# Activity Recognition and Temperature Monitoring (ART) Feasibility Study

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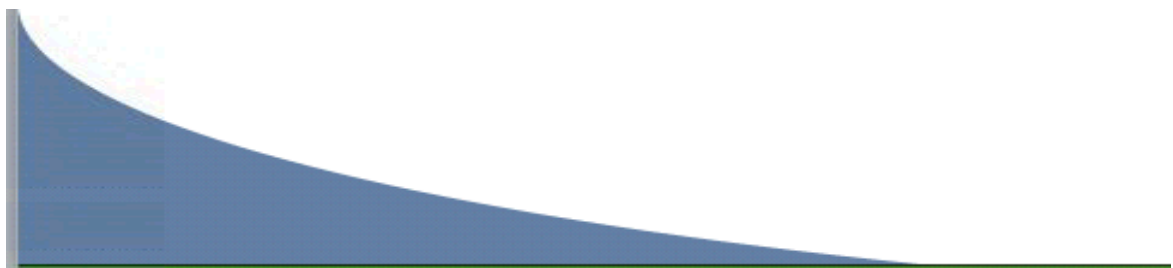# Activity Recognition and Temperature Monitoring (ART) Feasibility Study

Domestic Kitchens and Food Safety: Exploring Practices, Technology and Design

# FINAL REPORT

Contract number: FS244026

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# Executive Summary

Activity recognition and temperature monitoring (ART) devices are an innovation in the capture of synchronised and timed temperature and activity data. This feasibility study aimed to analyse and evaluate the value of ART devices in domestic food safety research for supporting food safety policy.

The objectives of the ART feasibility study were to explore the:
1. technical and operational issues associated with:
   a. deploying ARTs in domestic kitchens, in particular the ease and cost of ART installation and removal by researchers and households;
   b. Processing and analysing ART data
2. value and contribution of ART data (on its own and with other social science data) to domestic kitchen food safety research
3. cost considerations associated with scaling-up ART technology with larger, more representative sample sizes.
4. relevance of the ART findings to the work of the FSA.

Twenty three households were recruited to explore a) the process of deploying (installation, removal and return) ART devices using researcher only deployment (n=13), household only deployment (n=5) and researcher install, and household removal and return (n=5); and b) the data generated by these devices. Three ARTs were located in each household in pre-selected sites associated with domestic food hygiene (and the FSA's 4 Cs campaign), namely: inside the door of the refrigerator (to reflect chilling); the cutlery drawer (to reflect cross-contamination and general kitchen activity); and the hot tap (which cross-cuts a number of the 4 Cs including cleaning hands and cross-contamination). The fourth ART site was household determined.

**Key Findings:**

**ART Deployment**
- Installation of ARTs was generally straightforward for both the research team and participants and no households reported changes to their kitchen practices during ART deployment.
- Only households aged over 80 years expressed a preference (based on personal convenience) for the researcher to install the ART devices, suggesting future ART studies should consider using a mixed (researcher and household) deployment strategy.

**Processing and Analysis of ART Data**
- The analysis of the ART data demonstrated proof of concept in analysing: 1) temperature and activity across multiple time periods from a period of one second to the full data collection period (approximately 12-14 days); and 2) the relationship between temperature, activity and time data.

- For future studies, investments in programming could offer more analytical options in, and speed up, the data analysis process. The use of software with a larger processing and graphical visualisation capacity than Excel (such as MATLAB) is recommended.

**ART Data Capture**
- Data on refrigeration performance was the most promising area of data capture.
- Refrigerator temperature data was captured for all households. There was a loss of 15% of activity data across all appliances, which could be minimised by various means in future studies, such as access to additional ARTs and further software developments.
- Temperature and activity readings were captured from one position within the refrigerator in this study, the interior door. Future studies may benefit from multiple temperature readings from additional static positions within the refrigerator.

**Value of ART Data**
- The findings on refrigerator temperature demonstrate the superiority of ARTs in reporting temperature at a fine level of detail compared with devices used in other published studies.
- The capacity of ARTs to link changes in refrigerator temperature and recovery following the opening and closing of the refrigerator door (an event) provides linked temperature and activity data which has been previously unavailable. These data can facilitate an exploration of how refrigerator activity can influence temperature performance and potentially support the calculation of how long refrigerators are operating outwith of the recommended range (0-5°C).
- Combining data from the 4 sites showed household patterns of activity over days, weeks and the full data collection period but the value of this is unclear.
- Activity data from non-refrigerator sites were of limited value on their own.
- There may be some potential to look at ART data alongside quantitative studies and other fridge specific data.

**Scaling-up**
- The feasibility of using ARTs in future research could best be realised in a scaled up refrigerator study (n=300), capturing data from several positions (4 recommended) within the fridge using a mixed deployment strategy.

**Conclusion**

ARTs have demonstrated technical proficiency in recording refrigerator temperature and activity data and have demonstrated ease of deployment, are unobtrusive when deployed and have superior reading and memory capacity compared to other commercially available temperature logging devices.

The feasibility of using ARTs in future large scale refrigerator studies is therefore demonstrated.

# Contents

# Figures

# Tables

# Acknowledgements

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# Copyright statement

# Chapter 1: Study Background

## 1.1 Introduction

Safer food for the nation is the strategic objective for the FSA[1] (Food Standards Agency 2011) and reducing the burden of foodborne illness is a key part of this goal. Part of FSA's work in this area is focused on food prepared and eaten at home. In late 2011 the FSA commissioned an 18 month study 'Domestic Kitchens and Food Safety: Exploring Practices, Technology and Design', referred to as 'Kitchen Life' (KL). The central aim of this project was to record, analyse and interpret kitchen-based practices, the factors that underlie them, and their potential to impact on food safety. This work is intended to complement the FSA's other work about the domestic setting.

Activity Recognition and Temperature monitoring (ART) devices are a data capture innovation that were originally integrated into the overall Kitchen Life study design. ARTs are an augmentation of more established activity recognition (AR) monitors, which are small, unobtrusive devices that collect data on movement. In previous studies ARs have been placed in several kinds of kitchen utensils such as knives, ladles, spatulas, whisks, peelers and chopping boards (Pham *et al*., 2010; Wagner *et al*., 2011) and on kitchen fixtures and appliances such as cupboards, waste bins and refrigerators (Hooper *et al*., 2012; Thieme *et al*., 2012; Kendall, 2013). Within pervasive computing[2], these studies have enabled: 1) inferences to be made about the level of skill exhibited in the performance of tasks (i.e. quantifying the quality/type of movement associated with for example, chopping, stirring and peeling) (Wagner *et al*., 2011; Ploetz *et al*. 2011a); 2) 'behavioural imaging' which (within pervasive computing) focuses on time sequencing and the performance of tasks (Weeden *et al*., 2011; Kendall, 2013); and 3) an understanding of how the use of space, kitchen design and technology is influencing the way, and order, in which activities are performed within the home (Crabtree and Rodden, 2004; Olivier *et al*., 2009; Kendall, 2013; Comber *et al.,* in press). Through such research, ARs have demonstrated that it is technically feasible to infer knowledge about human behaviour by analysing readings (Mankoff *et al.,* 2002; Robinson *et al*. 2008; Atallah and Yang, 2009; Ploetz *et al*. 2011b).

In the Kitchen Life pilot study, AR devices with temperature monitoring sensors (and hereinafter referred to as ARTs) were initially tested. ARTs have the ability to capture synchronised timed activity and temperature data within one small wireless device. To date, such synchronised data has not been reported in the academic literature. During testing these devices were found to be insufficiently sensitive in responding to temperature fluctuations and so the ART devices were reengineered to include an external high sensitivity thermocouple (see Figure 1.1). The redesign and testing of these ART devices

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[1] The FSA Strategy has since been refreshed; for more information please see http://www.food.gov.uk/about-us/publications/busreps/strategicplan/
[2] Pervasive computing refers to the use of computational devices such as activity recognition monitors that are incorporated in everyday objects and activities. It is a branch of human computer interaction where computing science intersects with behavioural and other sciences.

caused a delay such that the ARTs were only deployed in 2 of the 6 pilot KL households. Nevertheless, the FSA judged it worthwhile to continue exploring the use and data contribution of these devices within domestic food safety research. Therefore an ART feasibility study was designed with revised aims and objectives and separate from the main ethnographic Kitchen Life study[3].

**Figure 1.1: Activity recognition and temperature monitoring (ART) components**
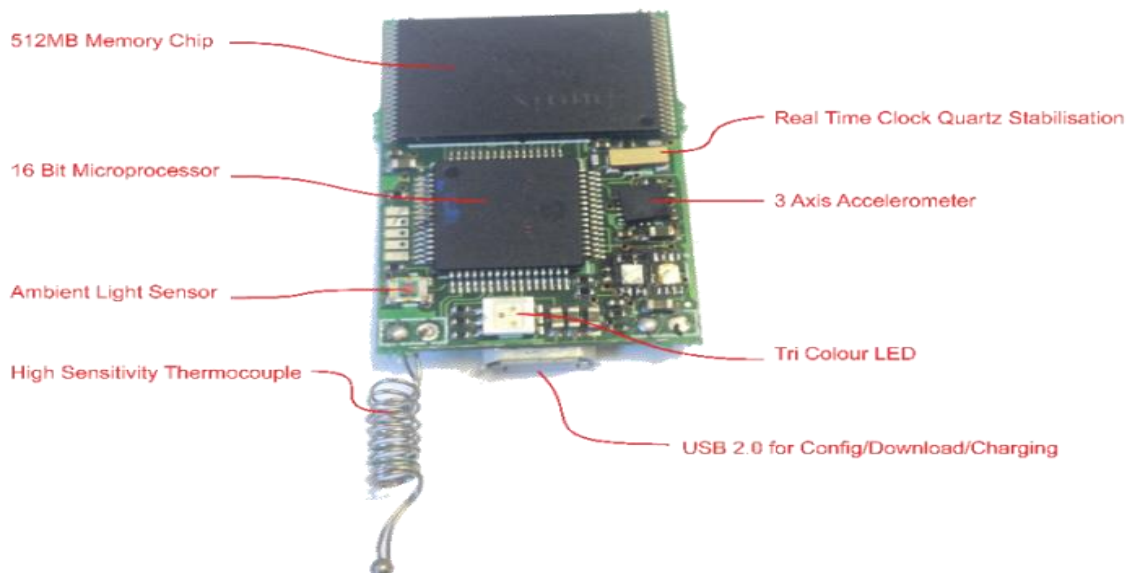


## 1.2   Aim and Objectives

This feasibility study aimed to analyse and evaluate the value of using ART devices in domestic food safety research for supporting food safety policy.

The objectives of the ART feasibility study were to explore the:
1.  technical and operational issues associated with:
    a.  deploying ARTs in domestic kitchens, in particular the ease and cost of ART installation and removal by researchers and households;
    b.  processing and analysing ART data;
2.  value and contribution of ART data (on its own and with other social science data) to domestic kitchen food safety research;
3.  cost considerations associated with scaling-up ART technology with larger, more representative sample sizes; and
4.  relevance of the ART findings to the work of the FSA.

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[3] The findings from the Kitchen Life study conducted by the University of Hertfordshire are published in a separate report.

## 1.3    Report Outline

In addressing the aims above, the remainder of the report is organised as follows:

**Chapter 2: Methods, Approach and Data Capture:** This feasibility study was based upon data generated by 4 ARTs in each of 23 households.  This chapter describes the household recruitment strategies, the siting of the ARTs within the households' kitchens and the methods of ART deployment.  The technical and operational issues associated with the ART data captured, processed and analysed are discussed and thus address objective 1b.

**Chapter 3: Deployment Findings and Feedback:** This chapter describes the technical and operational issues (incorporating household feedback) associated with the deployment of ARTs in domestic kitchens by researchers and households. This chapter addresses objective 1a.

**Chapter 4: Refrigerator and Temperature Activity Findings:** The findings of the temperature and activity data for the refrigerator are presented in Chapter 3.  This analysis which focuses on the refrigerator presents the ART temperature and activity data alongside selected Food and You (2010) data for the KL households. This chapter contributes to addressing objective 2.

