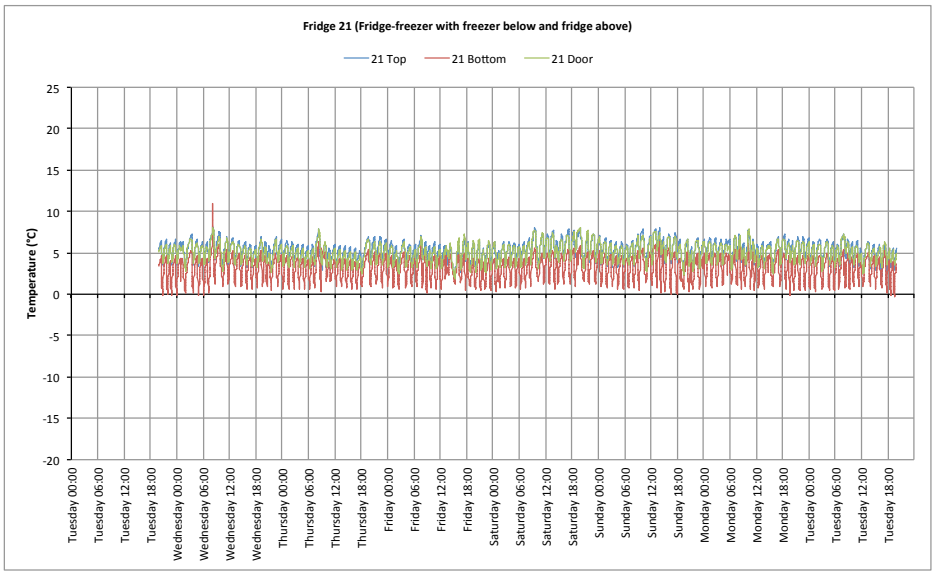
Monday 18:00
Tuesday 00:00
Tuesday 06:00
Tuesday 12:00
Tuesday 18:00


Fridge 21 (Fridge-freezer with freezer below and fridge above)
21 Top
21 Bottom
21 Door
Temperature (°C)
25
20
15
10
5
0
-5
-10
-15
-20
Tuesday 00:00
Tuesday 06:00
Tuesday 12:00
Tuesday 18:00
Wednesday 00:00
Wednesday 06:00
Wednesday 12:00
Wednesday 18:00
Thursday 00:00
Thursday 06:00
Thursday 12:00
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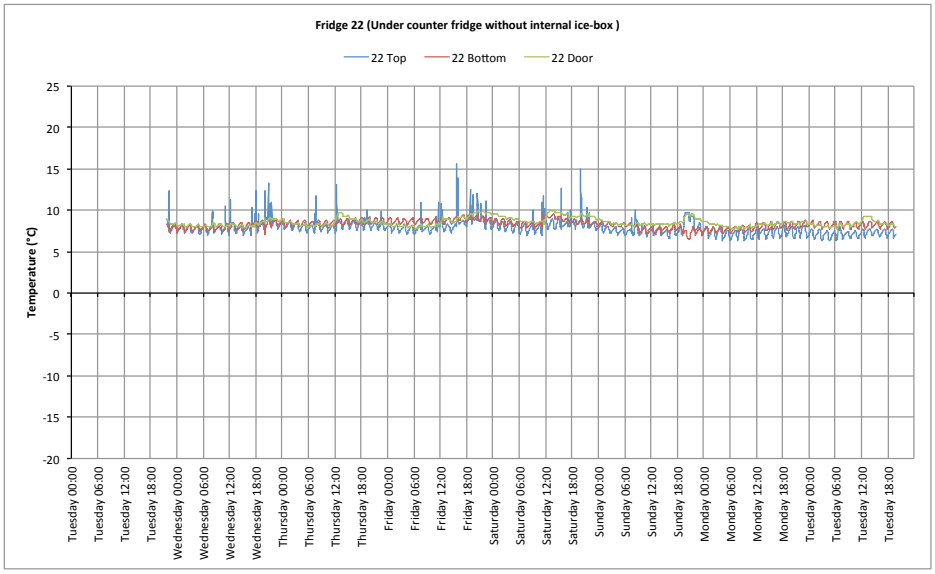
Monday 12:00
Monday 18:00
Tuesday 00:00
Tuesday 06:00
Tuesday 12:00
Tuesday 18:00


Fridge 22 (Under counter fridge without internal ice-box)
22 Top
22 Bottom
22 Door
Temperature (°C)
25
20
15
10
5
0
-5
-10
-15
-20
Tuesday 00:00
Tuesday 06:00
Tuesday 12:00
Tuesday 18:00
Wednesday 00:00
Wednesday 06:00
Wednesday 12:00
Wednesday 18:00
Thursday 00:00
Thursday 06:00
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Monday 12:00
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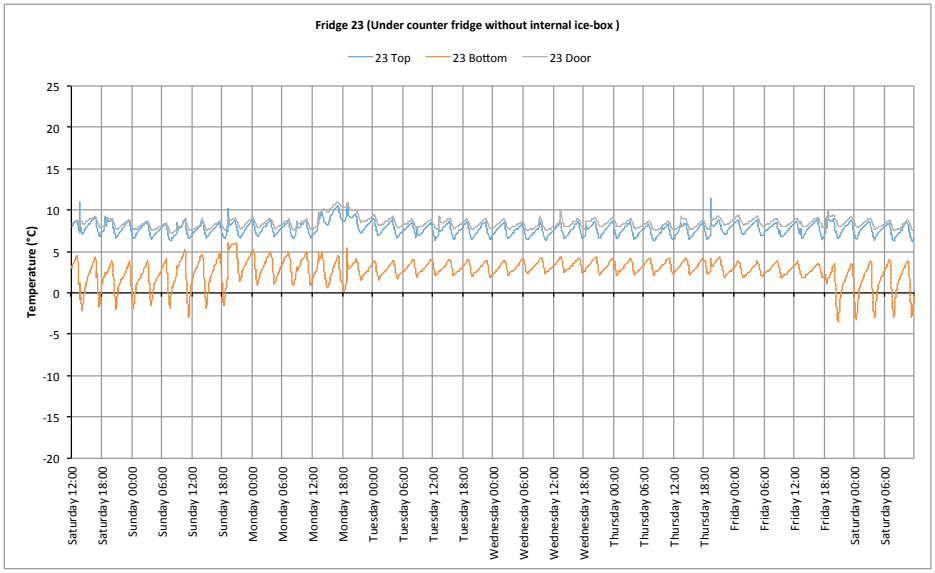
Tuesday 00:00
Tuesday 06:00
Tuesday 12:00
Tuesday 18:00


Fridge 23 (Under counter fridge without internal ice-box)
23 Top
23 Bottom
23 Door
Temperature (°C)
25
20
15
10
5
0
-5
-10
-15
-20
Saturday 12:00
Saturday 18:00
Sunday 00:00
Sunday 06:00
Sunday 12:00
Sunday 18:00
Monday 00:00
Monday 06:00
Monday 12:00
Monday 18:00
Tuesday 00:00
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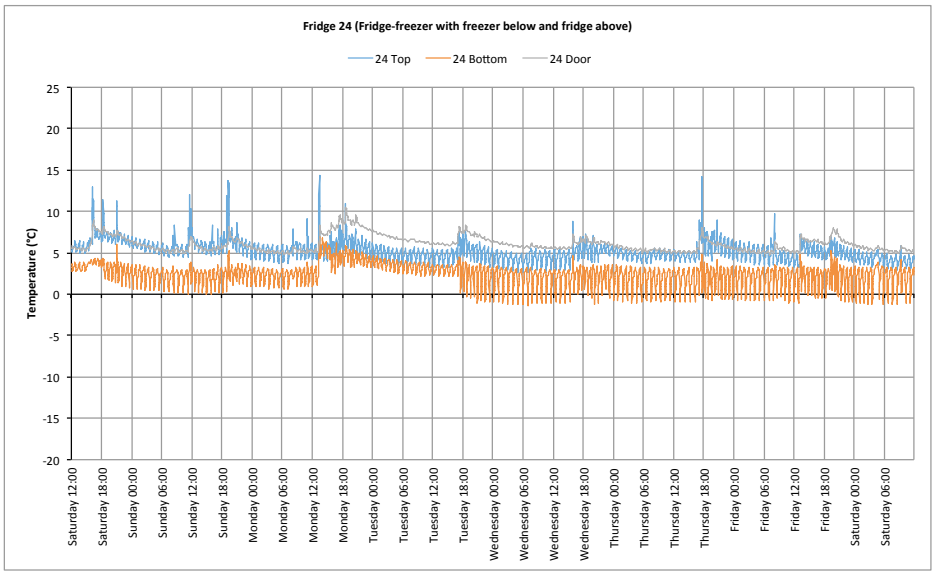
Friday 06:00
Friday 12:00