**Chapter 5: Activity Monitoring at Other Sites in the Kitchen:** The activity related findings for the tap, cutlery drawer and fourth site are considered separately and in conjunction with each other to consider kitchen routines and the sequencing of activities.  This chapter also contributes to addressing objective 2.

**Chapter 6: Scaling up ART research:** This chapter discusses the rationale and cost considerations associated with scaling-up ART technology to a larger, more representative sample size of 300 households. This chapter addresses objective 3.

**Chapter 7: Discussion:** Based upon the analyses in the preceding chapters, this final chapter discusses the value and contribution of ART data to domestic kitchen food safety research and the potential relevance of these insights to the work of the FSA. In doing so this chapter addresses objective 4.

## 1.4    Report Caveat

This feasibility study examined the efficacy of ARTs as data generation devices in 23 households.  Although the sample size is appropriate for a feasibility study to demonstrate proof of concept for the data generating potential of the ARTs, it is too small for comparative household results, such as refrigerator temperatures, to be statistically significant and thus no inferences should be made about these findings.

# Chapter 2: Methods, Approach and Data Capture

## 2.1 Introduction

This chapter describes recruitment of the 23 households for this feasibility study; the rationale for the use and positioning of 4 ARTs into the kitchens of each household; the ART deployment strategies; details on the data captured by the ARTs including a discussion of data loss; and the data analysis process. Ethics approval for this feasibility study was granted by the Faculty of Science, Agriculture and Engineering Research Ethics Committee at Newcastle University in June 2012. Prior to deploying the ARTs into participating households, the devices were tested and calibrated as explained in Appendix 1.

## 2.2 Household recruitment

Data collection took place between September 2012 and April 2013. Twenty three households were recruited to explore the process of installing and removing the ART devices and the data generated by them. Households were recruited from the Kitchen Life (KL) study and supplemented by participants from previous food research studies carried out by Newcastle University. The 20 households participating in the KL study[4] were invited to participate in the ART study and 13 consented (see appendix 2 for KL consent form). Reasons for non-participation included: unavailability; lack of interest; and reaching the final stages of pregnancy. Within the consenting KL households, the research team installed and removed the ART devices.

To examine alternative methods of deployment (AD) which included researcher installation and removal and household installation, removal and postal return of ARTs, a purposive sample of 10 households was randomly recruited from 2 databases of participants from previous food and nutrition research held by Newcastle University[5]. Recruitment for the 10 AD households followed the sampling principles of the KL study resulting in half of the households falling within the 60+ years age profile. In 5 of the AD households (n=5) the research team installed the ARTs and the household removed and returned them by post. The remaining 5 AD households received the ARTs by post and installed, removed and returned them by post, with no input from the research team.

Overall, the final sample of 23 households included a mix of ages (including those over 60), occupancy, presence of children, pet ownership, working status and regular use of an eating area in the kitchen. While no households with pregnant women[6] consented to participate in

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[4] The KL study participants were drawn from a pool of 800 randomly selected respondents from the FSA's 'Food and You' (2010) survey, who had given permission to be contacted about participating in further FSA funded research. From these 800 18% responded to the invitation to participate in Kitchen Life; 20 households were then purposefully sampled. Age (60yr+) and pregnancy-status were the main selection criteria because of the Agency's interest in groups thought to be particularly vulnerable to foodborne illness. Therefore 10 households recruited included participants aged 60+ years, and the 10 households aged under 60 years included 2 households with pregnant women.

[5] See appendices 5, 6 & 7 for AI recruitment letter, information leaflet and reply slip.

[6] Pregnant women, young children, individuals over 60 and individuals with compromised immunity conditions are all considered vulnerable to foodborne illness by the Food Standards Agency.

the ART feasibility study, households with occupants over 60 (including 3 with occupants over 80 years) did participate in the feasibility study[7].

## 2.3   ART Deployment

Four ARTs were deployed in each household to explore the value of using single and multiple devices.  As the ARTs measure movement, the sites needed to be located on appliances or fixtures that moved, such as a door or drawer.  Three ARTs were located in pre-selected sites and the fourth ART site was selected by the household.  The choice of sites was informed by the FSA's food hygiene campaign that relates to food safety in the home and which is commonly referred to as the 4Cs.  The ART sites were selected to reflect sites associated with the 4Cs precautionary message which advocates: 1) **C**leaning hands properly; 2) **C**ooking food properly, 3) **C**hilling food properly; and 4) avoiding **C**ross-contamination (FSA, 2006[8]).  The sites selected were the:

1)  **Interior-side of the refrigerator door:** This site was pre-selected because the refrigerator is estimated to be a significant factor in 28% of domestic foodborne disease outbreaks (Contor *et al.,* 2009; Kilonzo-Nthenge *et al*., 2008; Ryan *et al*., 1996).  The capability of refrigerators to 'chill' (and slow/prevent pathogen growth) also forms an important link in the wider chain of cross-contamination in the domestic kitchen (Contor *et al.,* 2009; Kilonzo-Nthenge *et al*., 2008; Ryan *et al*., 1996).
2)  **Cutlery drawer:** This site (on either the interior- or exterior side of the drawer) was pre-selected because it is a site associated with general kitchen activity, some of which is related to the preparation and eating of food; frequent touching of the cutlery drawer makes it a potential site for cross-contamination.
3)  **Hot tap:** The ART was placed either on the stem of the hot tap or the hot tap pipe where possible.  This site cross-cuts a number of the 4 Cs including cleaning hands[9] and cross-contamination.  Tap usage is also an indicator of general kitchen activity.
4)  **Fourth site:** The fourth site was determined after consultation with the household and an appliance or fixture commonly used in their food storage, cooking or cleaning (e.g. dish washer) was selected.  The reason for using a fourth site was to assess the potential value added to capturing kitchen activity at household selected sites compared with the other preselected sites.

For the first 6 KL households, the 4th site was selected following analysis (by the ART research team) of transcripts from the qualitative study conducted by the University of Hertfordshire and consultation with the households. For the remaining 7 KL households the

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[7] The KL study also aimed to maximise variation in the sample households by recruiting households that met other, selected criteria, including: who participants lived with (including people's ages and their relationship to the person we wrote to); whether anyone in the household was pregnant; whether anyone received help with cleaning, washing up, preparing food or whether they had meals delivered ('meals on wheels', for example); whether they had any pet/s; any appliances located outside the kitchen; whether they sat and ate regularly in the kitchen; and the type of house they lived in (detached or terraced, for example).

[8] http://www.food.gov.uk/multimedia/pdfs/4cstrategydoc.pdf

[9] Whilst hand-washing guidelines do vary, some best practice recommendations advise washing hands with warm soapy water (CDC, 2013; FSAI, 2013) and hence the preference for siting the ART on the hot tap rather than cold tap where possible.

KL team provided a list of suggested sites for each household based on their analysis of the qualitative data they collected. The ART team discussed the suggested sites with the households and after consultation a 4th site was agreed between the households and the ART research team. The 10 AD households were provided with a list of 4th site options (on AD reply slip; see appendix 7) based on sites that had emerged during data collection with the KL households; this included dishwashers, microwaves freezers, and ovens. The site they reported using most often was selected as their 4th site.

All ARTs were attached to appliance surfaces with a non-marking electrical tape. This system worked in all but one site - the interior door of a modern anti-bacterial lined refrigerator. In this refrigerator, the ART device was supported in an upright position on the top internal shelf of the refrigerator door.

The ARTs were left in participants' homes for approximately 2 weeks. As the devices were continuously recording data during transit and installation a settling-in period was factored in for the ARTs in refrigerators (specifically to allow them to adjust from ambient to refrigerator temperatures[10]). Study data were then extracted from midnight (00:00) on the day after installation until 23.59 on day before removal. This meant that there were approximately 12-14 days of ART data per household. Five households had commitments which meant that devices were installed for shorter (2 households) or longer (3 households) periods. While this impacted on the amount of data captured across households, it was not considered to have had a significant impact on the value of the feasibility findings. That said, this finding suggests that any future studies using ARTs should consider implementing recruitment strategies that ensure a comparable installation period, for example by setting a minimum data collection period and/or over-recruiting households to achieve this.

In total, 16 ART devices were used during the study and data collection occurred in up to 4 households simultaneously. On removal of the ARTs, data were downloaded and the ART devices were visually checked for damage, technically checked for bugs, re-charged, then used for subsequent deployment within other households.

## 2.4 ART Data Capture

The useable refrigerator temperature and activity data from each ART device per household is shown in Table 2.1.

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[10] Data analysis shows the ARTs were recording temperatures of approximately 23°C prior to installation and took about 6 to 10 hours to 'settle' to the median operating temperature of the refrigerator.

**Table 2.1: ART Data Capture**

| HH | ART Location | | | | | No. of devices | No. of days data captured | Data Capture Problem |
|---|---|---|---|---|---|---|---|---|
| | Refrigerator | | Tap | Cutlery drawer | 4th Site | | | |
| | Temp | Activity | | | | | | |
| KL01[11] | ✓ | ✓ | ✓ | X | ✓ | 4 | 13 | Technical |
| KL02 | ✓ | ✓ | ✓ | ✓ | ✓ | 5 | 13 | |
| KL03 | ✓ | ✓ | X | ✓ | ✓ | 4 | 14 | Technical |
| KL04 | ✓ | ✓ | ✓ | ✓ | ✓ | 5 | 16 | |
| KL05 | ✓ | ✓ | ✓ | X | ✓ | 4 | 23 | Technical |
| KL06 | ✓ | ✓ | ✓ | ✓ | ✓ | 5 | 18 | |
| KL07 | ✓ | ✓ | ✓ | ✓ | ✓ | 5 | 13 | |
| KL08 | ✓ | ✓ | ✓ | ✓ | ✓ | 5 | 13 | |
| KL09 | ✓ | ✓ | ✓ | ✓ | ✓ | 5 | 13 | |
| KL10 | ✓ | ✓ | ✓ | X | ✓ | 4 | 12 | ART availability |
| KL11 | ✓ | ✓ | ✓ | ✓ | ✓ | 5 | 13 | |
| KL12 | ✓ | ✓ | ✓ | ✓ | ✓ | 5 | 13 | |
| KL13 | ✓ | ✓ | ✓ | ✓ | ✓ | 5 | 13 | |
| AR[c]14 | ✓ | ✓ | ✓ | ✓ | ✓ | 5 | 13 | |
| AR15 | ✓ | X | X | ✓ | ✓ | 3 | 13 | Technical and household interference |
| AR16 | ✓ | X | ✓ | ✓ | ✓ | 4 | 12 | Technical |
| AR17 | ✓ | ✓ | ✓ | ✓[a] | ✓ | 5 | 13 | |
| AR18 | ✓ | X | X | X | ✓ | 2 | 10 | ART availability and household interference |
| AH[d]19 | ✓ | X | X | ✓[b] | X | 2 | 13 | Technical and household interference |
| AH20 | ✓ | ✓ | ✓ | ✓ | ✓ | 5 | 6 | |
| AH21 | ✓ | ✓ | ✓ | ✓ | X | 4 | 14 | Researcher error |
| AH22 | ✓ | ✓ | ✓ | ✓ | ✓ | 5 | 13 | |
| AH 23 | ✓ | ✓ | ✓ | ✓ | ✓ | 5 | 12 | |
| Total | 23 | 19 | 19 | 19 | 21 | 101 | | ART data were captured at 101 of the planned 115 sites across the 23 households. |

[a] Household had no cutlery drawer thus ART was placed on the grill, an alternative frequently used appliance

[b] The hot water tap was inefficient at producing hot water so the kettle was used to heat water for use in the kitchen, including for hand-washing. The ART was therefore placed on the kettle.

[c] AR refers to researcher installed and household removed and postal returned ARTs

[d] AH refers to household installed, removed and postal returned ARTs

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[11] KL household numbers do not align to those used in the KL study

All ART devices were returned (by post) by AD households which provided a full data set from which the useable data were assessed. However, in a larger scale study, 100% returns would be unlikely and we surmise that this 100% return rate reflects the high motivation of the Newcastle University food research database members whose inclusion is based upon a willingness to participate in research. Second, refrigerator temperature data were available for all 23 households and useable activity data were available for 78 of the 92 sites across the 23 households, equating to 91% of activity data across all appliances. Nine percent of the total data were missing or unusable due to technical reasons, household interference, ART availability and researcher error (more detail on each, below). On final analysis, 14 of the 23 households had full and usable data sets.

### Technical problems

A firmware bug on the devices which related to the storing of the timestamp was found after fieldwork. This affected data from 6 households (3 x KL and 3 x AD households) and therefore data were excluded from the reported results. Only the activity data were affected by this bug. The continuous temperature data were unaffected and so this has been analysed and included in this report. In future ART studies this specific problem could be dealt with through further software development.

### Household interference

Anomalies in the ART data suggest there may have been some household interference such as removing, handling and reattaching the ARTs to their original sites. This occurred in 4 households in the AD study. The data affected can be seen in Table 2.1. An additional reason for deducing household interference is that none of the 4 households reported problems with their ARTs during deployment (such as devices becoming detached). One potential reason for household interference may be curiosity. The devices incorporate a small battery light which flashes when turned on and this feature may encourage participants to inspect the device. No temperature data were missing due to human interference, possibly because the devices collecting this data were out-of-sight. To minimise household interference, future deployments should encourage inspection only on the day of installation and request no removal until final day of deployment.

### ART Unavailability

Due to a software bug with one of the devices following its return, only 3 devices were available for redeployment into 2 households (numbers 10 and 18). Therefore data were missing for these households. The lack of replacement devices was a limitation and indicates the need for spare devices in future studies to minimise data loss due to unavailability of devices.

### Researcher Error

For one AD household, one of the 4 devices was not turned on by the researcher prior to posting the devices and therefore no data were recorded on the device for that site. Researcher error could be minimised in a larger study (involving more researchers) by improving researcher procedural checklists.

It is worthwhile noting that the batteries worked for the full duration of all the deployments including one household where the ARTs were in situ for 23 days. The ART batteries are expected to work for approximately 28 days. In addition, in all but one case the devices remained securely in place for the full data collection period. One household replaced the device after it fell off their cutlery drawer and reported no problems after that. This incident did not seem to adversely affect the data captured by this device.

## 2.5   Other data

To explore the potential complementarity and value offered by ART data to other streams of social science data and to support the objectives of this study, the ART generated data was supplemented by the following data:

1. **Household profile data:** This included type of dwelling (detached, semi-detached, flat etc.); the number, age and employment status of adults; children in the household; pet ownership; using an eating area within the kitchen - this information was available for the full sample of households (n=23). Such data were used to explore possible relationships between refrigerator temperature and specific household characteristics. The small sample size meant that an analysis of this type could only be exploratory as the sample size did not support the identification of be statistically significant relationships.

2. **Kitchen go-along transcripts:** Transcripts of household-led guided tours of KL kitchens, which are referred to as 'kitchen go-alongs', were available for 6 of the KL households. These data and their subsequent analysis by the ART research team supported the identification of potential $4^{th}$ site locations in the households and facilitated the consideration of the relationship (where appropriate) of this qualitative data to the ART data.

3. **Food and You (2010) responses:** KL households were matched to their Food and You (2010) responses. Responses to questions relating to refrigerator-based knowledge and practice were extracted to consider the value of looking at social survey data, in conjunction with ART generated temperature data.

4. **Household feedback on ART deployment:** Household feedback on installation, removal and postal return was sought from all households where appropriate. These data gave an insight into household tolerance for the ARTs and their thoughts on mode of ART deployment. It also established whether participants thought that their practices changed as a consequence of ART deployment (see Appendix 8 for feedback questions). The KL households were also provided with a one page summary of their ART results. Feedback on this letter (collected by the KL research team from the University of Hertfordshire) was used to inform recommendations for the future use of such letters in future scaled up ART research (see Appendix 4 for questions relating to ART results letter).

## 2.6    Data analysis

Raw data from the ARTs were extracted as .cwa files and processed into .csv files for importation into Excel[12]. Prior to starting the analysis, a number of decisions were made about how to interpret the data.

The completed open <u>and</u> close action associated with the refrigerator door and/or cutlery drawers and the turning on <u>and</u> off of kitchen taps were defined as an 'event'. Where similar patterns of activities are observed over a number of days, these were referred to as 'routines'.

A decision also had to be made about the time periods in which events were analysed. Bar charts showing the number of events over a specific time period give a visual representation of the number and length of activities occurring in the kitchen. Where patterns of activities are observed over a number of days, it was possible to identify similar patterns across different days indicating that potential routines were being performed. For the purpose of this study, events were recorded within the one hour time period in which they occurred. These time periods could have been shorter (for example every 30 minutes or 15 minutes), but for proof of concept purposes they were kept to the hour. Therefore, for a household using the kitchen at quarter to the hour and finishing kitchen-based activities half an hour later at quarter past the hour, these activities would be captured in bar charts representing activity taking place across 2 one-hour blocks.

Clearly using a shorter time reporting period would give a more accurate and finer visual representation of these regularly repeated activities or routines.

**Data analysis per ART location**

The data analysis process started with analyses of the ART data per site and per household. Per site, the refrigerator data were analysed first. Refrigerator temperature data were collected at a rate of 25 temperature readings per second (which was the capacity of the ARTs), but a median temperature was returned for every one second[13]. This was based on the assumption that human activities were likely to be performed at the level of seconds rather than milliseconds. The reporting of the temperature data for analysis could have been at any time period determined by the researcher as the ARTs can be programmed to return data at different time intervals. In other refrigerator temperature performance studies (See table 7.1), the lowest rate of data capture using commercially available temperature data loggers was once every 8 seconds (Evans *et al*, 1991).

Every temperature and event recorded was time- and date-stamped which facilitated the tracking of temperature changes during and after an event. The temperature data were analysed in terms of median temperature and minimum and maximum temperature ranges per day and over the full data collection period. Based upon these findings, additional temperature analysis was undertaken for selected household to estimate the amount of

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[12] It is recommended that future studies consider using alternative software such as Matlab as Excel is restricted in the amount of data that it can process into graphical format (i.e. max of 32,000 data points).
[13] For each day, 86,400 temperature readings were returned corresponding to one for every second.

time their refrigerator recorded temperatures above 5°C and 10°C – i.e. outside of the recommended refrigerator temperature range. Refrigerator temperature and activity data were also linked by examining temperature fluctuations during an event and the length of time taken for refrigerator temperatures to recover following an event.

Median temperature for the full data collection period for KL households were also considered alongside the Food and You (2010) survey responses from each of the KL households, namely responses to refrigerator specific questions. This enabled the research team to consider the potential complementarity and contribution, if any, that ART data could make to this FSA evidence source.

Activity data were represented by the number of events captured at each site. Although data could be reported over any duration (for example per hour, day, week etc.), summary data over the full recording period is provided within this report. This included the maximum and minimum number of events across the reporting period for each ART site, the average duration of the events at each site (e.g. how long the (hot) tap was running or the fridge door open) and the average time the site was in use per 24 hour period.

**Data analysis per household**
Within households, the time periods in which activities occurred at the 4 different ART sites were compared within a 24 hour period. These daily periods of activity were compared across different days to identify the potential presence of routines.

Finally, the order in which kitchen-based activities occur may have an impact on food hygiene practices. For example, hand-washing would be recommended as best practice prior to preparing food. Therefore, the potential to use ARTs to examine the sequence in which kitchen-based fixtures and appliances are used was explored by analysing the order in which events occurred across the sites within a particular time frame.

## 2.7   Analytical Reflections

The small sample size and decisions relating to: a) the reporting of activities in specific time periods; b) manual analysis in Excel; and c) problems encountered in data capture have resulted in a number of issues that need to be considered in future ART kitchen based studies. These include:

- Using a sample size with sufficient power to yield results with statistical significance (and building in potential data loss), which are discussed in more detail in Chapter 4.
- Reducing the potential for data loss through: additional software development to minimise bugs; purchasing additional ARTs for replacement (damage and possible loss) purposes; developing researcher checklists for deployment; and asking households to inspect ARTs prior to installation rather than during operation.
- Making a priori analytical decisions about the length of time (1 hour/ 30 minutes / 15 minutes) in which activities are reported.

# Chapter 3: ART Deployment Findings and Feedback

## 3.1 Introduction

Three different installation and removal combinations were trialled (see Table 3.1) to explore the ease, cost and household experiences of researcher and self-installation and removal of ARTs. These deployment findings are reflected upon with the aim of informing potential future ART studies.

**Table 3.1: Installation and removal combinations tested**

|  | Installation | Removal |
|---|---|---|
| **13 KL Households** | Research Team | Research Team |
| **5 AD Households** | Research Team | Household removal and postal return |
| **5 AD Households** | Sent out by post and installed by household | Household removal and postal return |

## 3.2 Researcher deployment

For the KL households and 5 AD households where the research team installed the ARTs, no problems were encountered except with the refrigerator in household 6 and with the installation of ARTs on the hot tap pipes which are discussed below.

*Researcher Installation – Problems with Refrigerator*
Household 6 had a modern high end refrigerator with an antibacterial coating. This prevented the ART device being taped to the internal door and instead the ART had to be supported by a condiment jar on the top internal door shelf. Although this was not considered problematic to household 6, it does pose an increased likelihood of potential interference or damage, though none was noted in this case. This also suggests the need to consider possible alternative designs and/or methods for deploying ARTs in modern, antibacterial lined refrigerators.

*Installation of ARTs on Taps*
The placement of the ARTs on the hot taps was considered problematic by the research team due to the hot tap pipes being located at the back of low level, under sink cupboards which can be difficult to reach. For this reason, the decision was taken following the problematic installation of ARTs on the hot pipes of the first 3 households to install the remaining ARTs on the stem of the hot tap (n=1) or mixer tap (n=18) (See appendix 10 for tap positions selected). This, however, raised analytical concerns. ARTs on a mixer tap can only distinguish when water is flowing and not whether the water is hot or cold. It is possible that the current ART devices could be reengineered to have this capability. Given the importance of handwashing to domestic food safety management; it is argued that such a development may be a worthwhile consideration for future ART research.

## 3.3   Household deployment and feedback

*Household Installation*

The ART devices were sent out by first class post to the 5 AD households selected to self-install. No problems were reported with this method of delivery. Each self-installation AD household received a comprehensive ART installation and removal guide (See appendix 11). None of the 5 households contacted the research team during the installation and removal. They reported that the guide was easy to follow and no problems were experienced during installation and removal.

*Household removal and postal return*

All AD households removed the ART devices themselves (using the removal guide provided). Nine of the 10 households posted the ART devices back in pre-paid special delivery envelopes. All these households confirmed that they had easy access to a post office and mailed the package as required. A 1<sup>st</sup> class stamped addressed Royal Mail pre-paid padded envelope was provided to the 10<sup>th</sup> household as they were unable to easily access a post office. All packages were received by the research team on the expected day. No problems were encountered by the research team in the removal of the ART devices in the KL households.

*Household Feedback*

Feedback was sought from households in relation to the installation and removal of the ART devices. This feedback was gathered for the KL households when the devices were being removed by the research team and, for the AD households, after the devices were returned by post. Specific questions asked included: the length of time taken to install and remove the ARTs and if this was acceptable (AD households); whether or not households altered their behaviour whilst the ARTs were installed; and whether or not they found the ARTs intrusive (See Appendix 8).

Overall, there was little or no expectation from households of what the ART devices would be like; no households reported any changes to their kitchen routines during data collection though it is not possible to verify whether any actual changes took place; no hygiene or other safety concerns were reported as having arisen from installation of the ARTs in the refrigerator; and the majority of participants were confident to receive the ARTs by post, install them and return them by post. The exception was participants aged over 80 years, who expressed a preference for researcher installation, if presented with this choice, as they considered it more convenient for them and their circumstances. For the AD households, no problems were reported with the packaging and postal arrangements. It was highlighted by one household that the guidance documents could have been printed double sided to save paper.

## 3.4   Cost analysis of trialled ART deployment

Table 3.2 outlines the estimated costs for each of the 3 deployment techniques trialled in the ART feasibility study. The higher costs associated with the research team deployment

are due to the additional staff time and travel costs associated. A breakdown of the cost categories is provided in appendix 12.