Friday 18:00
Saturday 00:00
Saturday 06:00


Fridge 24 (Fridge-freezer with freezer below and fridge above)
24 Top
24 Bottom
24 Door
Temperature (°C)
25
20
15
10
5
0
-5
-10
-15
-20
Saturday 12:00
Saturday 18:00
Sunday 00:00
Sunday 06:00
Sunday 12:00
Sunday 18:00
Monday 00:00
Monday 06:00
Monday 12:00
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Friday 06:00
Friday 12:00
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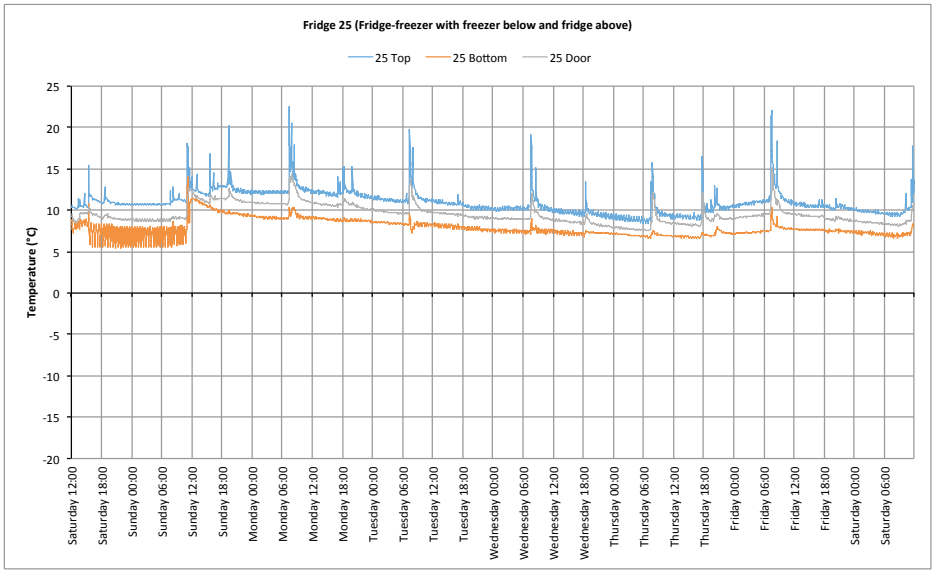
Saturday 00:00
Saturday 06:00


Fridge 25 (Fridge-freezer with freezer below and fridge above)
25 Top
25 Bottom
25 Door
Temperature (°C)
25
20
15
10
5
0
-5
-10
-15
-20
Saturday 12:00
Saturday 18:00
Sunday 00:00
Sunday 06:00
Sunday 12:00
Sunday 18:00
Monday 00:00