**Table 3.2: ART installation costs**

| Installation/Removal Technique | Estimated cost/household |
|---|---|
| Researcher install/removal | £2050 |
| Researcher Install/Household Return by post | £1590 |
| Postage of ART devices and Self install/removal. | £1200 |

## 3.5    Feedback on results letter sent to households

In order to understand the value of the results letter sent to KL households, approximately 12 weeks following ART removal, the KL research team contacted all KL households to ask for feedback based on the questions outlined in Appendix 8.  Overall, the KL households found the feedback letter easy to follow and understand.  A few households questioned the accuracy of the results including the number of days used in the calculations (n.b. the day of installation and removal is not reported as they don't constitute a full 24 hour reporting period) and whether the data may have been influenced by pet dogs barking or jumping up and down. A few households did not see the relevance or contribution of measuring activity and in particular activity associated with the tap and cutlery drawer. The households, in general, found the results interesting though some were surprised, or questioned the level of activity reported for some sites. One household noted that they would have expected FSA guidance on recommended refrigerator temperature to accompany such a letter.  Although the value of results is mixed, the format used in this study is appropriate to convey the top line results.

## 3.6    Deployment Reflections

This feasibility study has demonstrated that ARTs can be installed (adhered to a surface with tape) and removed with relative ease by both researchers and households.  However, the preferences of households aged 80+ years for researcher installation indicates that future ART deployment strategies would need to be tailored to the sample's characteristics (with increased researcher resource to accommodate researcher installation preferences).

The study findings also suggest that presence of ART devices does not change self-reported kitchen-based routines.  However, as noted in Table 2.1, data interference through possible handling of ARTs during deployment at non-refrigerator sites suggests future ART research participants should be encouraged to only inspect the ARTs prior to installation.

The provision of feedback to research participants, which can be a requirement of ethics approval, was acceptable in the format presented.  Although some households queried the results, the main recommended change to the information provided is the inclusion of guidelines on refrigerator temperature range.  Feedback also suggests that the 12 week timeframe for reporting results is appropriate for future studies.

# Chapter 4: Refrigerator Temperature and Activity Findings

## 4.1 Introduction

This chapter presents an overview of the key findings from the ART Feasibility study that relate to refrigerator temperature, activity and performance. Readers are reminded that temperature and activity results are not statistically significant and instead should be interpreted only as indicating the types of data analysis that can be performed.

## 4.2 Refrigerator temperatures

Calculating the median operating temperature of refrigerators is important to understanding refrigerator performance. Median temperature can be calculated from ART data across different time periods. To illustrate, for the 23 households, the median refrigerator temperature was calculated for each day (24 hour period) and across the full data collection period. Figure 4.1 plots the distribution of median refrigerator temperature for each household for the full data collection period. Four households had median refrigerator temperatures within the recommended temperature range of 0-5°C. The median refrigerator temperature across all 23 households was **8.2°C.** Furthermore, 3 distinct refrigerator temperature groups emerged:

1. Those with median refrigerator temperature within the recommended operating range of **0-5°C** (4 households)
2. Those with median refrigerator temperatures between **6°C and 9.5°C** (17 households)
3. Those with median refrigerator temperature of **over 13°C** (2 households)

To check the accuracy and consistent of the temperature readings for each household it is necessary to calculate the standard deviation of the median refrigerator temperature. In this study the standard deviation ranged from 0.3-1.8°C. For example, the standard deviation for household 18 was 0.85 denoting that, if a normal distribution is assumed, 95% of the temperature readings recorded across the data collection period where within ±0.85°C (3.75-5.45°C) of the median refrigerator temperature (4.6°C). This provisionally indicates statistical confidence in the accuracy of the temperature readings captured by the ART devices.

It is technically possible to infer the temperature range and magnitude of difference between the minimum and maximum temperatures for refrigerators. To illustrate, across the households, the minimum and maximum refrigerator temperatures were recorded and some variation was observed. The minimum refrigerator temperatures recorded ranged from **-1.9 to 11.8°C** and maximum temperatures ranged from **9.2 to 18.0°C**.

**Figure 4.1: Median refrigerator temperatures per household (n=23)**
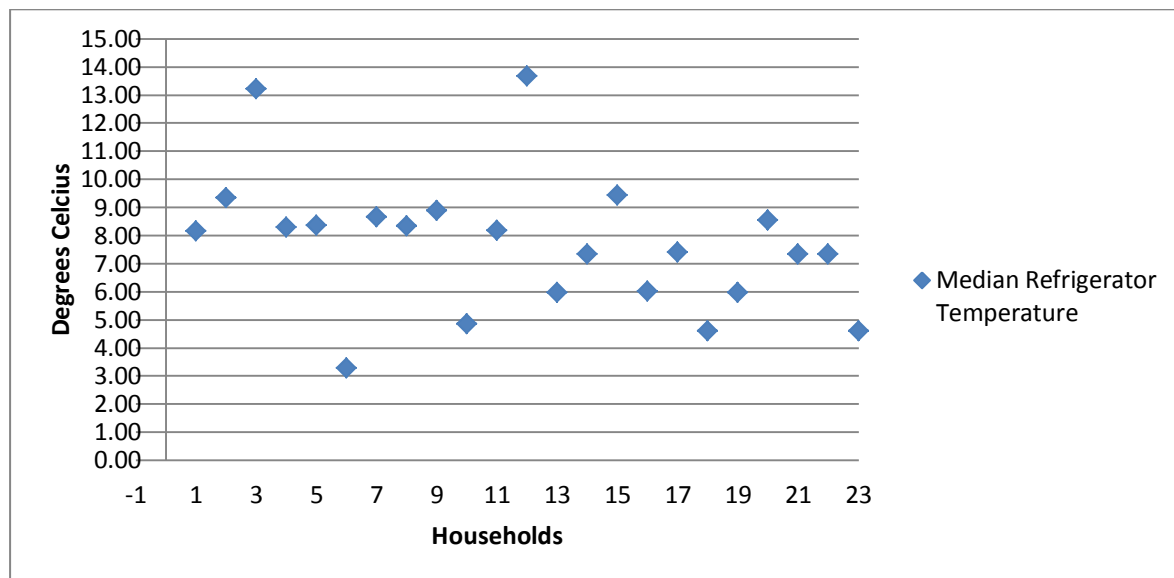


Using the data collected across the full collection period, the magnitude of the differences between the minimum and maximum temperatures recorded ranged from 3.3°C and 17.3°C. As with median refrigerator temperatures, 3 distinct groups of households emerged: 1) those with a temperature range of **≤ 5°C** (4 households); 2) those with temperature range of between **5-10°C** (11 households); and 3) those with a temperature range of **> 10°C** (8 households). Interestingly, the 8 households with the largest temperature range (> 10°C) were found to have the lowest median operating temperatures with a group median refrigerator temperature of 5.4°C. This was lower than the other groups who had group median operating temperatures of 8.1°C (≤ 5°C range – 4 households) and 8.2°C (between 5-10°C range – 11 households) respectively.

Explanations for these differences could not be statistically inferred from such a small sample size. However, evidence from previous studies suggests refrigerator temperature performance can be influenced by: age and type of refrigerator (refrigerator only, with incorporated ice box, fridge-freezer combination); condition of door seals; type of shelves (solid or wire which impact air flow); position within the kitchen or other space (i.e. in direct sunlight); and ambient air temperature (Peck et al., 2006; Kim, Keoleian and Horie, 2006; James et al., 2008; George et al., 2010). Future research should consider more explicitly the relationship between these factors and refrigerator temperature performance.

Given the importance, from a food safety perspective, where 5°C is the recommended upper refrigerator operating temperature (at this temperature the majority of foodborne pathogens are unable to grow), it was considered insightful to explore, using the ART data, how often (within a day and across a number of days) refrigerators in the 4 households with median operating refrigerator temperature of ≤ 5°C recorded temperatures above the upper 5°C level. For each household, the total number of minutes during which the refrigerator recorded temperatures >5°C was recorded. For illustrative purposes, figure 4.2

presents the number of minutes during which the refrigerator in Household 6 recorded temperatures >5°C, over the full data collection period (18 days).

**Figure 4.2: Minutes per day household 6 refrigerator exceeded 5°C**
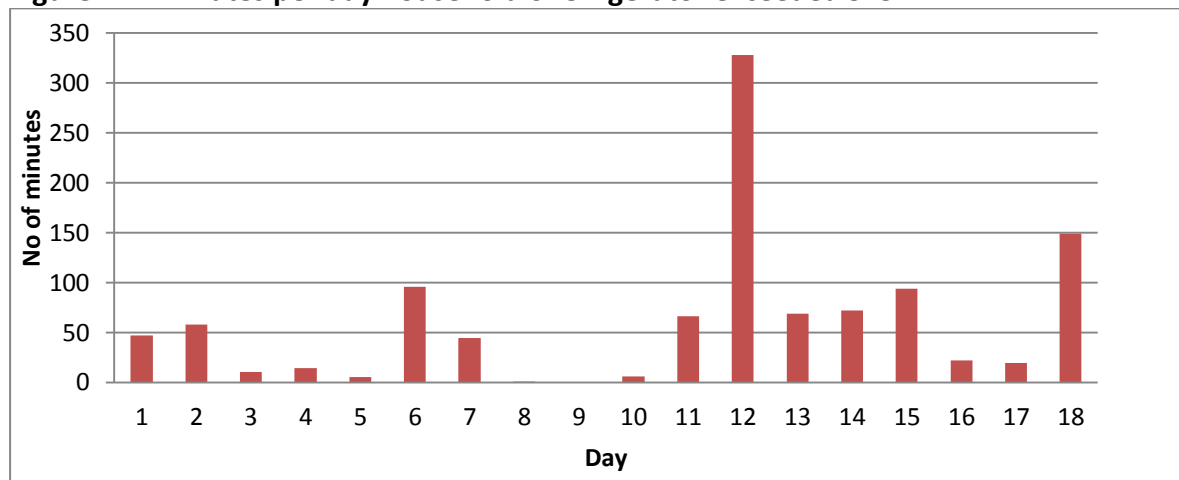


The median refrigerator operating temperature for household 6 was 3.3°C (with a min/max range of > 10°C namely -1.92°C to 11.4°C). The refrigerator was found to be operating at temperatures > 5°C for on average 45 minutes per day.  Temperature data were collected for 18 days and across this time period the refrigerator was found to be operating at temperatures >5°C for a total of 1098 minutes (18.3hrs).  This represented 4.2% of the total time (25920 minutes; 432hrs; 18 days) during which temperature data were collected.  This analysis also showed that during days 8 and 9 when the household was on holiday, the 'resting' refrigerator temperature (when no activity was recorded) remained below 5°C with a median operating temperature over those 2 days of 2.7°C.

In future studies, time-temperature analysis (as described above) could also be conducted to calculate the length of time domestic refrigerators were operating at different temperature points deemed to be a high priority by stakeholders. One temperature point which could be deemed a high priority for such analysis is 10°C. There is increasing concern amongst food safety experts of the role and contribution to food spoilage and foodborne disease (in the refrigerator) of pathogenic bacteria known as psychrophiles and psychrotophs. These bacteria are known to thrive at low temperatures and some have optimum growth rates as low as 10°C (Morita, 1975; Schofield, 1992). Listeria Monocytogenes, a high priority foodborne pathogen for the FSA (FSA, 2011), is a notable example of a psychrophic pathogen (Schofield, 1992; Gandi & Chikindas, 2007). Using ART data, it was possible to undertake such time-temperature analysis. Household 8 had a median operating refrigerator temperature of 8.3°C. Refrigerator temperatures were recorded at ≥ 10°C for 9.2% (1720mins) of the total data collection period (i.e. 13 days; 312 hrs; 18720mins).

## 4.3    Refrigerator activity and temperature recovery

Table 4.1 presents a synthesis of the activity and temperature recovery results across the households for which refrigerator activity data were available. As noted earlier, refrigerator

activity is reported as an event, where an event is defined as a completed open and close action associated with the refrigerator door.  The results are presented as a range from the lowest to the highest calculated across the households for each measure.