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Monday 12:00
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Friday 12:00
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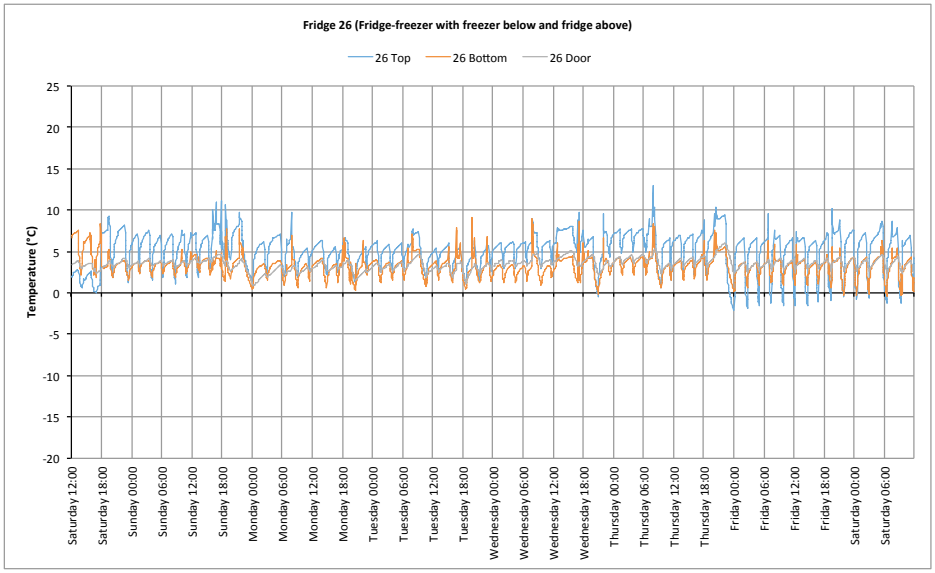
Saturday 00:00
Saturday 06:00


Fridge 26 (Fridge-freezer with freezer below and fridge above)
26 Top
26 Bottom
26 Door
Temperature (°C)
25
20
15
10
5
0
-5
-10
-15
-20
Saturday 12:00
Saturday 18:00
Sunday 00:00
Sunday 06:00
Sunday 12:00
Sunday 18:00
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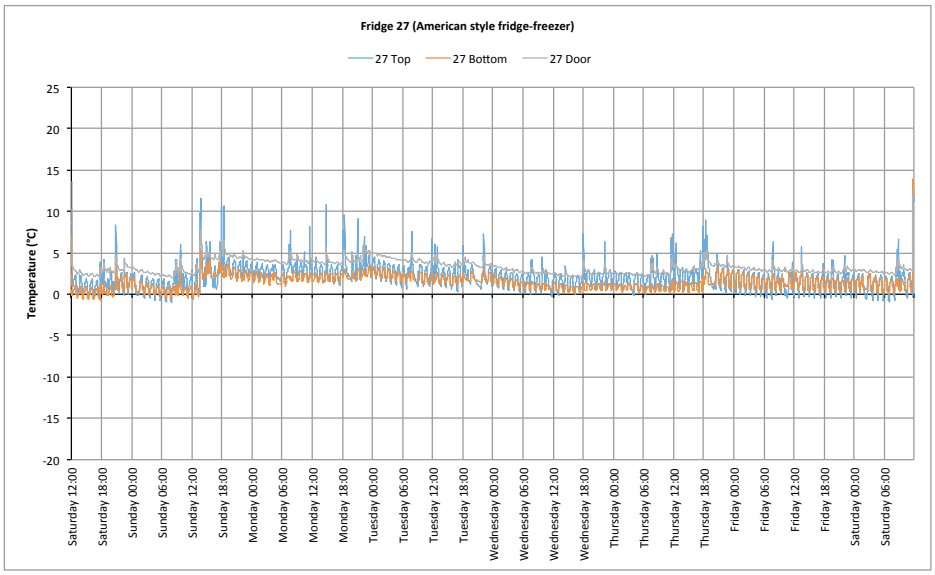
Friday 06:00
Friday 12:00
Friday 18:00
Saturday 00:00
Saturday 06:00


Fridge 27 (American style fridge-freezer)
27 Top
27 Bottom
27 Door
Temperature (°C)
25
20
15
10
5
0
-5
-10
-15
-20
Saturday 12:00
Saturday 18:00
Sunday 00:00
Sunday 06:00
Sunday 12:00
Sunday 18:00
Monday 00:00
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Monday 12:00
Monday 18:00
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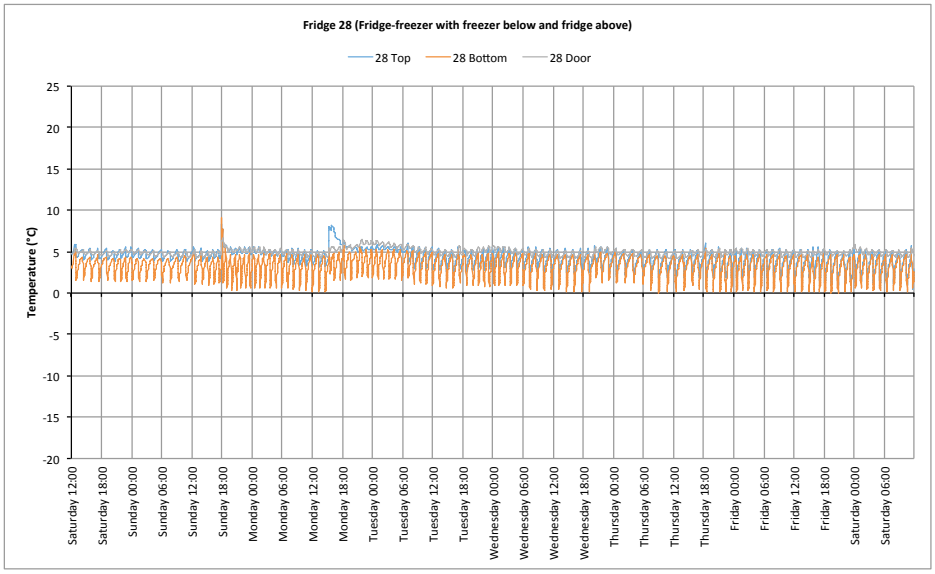
Thursday 06:00
Thursday 12:00
Thursday 18:00
Friday 00:00
Friday 06:00
Friday 12:00
Friday 18:00
Saturday 00:00
Saturday 06:00


Fridge 28 (Fridge-freezer with freezer below and fridge above)
28 Top
28 Bottom
28 Door
Temperature (°C)
25
20
15
10
5
0
-5
-10
-15
-20
Saturday 12:00
Saturday 18:00
Sunday 00:00
Sunday 06:00
Sunday 12:00
Sunday 18:00
Monday 00:00
Monday 06:00
Monday 12:00
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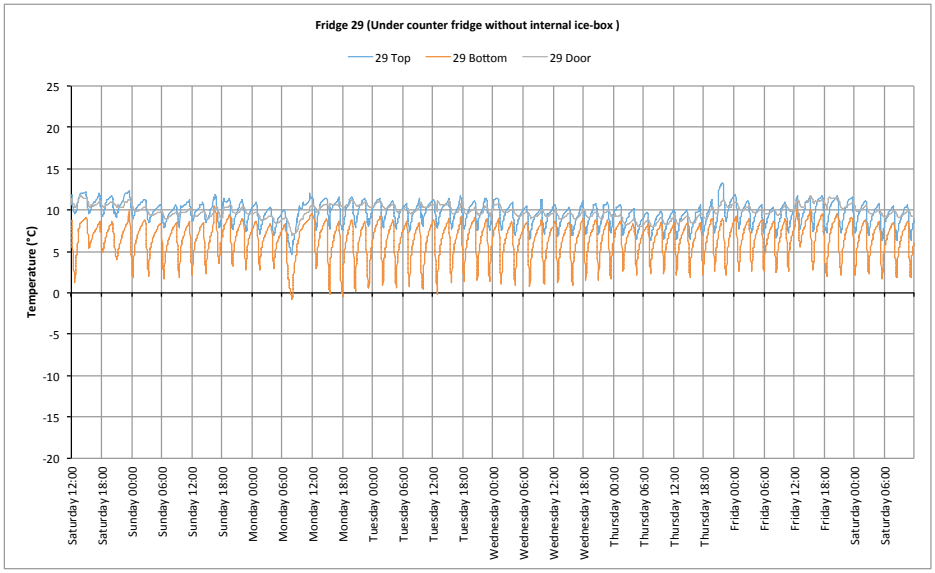