**Table 4.1: Refrigerator Activity**

| Activity and temperature recovery measures | Range |
| --- | --- |
| Minimum and maximum number of refrigerator events[14] per day | 1 - 60 |
| Average no. of refrigerator events per day | 9-32 |
| Minimum and maximum length of  refrigerator event | 1-61sec |
| Average length of a refrigerator event | 12-33sec |
| Average time the refrigerator was active per day | 2-13min |
| Minimum time taken for refrigerator to recovery to within 5% of start temperature following an event | 1-41sec |
| Maximum time taken for refrigerator to recovery to within 5% of start temp after an event | 97-123sec |
| Average time taken for refrigerator to recovery to within 5% of start temperature following an event | 58-96sec |
| Maximum temperature fluctuation during an event | 1.1-7.6°C |
| Mean temperature fluctuation during an event | 0.2-3.6°C |
| Minimum temperature recorded at the start of an event | 0.2-9°C |
| Maximum temperature recorded during an event | 11.2-17.3°C |
| % proportion of total activity recorded at the refrigerator | 17-58%[15] |
| Average % proportion of total activity recorded at the refrigerator across the households (n= 18) | 38% |

The synchronised, time stamped temperature and activity data made it possible to examine refrigerator temperature recovery following an event (opening and closing).  This was measured by calculating the length of time between the refrigerator being opened and the time taken following refrigerator closure for the internal temperature to recover to within 5%[16] of the start temperature (see Figure 4.3).  As illustrated in Figure 4.3, refrigerator temperature recovery was shown (as expected) to be non-linear in nature. The bulk of the temperature recovery took place soon after the completion of the event.  Across the 23 households, refrigerator recovery time ranged from 1-123 seconds with an average recovery

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[14] An event is defined as a completed open and close action associated with the refrigerator door and or cutlery drawers, and the turning on and off of kitchen taps.

[15] These data will be discussed in more detail in chapter 5 when considered alongside the data for the other sites and within the discussion about whether the fridge can act as a proxy site for activity within the wider kitchen.

[16] In calculating the refrigerator recovery time, a cut-off point of 95% temperature recovery was applied as it was determined to statistically represent the point at which the majority of temperature recovery had taken place. Given that the average temperature fluctuation recorded during an event ranged from 0.2-3.2°C, it can be assumed that, based on 95% temperature recovery, the refrigerator temperatures had recovered to within 0.01-0.16°C of the recorded start temperature. This tolerance range was deemed acceptable for the purposes of this study.

time of between 58-96 seconds. The non-linear nature of refrigerator temperature recover reinforced the efficacy of choosing a 95% cut off point for temperature recovery as Figure 4.3 illustrates how the vast majority of temperature recovery happens very soon after the event has been completed (the refrigerator door is closed).

Figure 4.3 illustrates the refrigerator recovery process by presenting a selected 5 minute period from Day 1 in household 1. This outlines what the refrigerator recovery process looked like for a specific event and highlights how the majority of the temperature recovery takes place within approximately 40 seconds of the event ending. During this time, 2 refrigerator events happened in quick succession. The combined length of the 2 events was 19 seconds. The temperature recorded at the start of the first event was 8.17$^o$C. The temperature rose to a maximum of 8.7$^o$C during the events. It took 90 seconds for the refrigerator temperature to recover to within 5% of its starting temperature. The median refrigerator temperature for household 1 was 8.16$^o$C.

**Figure 4.3: Temperature recovery following refrigerator event in Household**
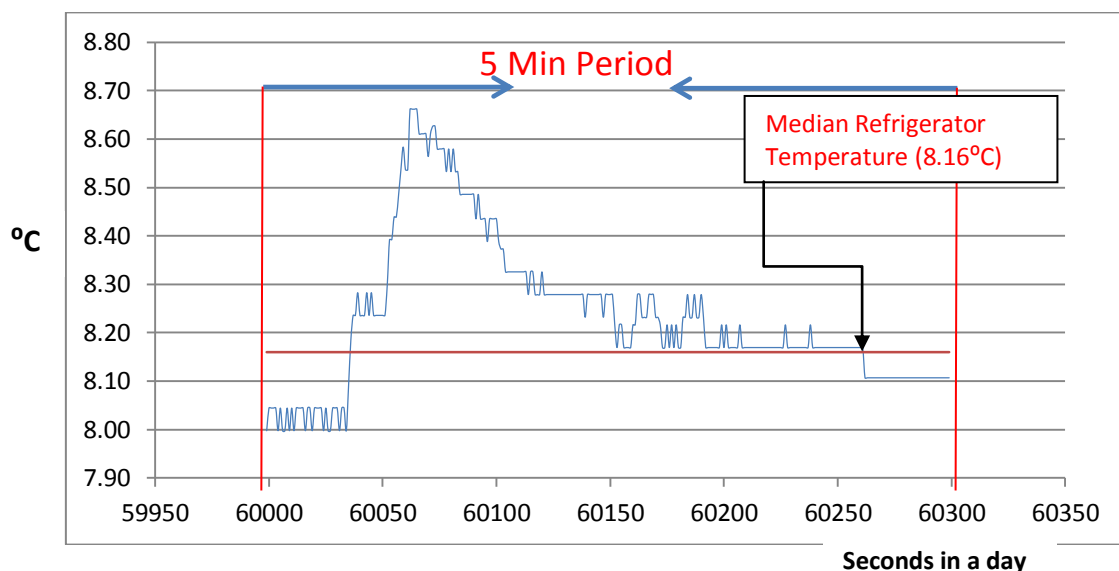


Figures 4.4 and 4.5[17] illustrate how activity, temperature and time can also be analysed and presented simultaneously to demonstrate the daily and weekly relationship between the number of refrigerator events, the average length of a refrigerator event (in seconds) and the median daily refrigerator temperature, using household 11 as an example.

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[17] For household 11, data were collected for 13 24 hour periods. As a result, not all days are calculated using two full days of activity and temperature data. For household 11, only one full 24 hour data set was available for Wednesday.

**Figure 4.4: Daily refrigerator activity and temperature for household 11**
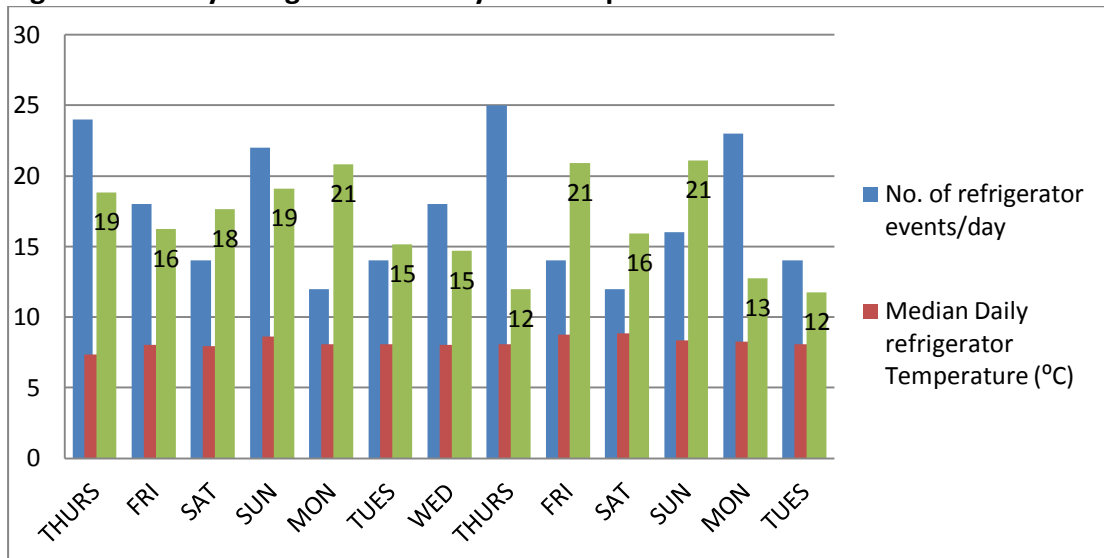


**Figure 4.5: Weekly refrigerator activity and temperature for household 11**
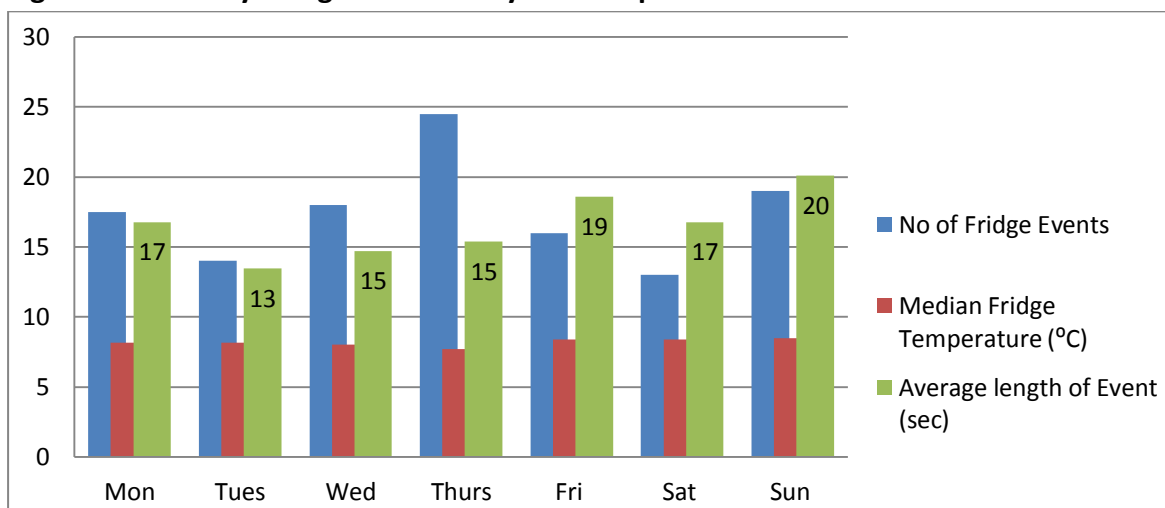


This type of analysis can be conducted at multiple levels of aggregation such as at the level of: a single event; a specific hour period, a specific time period (morning; afternoon; evening; peak activity times), daily (Figure 4.4), weekly (Figure 4.5) or across the full data collection period. Such analysis produces a timed activity picture for each household's refrigerator and suggests that there is potential to use ART data, on its own or in combination with other types of data, to explore refrigerator routines and to assess the impact, if any, that such routines may have on the temperature performance of the refrigerator.

Similar analysis was conducted using the refrigerator activity and temperature data for household 6. It was identified that on day 12 there was an increase in temperature following an increase in activity the day before. Between 10pm-1am on days 11 and 12, there were 11 refrigerator events recorded. This was higher than usual for this household based on the

activity analysis performed across all days and time periods. The median operating temperature of the refrigerator in household 6 rose from 3.3°C on day 11 to 4.4°C on day 12 (See Figure 4.2).

Supplementary qualitative data from the KL study, which was available for household 6, provides some possible explanation: the household reported in the transcript (provided from the 'kitchen tour' conducted by the University of Hertfordshire team) that they typically shop for food late at night because it suits their routine and the supermarket is less busy. Thus the activity recorded at the refrigerator between 10pm-1am on days 11 and 12 may have been associated with loading the refrigerator with shopping. This may explain the higher refrigerator temperatures due to both opening and closing events and the effort required of the refrigerator to cool down the recently introduced food to the normal median refrigerator operating temperature. The refrigerator was found to have spent longer than usual above 5°C on Day 12 (328mins compared to the average of 45minutes calculated for this household). There was also a similar increased level of refrigerator activity identified late at night on day 18 which could indicate a food shopping trip approximately one week later.

This type of analysis illustrates how the length of refrigerator events can vary between days and may indicate that different types of refrigerator related events are taking place on different days and during different time periods during the day. These may include: the loading of shopping; cleaning; and routine refrigerator usage associated with getting food/drinks out of the refrigerator for use in meal preparation. However, building such a picture of kitchen practices is only possible if ART data are analysed in conjunction with other social science data. One alternative option may be to collect ART data alongside social survey data; this option is discussed further later in the report.

## 4.4 ART refrigerator data and Food and You Data

Table 4.2 presents selected refrigerator data from Wave 1 of the FSA Food and You Survey for each KL household alongside the median refrigerator temperature calculated for each household using the ART data. The responses provided by each KL household to 5 key refrigerator questions were extracted from the survey data and they related to: reported knowledge of recommended refrigerator temperature ranges; whether, with what device and how frequently the household reported checking (if at all) their refrigerator temperature and the type of refrigerator they owned.

**Table 4.2: Refrigerator and 'Food and You'**

| Household | Reported recommended refrigerator temp. (Q4.12) | ART median refrigerator temp. | Do you check your refrigerator temp? (Q4.9) | Frequency of checking refrigerator temp. (Q4.) | How do you check refrigerator temp? (Q4.11) | Type of refrigerator (Q4.)[18] |
|---|---|---|---|---|---|---|
| 1 | DK | 8.2°C | No | N/A | N/A | FSF |
| 2 | DK | 9.4°C | Yes | At least daily | Feel food | FIF |
| 3 | DK | 13.2°C | Yes | Once/month | Feel food | FFSD |
| 4 | 0-5°C | 8.3°C | No | N/A | N/A | FSF |
| 5 | 10°C+ | 8.4°C | No | N/A | N/A | FFSD |
| 6 | 0-5°C | 3.3°C | Yes | At least daily | Use external thermometer | FFSD |
| 7 | DK | 8.7°C | Yes | At least daily | In built display | FSF |
| 8 | 5-8°C | 8.3°C | No | N/A | N/A | FFSD |
| 9 | 0-5°C | 8.9°C | Yes | Once/month | Use external thermometer | FFSD |
| 10 | DK | 4.9°C | No | N/A | N/A | FNF |
| 11 | DK | 8.2°C | Yes | < 1/ week – > once/month | In built display | FFSD |
| 12 | 0-5°C | 13.7°C | Yes | 1-2 a year | In built display | FSF |
| 13 | 0-5°C | 6°C | Yes | Once a week | In built display | FFSD |

Due to the small sample size of the ART Feasibility study, it is not possible to infer whether there are any statistically significant relationships between the Food and You and ART data. However, this is something which could be considered in future studies, if the FSA deem it of interest to explore such possible associations. To illustrate, exploratory analysis was conducted to demonstrate possible relationships between self-reported data, ART data, type of refrigerator owned and other demographic/profile data. Potential relationships, worthy of further examination with a statistically significant sample were identified and these included potential relationships between refrigerator temperature & activity and the: number of household occupants; regular use of eating area in the kitchen; reported knowledge of best practice guidelines; the presence of pets and children; number of refrigerator activities; home ownership; age and type of refrigerator and reported practice of checking refrigerator temperature.

The answers to this and other emerging questions (detailed in chapter 7) are likely to be complex and multifactorial. Past refrigerator temperature studies have highlighted a range of factors that may impact on refrigerator temperature and recovery performance. Taking insights from both the ART Feasibility Study and past studies, Table 4.3 outlines these factors. Future analysis, with a statistically significant sample size, would allow for the testing of differences between households with respect to one or a combination of these factors. Recommendations are made in Table 4.3 as to how the data required for each

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[18] FSF: Fridge separate freezer; FIF: Fridge integrated freezer; FFSD: Fridge freezer with separate doors; FNF: Fridge no freezer

factor could be collected.  Due consideration has been given to the feasibility of collecting such data in a scaled up study.

**Table 4.3: Factors that potentially influence Refrigerator performance**

| Factors | Evidence | Data Source |
| --- | --- | --- |
| **Reported knowledge of recommended refrigerator operating temperature range** | Exploratory analysis of Food and You, household profile and ART data | Self reported via survey |
| **Reported practice of checking refrigerator temperature** | George *et al.* (2010) and Exploratory analysis of Food and You, household profile and ART data | Self reported via survey |
| **Device used to monitor refrigerator temperature** | George *et al.* (2010) | Self reported via survey and photographic taken by researcher/household on installation of ARTs |
| **Variation of temperature between different sites within the refrigerator under 'real kitchen life' conditions** | James and Evans, 1992; Sun, Singh and O'Mahoney, 2005 | Multiple ARTs installed in refrigerator |
| **Number and length of refrigerator events** | Exploratory analysis of Food and You, household profile and ART data | ART data from the refrigerator |
| **Age of the refrigerator** | Peck *et al.,* 2006; George *et al.,* 2010 | Self reported via survey |
| **Type and capacity of refrigerator** | Laguerre & Flick, 2010; George *et al.*, 2010, Exploratory analysis of Food and You, household profile and ART data | Self reported via survey and/or photographs taken by researcher/household on installation of ARTs |
| **Person/Organisation responsible for refrigerator maintenance and/or replacement** | Exploratory analysis of Food and You, household profile and ART data | Self reported via survey |
| **Type of shelves within the refrigerator (solid or wire)** | George et al., 2010 | Photographs taken by researcher/household on installation of ARTs |
| **Condition of the refrigerator door seals** | George *et al.,* 2010 | Photographs taken by researcher/household on installation of ARTs |
| **Positioning of Refrigerator** | George *et al.*, 2010 | Photographs taken by researcher/household on installation of ARTs |

This exploratory analysis demonstrates the potential value of considering multiple types of data in order to develop a more holistic view of refrigerator temperature performance[19]. Such a multifactorial examination could support policymakers in prioritising potential intervention and/or communication options aimed at improving the temperature performance of domestic refrigerator and minimising the amount of time domestic refrigerators are operating outwith of recommended guidelines.

## 4.5    Reflections on refrigerator findings

ARTs are a technology that provide temperature readings based on tightly bounded standard deviations.  They have superior capacity to existing technology with respect to frequency of readings taken (25 readings/second), the number of readings they can store and in their ability to unobtrusively collect time-stamped, synchronised temperature and activity data.  One limitation of the feasibility study was that temperature readings were collected from only one location within the refrigerator, namely the inside of the refrigerator door. It is argued that refrigerator temperatures can vary between different parts of the refrigerator (Laguerre et al, 2002; 2007; Laguerre & Flick, 2010) with Laguerre and Flick (2004) demonstrating that for an empty refrigerator, the temperature can typically vary by 4°C.  This may explain why the median refrigerator temperature for the ART feasibility study is outside the range reported by these studies and in particular those that collected temperature data from multiple sites.  However, it is also worth noting that some refrigerator performance studies have only examined temperatures within refrigerators that don't contain food (Laguerre and Flick, 2004).  Future ART refrigerator studies should consider the collection of temperature data from multiple sites (i.e. top, middle, bottom shelves and from inside the door) within the refrigerator.

The age of refrigerators has been a problematic area for refrigerator temperature performance studies as households often find it hard to estimate the age of their refrigerator or do not know the age because they were not responsible for purchase, typically inheriting the refrigerator from previous households.  Exploratory data from Kendall (2013) suggests that ARTs may be sensitive enough to trace the rhythm of refrigerator recovery cycles and these cycles are thought to be linked to refrigerator age. This analysis was not part of the agreed remit of the FSA ART feasibility study though may prove valuable to undertake in future scaled up ART studies. There may also be potential in looking at ART data alongside social survey data

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[19] A detailed discussion of the full range of factors which are considered to influence refrigerator temperature performance is presented in chapter 7

# Chapter 5: Activity Monitoring Findings from Other Sites in the Kitchen

## 5.1    Introduction

In this chapter, activity monitoring findings for the tap, cutlery drawer and 4th site locations are examined and their value assessed.

## 5.2    Appliance usage

The date and time-stamping of ART data shows: when (the hour period) the appliance or fixture was in use; the frequency with which the appliance or fixture was used (calculated by counting the number of events in a 24 hour period); the length (sec) of each event; and the total length of time the appliance or fixture was active (e.g. the number of minutes that the refrigerator door was open or the tap was turned on in a 24 hour period).  These data are illustrated for the tap, cutlery drawer and 4th site respectively as a demonstration of ART data possibilities only.  The reader is again cautioned against making any inferences from the summary data which are not statistically representative at the population level due to the small sample size.

**Tap**

Table 5.1 shows activity data for the taps based upon a sample of n=19 households (see Table 2.1).  The data show that the tap was turned on for a minimum of 1 second and maximum of 55 seconds across all households, and the average length of time the tap water was running was between 15 and 25 seconds.  The average number of times the tap events (tap was turned on and off) across the sample ranged from 4 to 32 times in a day.  However, the tap data must be treated with caution as the complexity of differing tap formats makes it difficult to assess the usefulness of this type of activity data (for more discussion see Chapter 3).

**Table 5.1: Key tap activity results (n-=19 households)**

| Key activity measures - Tap | Range |
|---|---|
| Minimum and maximum number of tap events/day | 1-55 |
| Average number of tap events/day | 4-32 |
| Average length of a tap event | 15-25 sec |
| Average time the tap was active/day | 1-12min |
| Proportion of total activity recorded at the tap | 6-40% |
| Proportion of total activity recorded at the tap across the households | 18% |

**Cutlery Drawer**

Table 5.2 shows activity data for the cutlery drawer based upon a sample of n=19 households (see Table 2.1).  The data show that the cutlery drawer was opened for a minimum of 1 second and maximum of 56 seconds across all households.  The average number of times the cutlery drawer was opened and closed across the sample ranged from 4 to 47 times in a day. What can be inferred from these data alone, is fairly limited.

**Table 5.2: Key cutlery drawer activity results (n=19 households)**

| Key activity measures Cutlery Drawer | Range |
|---|---|
| Minimum and maximum number of cutlery drawer events/day | 1-56 |
| Average number of cutlery drawer events/day per | 4-47 |
| Average length of a cutlery drawer event | 10-33sec |
| Average time the cutlery drawer was active/day | 1-12 min |
| Proportion of total activity recorded at the cutlery drawer | 15-42% |
| Proportion of total activity recorded at the cutlery drawer across the households | 26% |

**Fourth site**

The 4th site differed across households with the most frequently chosen site being the freezer (n=8 households), followed by the dishwasher (n=7), the microwave (n=6), the oven (n=1) and the washing machine (n=1). Due to the sites being different, the patterns of usage were non-comparative. However, to understand if the 4th site was contributing to an understanding of the presence of overall activity within the kitchen, the proportion of activity associated with each of the 4 sites was determined per household. This analysis was conducted on 14 households for which full data sets were available (see Table 2.1) and is shown in Table 5.3. The data shows that it is difficult to draw conclusions from the data in Table 5.3 as the contribution of the 4th site to total activity varies across households.

It is worth noting however, unlike the tap, that activities associated with the top 3 4th sites (freezer; dishwasher; microwave) are all tightly related to the primary function of each appliance namely: storage (freezer); cleaning (dishwasher) and cooking (microwave) respectively. In all cases, there are very few alternative reasons why these appliances would be used other than for the purpose that they are primarily intended. Based upon these reflections, ARTs may be suitable for use in future studies if there is interest in measuring activity levels (and potentially freezer temperatures) associated with these appliances.

**Table 5.3: 4th Site Activity**

| 4th Site | Range |
|---|---|
| Proportion of total activity recorded at the freezer (n=6) | 4-16% |
| Proportion of total activity recorded at the dishwasher (n=3) | 23-26% |
| Proportion of total activity recorded at the microwave (n=3) | 17-27% |
| Proportion of total activity recorded at the oven (n=1) | 41% |
| Proportion of total activity recorded at the washing machine (n=1) | 9% |

## 5.3   Activity patterns

**Routines**

As with the fridge data, activity data from individual sites and in combination can be analysed at the level of the event, hour, day, week and deployment duration. Analysis of daily activity data can clearly show temporal household routines. To illustrate this, randomly selected data for household 4 (Figure 5.1) shows distinct periods of activity during day 6 of installation. This activity pattern is repeated across the duration of the

deployment, although the number of hours and the time of day across which the activity occurred varied.  These routines corroborate and are enriched by the self-reported practices derived from analysis of the transcripts from the Kitchen Life study (see Chapter 2).  For example, householder 4 is an octogenarian male who has routines across all aspects of his life.  He typically rises between 8am and 10am depending on how late he went to bed, and will prepare porridge (cooked in the microwave) and toast or a sandwich for breakfast.  The mid-day meal, which is typically eaten around 1pm is comprised of meat or fish accompanied by vegetables and potatoes.  These are usually defrosted and reheated portions of prior batch-cooked food.  The evening meal is described as 'light' and mainly involves heating or reheating soups and cooking eggs.  These activities are reflected in the times at which activities occur and the appliances which are in use as shown in Figure 5.1.  This analysis faces similar issues to those raised earlier, in Section 4.4.