Friday 06:00
Friday 12:00
Friday 18:00
Saturday 00:00
Saturday 06:00


Fridge 29 (Under counter fridge without internal ice-box)
29 Top
29 Bottom
29 Door
Temperature (°C)
25
20
15
10
5
0
-5
-10
-15
-20
Saturday 12:00
Saturday 18:00
Sunday 00:00
Sunday 06:00
Sunday 12:00
Sunday 18:00
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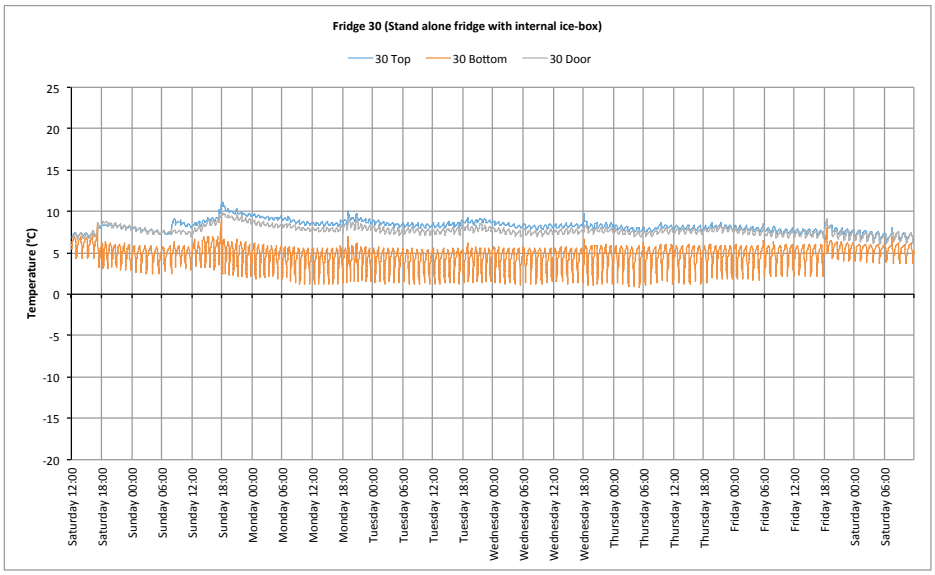
Saturday 06:00


Fridge 30 (Stand alone fridge with internal ice-box)
30 Top
30 Bottom
30 Door
Temperature (°C)
25
20
15
10
5
0
-5
-10
-15
-20
Saturday 12:00
Saturday 18:00
Sunday 00:00
Sunday 06:00
Sunday 12:00
Sunday 18:00
Monday 00:00
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Monday 12:00
Monday 18:00