**Figure 5.1: Time Period analysis of events for Day 6 in household 4**
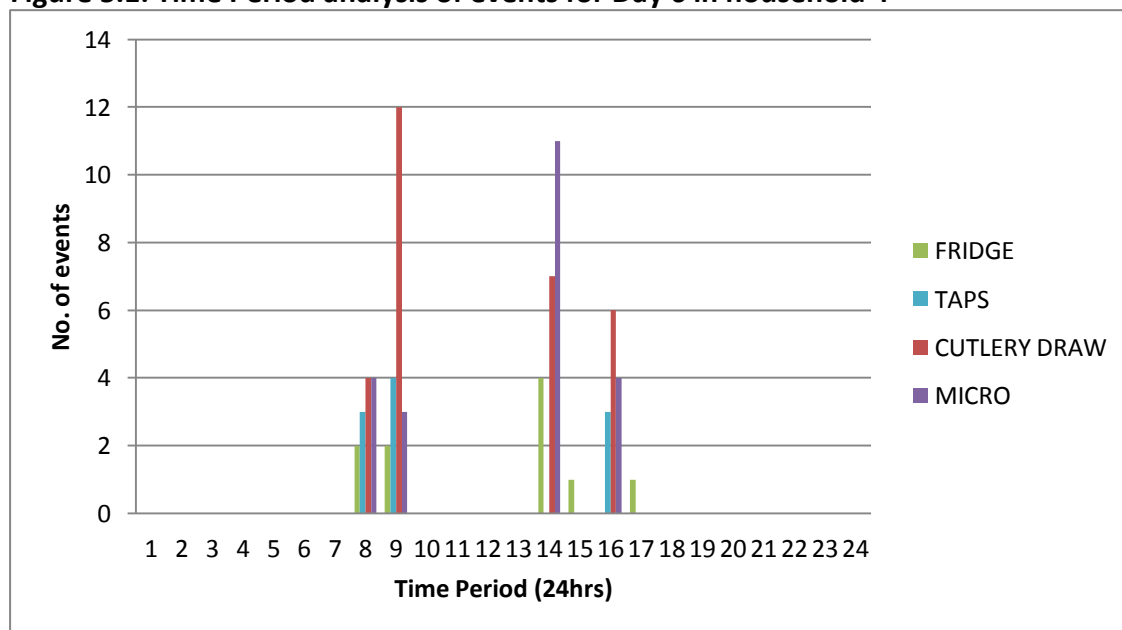


**Sequencing**

Event sequencing analysis allows researchers to establish the order that events are taking place and whether any events are taking place simultaneously across the sites.  The sequencing of activities is important for understanding if and for how long, there are interactions between the objects or things used in a period of activity.  An example of such an interaction is hand-washing prior to and after handling food which is consider important to avoid cross-contamination of pathogens.  This study illustrates the potential of ARTs to give details of sequencing and also the length of time households interact with the sites on which the ARTs are attached.  For example, Table 5.4 illustrates the activity recorded sequence of events in the morning of day 7 (Wednesday) for household 14.

Although a lack of tap usage is notable between 07.11 and 08.32, no further meaning can be layered upon this data without contextual information. For example, although a lack of tap usage suggests hand-washing has not been performed, we have no understanding of what

activities were performed prior to kitchen activity (for example hand-washing in a bathroom), nor if foods were touched when the refrigerator was opened and closed. This is a significant limitation of ART data without other information being available.

**Table 5.4: Sequence of AR activity for household 14**

| Site | Time | Length of event (Sec) |
|---|---|---|
| Cutlery drawer | 07:11:16 | 18.42 |
| Refrigerator | 07:11:32 | 33.75 |
| Cutlery drawer | 07:11:44 | 18.20 |
| Refrigerator | 07:12:06 | 17.25 |
| Refrigerator | 07:12:23 | 4.00 |
| Refrigerator | 07:57:42 | 3.00 |
| Refrigerator | 08:32:50 | 3.00 |
| Refrigerator | 08:32:54 | 27.75 |
| Taps | 10:11:21 | 12.54 |
| Taps | 10:11:33 | 14.54 |
| Taps | 10:11:47 | 20.97 |
| Refrigerator | 10:17:32 | 5.50 |
| Refrigerator | 10:18:34 | 4.25 |
| Refrigerator | 10:18:38 | 12.25 |
| Cutlery drawer | 10:20:03 | 18.41 |
| Cutlery drawer | 10:20:24 | 18.84 |

## 5.4    Activity-based reflections

ART activity data can provide insights into the time periods during which kitchen based activities occur and the synchronisation of activities associated with the fixtures and appliances to which ARTs are attached. However, a limitation of ART activity data on its own is the lack of context relating to who is undertaking the activity and why.

# Chapter 6: Scaling up the ART Research

## 6.1   Introduction

Previous studies have recommended the need for a large scale, statistically significant domestic refrigerator temperature study to be conducted in the UK to establish the temperature performance of domestic refrigerators. It has also been recommended that future studies should, where possible, collect activity data for the refrigerators under investigation (George et al., 2010). This ART feasibility study has demonstrated the efficacy of using ART devices for such scaled up refrigerator performance research; the ART devices tested have been shown to have the capacity to unobtrusively collect accurate, synchronised and timed temperature and activity data. That said, scaling up the use of ART technology is not without its challenges. The FSA asked the research team to consider these challenges and to estimate the costs associated with scaling-up ART technology for use with statistically significant sample sizes. These are discussed below.

## 6.2   Scaling Up considerations and estimated costs

Table 6.1 details the key challenges considered central to the scaling up of ART research. The justification and recommendations are informed by the findings of this feasibility study, the critical reflections of the research team and using evidence/recommendations from past domestic refrigerator temperature monitoring studies (See Table 7.1).

**Table 6.1: Scaling up Challenges**

| Categories | Justification of Scaling up Recommendations | Recommendation |
|---|---|---|
| **Sample Size** | Based on the evidence from earlier studies (see table 7.1), it is advised that a minimum sample size of **300** should be considered for future, scaled up ART studies. This would exceed the sample size of the best practice studies reviewed. | **N=300** |
| **Length of Study** | Based on the evidence (see table 7.1), it is advised that ART devices should be installed in homes for a minimum of 9 days (to support collection of 7 full 24hr data collection periods). Weekly median refrigerator temperatures were also calculated to investigate whether differences in median refrigerator temperature vary week on week. Across the 23 households, few differences were found with an observed difference of --0.7$^o$C to 0.3$^o$C calculated between the week 1 and 2 median refrigerator temperatures. As such, a 9 day data collection period is likely to be sufficient for measuring median refrigerator temperature. That said, a scaled up 9 day study may not be sufficiently long enough to capture fridge activity associated with a main food shop as 15-18% of households interviewed in the 2010 and 2012 Food and You surveys respectively reported doing their main food shop less frequently than once per week. In addition, it would be more difficult to establish routines if only one data set per weekday is available. The recommendation, therefore, is for a **16 day** data collection period to be adopted. This would allow for the collection of 14 full 24hr data collection periods. This would increase confidence in the temperature and activity results and support better identification of fridge activity routines including those associated with main food shopping. | **16 days (including day of installation and removal)** |
| **Range of data monitoring sites** | The recommendation is that future ART studies should focus on monitoring activity and temperature at the **refrigerator** only. The monitoring of other kitchen sites was found to have limited value. That said, other sites of specific interest to chilling and cooking (such as the freezer and microwave) which are primarily associated with one type of activity (i.e. chilling of food; heating of food and drink) could be considered for future monitoring if they were assessed to be of priority to the FSA. | **Refrigerator only** |
| **No of devices for monitoring temperature** | Based on the available evidence (see table 7.1), it would be advisable to monitor temperature at multiple points within the refrigerator due to known temperature variations that occur within a refrigerator. It is advised that temperature readings, using multiple ART devices, are taken from the top, middle and bottom shelves and from inside of the door (as done in this feasibility study). The mean refrigerator temperature should then be calculated combining the data captured across the multiple sites. Such an approach would provide a more robust calculation of mean operating refrigerator temperature and support a comprehensive study, under 'real life' conditions, of temperature variation within domestic refrigerators. | **4 devices** |
| **Devices** | No further technical refinement of the ART devices is required. Consideration is needed though to improve the aesthetic look of the devices and the affixing options available to overcome any potential problems associated with sticking devices to the inside walls of the refrigerator. These developments are designed to help reduce the likelihood of household interference. | **Improve aesthetics and affixing options** |
| **Software development** | Developments are required to improve:<br>1. The FridgeMon software used to charge, prepare and download data to address the researcher error and technical problems encountered. These developments have already started (outwith of the feasibility study)<br>2. The speed and automation of data processing. This support fast, reliable analysis of the ART data, would allow for key | **100 days development recommended.** |

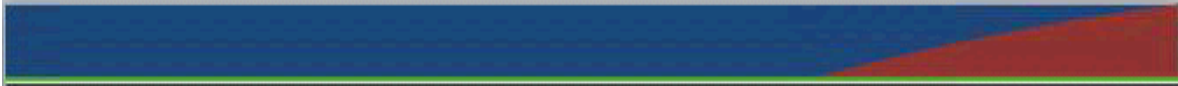| | results to be automatically calculated during the data processing stage and would reduce the amount of manual data analysis. | |
|---|---|---|
| **Installation methods** | The recommendation is to adopt a mixed installation approach in a scaled up ART study. The option of researcher/household installation should be offered to all potential participating households. This approach would have cost implications though it would maximise flexibility to respond to householder needs thus improving the range of household types that could be included in a scaled up ART sample. The sample size could be increased to accommodate the likelihood that some devices may not be installed properly (via household installation) and that data may either not be collected at all or may be found to be unusable. Based on the feasibility study and after the technical problems encountered are resolved by software developments (outlined above), over recruitment of between 5-10% (12-25 households) extra households should be considered to ensure a useable final sample of 300. | **Mixed Approach to suit household preferences and needs.** |
| **Return method** | Consideration should be given though to whether it is necessary to use special delivery packages which require posting at the post office as this may prove difficult for households in a scaled up sample spread over a wider geographic area and with a greater diversity of household specific needs. Using normal Royal Mail services would extend the time during which packages are in transit and may result in devices getting lost in the postal system though this will be countered by a reduction in postal costs. | **Consider using standard Royal Mail services** |
| **Damage/Loss** | No devices were damaged during the deployment (installation, data collection, removal or posting) process, either by the research team or the participating households. Technical problems led to a few devices being unavailable for the full data collection period resulting in 2 households only having 3 devices installed. After careful consideration and in line with other AR type studies, it is recommended that in a scaled up study, a loss/damage rate of 10% should be factored into calculations and extra devices ordered at the start of the study to ensure that damaged/lost devices can be easily and quickly replaced. | **Build in a 10% loss/damage rate** |
| **Additional Data e.g. profile records, video; photographs)** | In line with the recommendations listed in Chapter 4, it is recommended that additional data on the refrigerator in each household is collected including: age; type and capacity, responsibility for maintenance and replacement; condition of seals (reported/photographs); type of shelves; reported practice of checking temperature and the type (and location) of temperature monitoring devices; and reported knowledge of recommended operating refrigerator temperature range. | **Additional fridge specific data should be collected from all participating households.** |
| **Link to other Survey research** | It is recommended that future scaled up ART studies could be linked directly with other FSA survey research such as the Food and You survey. Survey interviewers could be trained to install the 4 ART devices in the refrigerators of consenting households and households could be asked to remove and return the ART devices by post. This would allow for ART data to be collected in parallel with survey data and would allow for analysis of self reported and actual data (collected very close to each other in time) for each participating household to be conducted. This may be of benefit to the comparative analysis of self-reported data as no significant changes in circumstances or appliances should have taken place between the collection of each data set. The linking of recruitment and/or data collection on a scaled up ART study is likely to result in some costs savings associated with household recruitment and installation. | **Linking recruitment and data collection to future surveys, like Food and You, could be considered.** |

## 6.3 Estimated costs of a scaled up ART study

Based on a proposed sample size of 300 households (See Table 6.1), Table 6.2 outlines the estimated costs (£407-471K) for undertaking an 18 month scaled-up ART study[20] depending on the installation approach chosen. It is proposed that such a study would require the following workplan: 1. Preparation, recruitment and software development (Months 1-6); 2. Data Collection (month 7-12); 3. Analysis and Reporting (Month 8-18). It is advised, based on the experience of the feasibility study, that data collection should not take place between November-April to minimise any delays associated with adverse winter weather conditions.