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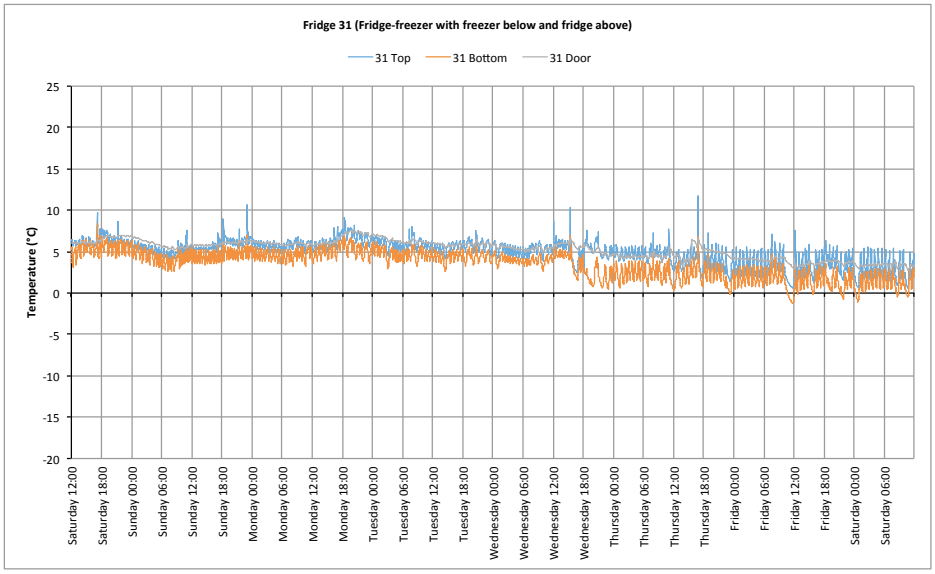
Saturday 00:00
Saturday 06:00


Fridge 31 (Fridge-freezer with freezer below and fridge above)
31 Top
31 Bottom
31 Door
Temperature (°C)
25
20
15
10
5
0
-5
-10
-15
-20
Saturday 12:00
Saturday 18:00
Sunday 00:00
Sunday 06:00
Sunday 12:00
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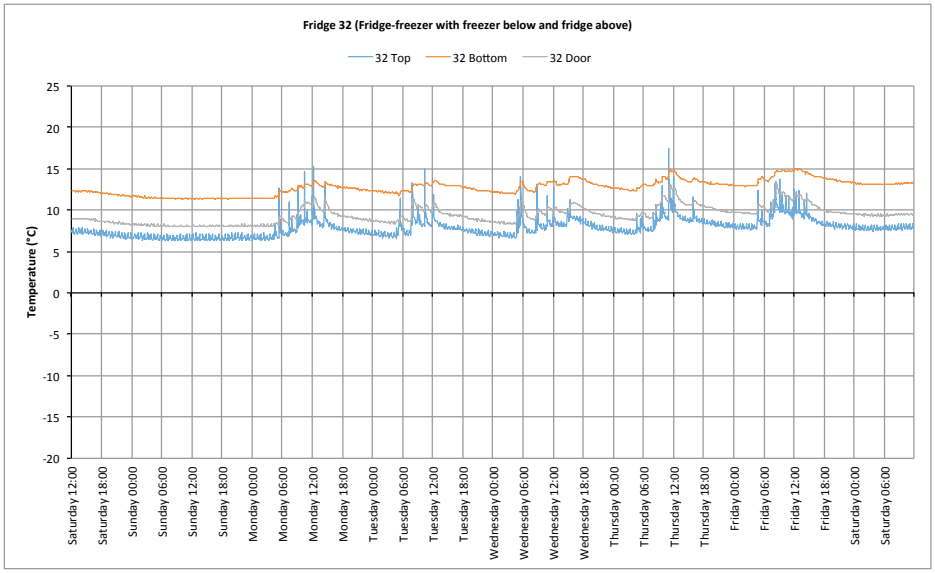
Friday 06:00
Friday 12:00
Friday 18:00
Saturday 00:00
Saturday 06:00


Fridge 32 (Fridge-freezer with freezer below and fridge above)
32 Top
32 Bottom
32 Door
Temperature (°C)
25
20
15
10
5
0
-5
-10
-15
-20
Saturday 12:00
Saturday 18:00
Sunday 00:00
Sunday 06:00
Sunday 12:00
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Saturday 06:00