**Table 6.2: Estimated Costs of a Scaled up ART study[21]**

| Key items/categories | Description | Total Cost Calculation (Researcher install) | Total Cost Calculation (Household install) |
|---|---|---|---|
| Cost per device | 275 (4 device/household installed in 5 6-week waves) at £100/device | £27,500 | £27,500 |
| Software Development | 100 days @ £350/day | £35,000 | £35,000 |
| Household Recruitment (social research agency) | £50/household | £15,000 | £15,000 |
| Cost per household (Prep of devices; Travel and Subsistence; cost of installation staff; 2 days of research staff time for analysis per household at £350/day) | £900 incl. vat/household This includes staff cost for analysing the ART data at the household level. | £270,000 | n/a |
| Household Installation (Prep of devices; Postage; Research staff time (as above) | £750 This includes staff cost for analysing the ART data at the household level. | n/a | £206,250 |
| Packaging | £10/household (60 packages required due to staggered data collection) | £600 | £600 |
| Guardian 24 licence | £750 (30 week data collection period) | £750 | £750 |
| Household incentive payments | £20/household | £6000 | £6000 |
| Researcher time for Cross Comparative Analysis and reporting | 100 days @ £350/day | £35000 | £35000 |
| Project Management (PI + other experts) | 2 days/week for study duration @ £500/day | £66,000 | £66,000 |
| Other Costs | Travel and Consumables | £15,000 | £15,000 |
| Total Estimated Cost (n=300) | | £470,850 | £407,100 |
| Total Estimated cost/household | | £1570 | £1357 |

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[20] An 18 month study is estimated to be the minimum length of time required to complete the proposed scaled up ART study.

[21] The costs outlined are estimates based upon the feasibility study and the requirement for further essential software and hardware development. No comparative costs were available from those who undertook previous temperature monitoring studies. Therefore the FSA will need to judge the cost effectiveness of undertaking such a proposed ART scaled up refrigerator study against the alternative methods available

It is possible that significant cost savings could be made if a scaled up ART study was directly linked with other FSA research such as the Food and You survey. The primary saving would involve survey interviewers installing the ART devices and collecting any additional photographic, profile and fridge specific data (related to the refrigerator) deemed necessary.  By adopting such an approach, potential cost savings could be made on household recruitment, travel and incentive costs associated with ART deployment. This approach would also offer complementary and supplementary information from the two data sources (the ART data and the survey data), which could provide useful insights about household practices.

## 6.4   Reflections on scaling up

ARTs have demonstrated their value in generating refrigerator temperature and activity monitoring data.  This value could best be realised in a scaled up refrigerator study.  To benefit from potential cost savings associated with household recruitment and a mixed deployment strategy, a scaled up ART refrigerator study could be usefully linked to other large scale surveys such as the FSA Food and You survey. This could be achieved through using survey interviewers to install the ART devices and would result in the collection of both survey and ART data from participating households. This in turn would facilitate multifactorial analysis of the range of factors considered to influence the temperature performance of domestic refrigerators.

# Chapter 7: Discussion

## 7.1  Introduction

Developments in technological know-how are resulting in innovations in data capture that have the potential to support domestic food safety research.  ARTs, which combine temperature and activity monitoring in one relatively small device (compared to temperature data loggers), are one such innovation and a number of options for using ARTs in domestic food safety research have been assessed in this study.  Based on the preceding analyses, this final chapter summarises the findings and reflects on the potential value of these insights for the work of the FSA.
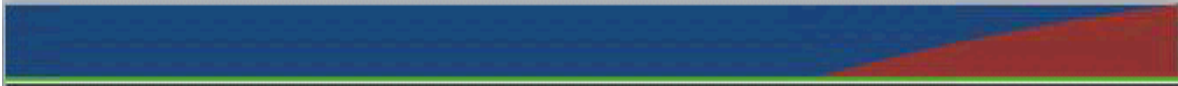
## 7.2  The Refrigerator

This feasibility study has tested the efficacy of using novel ART devices to effectively, more sensitively and over longer periods of time, capture synchronised temperature and activity data from key sites in the domestic kitchen demonstrating very notable potential at the refrigerator site. To our knowledge, this is the first time such synchronised refrigerator temperature and activity data has been captured and it represents the most time-sensitive refrigerator temperature recordings amongst the current published work. ART devices are capable, flexible, cost effective and unobtrusive to use in large scale domestic refrigerator studies. Such future scaled up studies would support a more holistic and statistically robust examination of the temperature performance of domestic UK refrigerators.

This study concludes that ARTs have demonstrated a potential contribution to future refrigerator temperature studies; this is discussed further now, in relation to the possible implications for the work of the FSA.

## 7.3  Contribution of ART data to Refrigerator Temperature Research

The refrigerator plays a central role in domestic food safety management (James *et al.,* 2008), particularly with respect to 'chilling' (one of the 4 Cs), where the refrigerator is considered to be a significant factor in 28% of domestic food borne disease outbreaks (Contor et al., 2009; Kilonzo-Nthenge *et al.,* 2008; Ryan et al., 1996).   Thus the performance of domestic refrigerators has been the focus of technical studies in this area (see Table 7.1).   In order to discuss the contribution of ART data to refrigerator temperature research it is necessary to first compare the functionality of, and quality of the data produced by ARTs, to that of alternative temperature measurement devices such as data loggers. As noted in chapter 4, ART devices compare very favourably with the other devices used by previous temperature monitoring studies. In particular, ARTs have been shown to have superior reading and memory capacity.

Previous temperature monitoring studies vary significantly in the rate at which they capture temperature data. It is not clear from these studies how they have chosen their data capture rates and how, if at all, these may relate to the actual lengths of 'real life'

refrigerator events. The ARTs have been shown to address this potential weakness by being able to accurately determine the duration and frequency over which refrigerator events take place. While, the average length of a refrigerator event was found to be between 12-33 seconds, some refrigerator events lasted as little as 1 second (see Table 4.1). This emerging evidence, alongside the superior memory capacity of the developed ARTs, provides clear justification for adopting a higher rate of temperature capture (every second) to those previously applied. Returning temperature data every second will ensure that no events are missed and that all refrigerator events can be synchronised with temperature data. This will also maximise the number of data points available for calculating median operating refrigerator temperatures. This should improve the accuracy of the results, maximise the flexibility of how finely grained the analyses can be conducted and ensure that refrigerator recovery times can be calculated for all events irrespective of their length. Future ART studies are not precluded from adjusting the data capture rate to different time intervals (i.e. every 5 seconds), if appropriate, as the ARTs can be programmed to return data at whatever time interval is required.
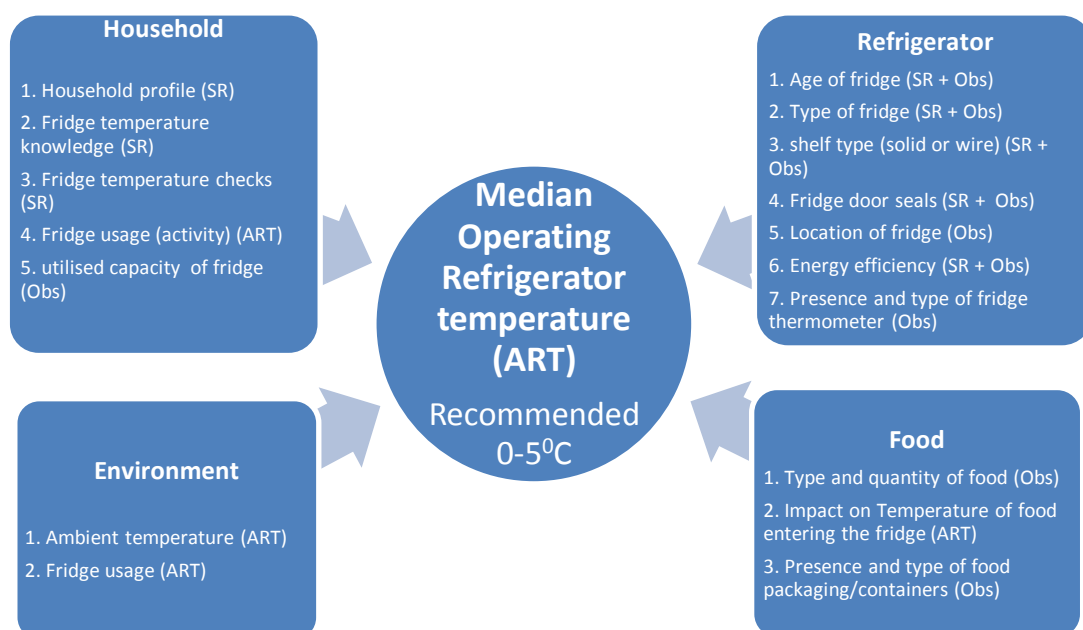
ARTs have demonstrated proof of concept in being capable of providing the data necessary to calculate median operating refrigerator temperature. This is an objective measure of refrigerator temperature performance and is the central anchor upon which temperature performance studies should be based around. That said, knowing the median operating refrigerator temperature is only one part of the puzzle. Throughout this report, reference has been made to the variety of interrelated factors that are considered to influence how and why a refrigerator is performing relative to the recommended temperature range (0-5$^0$C) (see Table 4.3). These factors include: 1) household profile; 2) the refrigerator itself; 3) the refrigerator environment; and 4) the food that is stored within.

Figure 7.1 indicates that for refrigerator performance studies, ARTs can calculate objectively the central anchor of median operating refrigerator temperature and refrigerator activity. However, the value of refrigerator temperature and activity data can only be fully maximised if supplementary contextual data is also collected (such as household profile, age of fridge etc.) to support the multivariate analyses of these interrelated factors.

**Table 7.1 : Overview of Past Temperature Monitoring Studies**

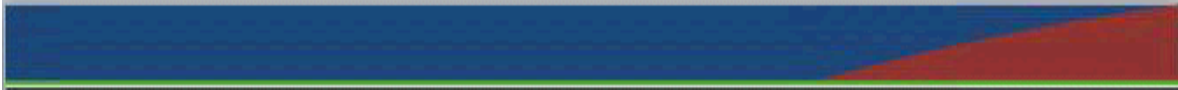| Authors | Country | Frequency and length of temperature recording | Sample Size (N) | Temp Monitoring method | % refrigerator within 0-5°C range | Mean Refrigerator Temperature | Activity Monitoring |
|---------|---------|------------------------------------------------|-----------------|------------------------|-----------------------------------|-------------------------------|---------------------|
| Evans et al.(1991) | UK | Every 8 secs to record mean temp every 5 mins, over 7 days | 252 | Data logger – 3 points within fridge (T, M, B shelf) | 30% | 6°C | none |
| Flynn et al. (1992) | Northern Ireland | Unreported | 150 | Thermometer in 25ml glass bottle | 29% | 6.5°C | none |
| Worsfold and Griffith | UK | Data Logger | 108 | Data Logger – strapped to a perishable product | 50% | 5.9°C | none |
| Laguerre et al. (2002) | France | 2-8min intervals for 7 days | 119 | Data logger – 3 points within fridge (T, M, B shelf) | 20% | 6.6°C | none |
| Kennedy et. al. (2005) | Ireland | Every 10minutes for 72hrs | 100 | Data Logger – 1 point (M shelf) | 41% | 5.4°C | none |
| Terpstra et al. (2005) | Netherland | Unreported | 31 | Glass thermometer kept for 24hrs inside a plastic bottle of water placed in the bottle rack in the door of the refrigerator | 32% under 7°C (not reported at the 0-5°C level) | Not reported | none |
| Breen et al. (2006) | UK | One temperature reading taken | 24 | Glass thermometer in gel | 67% | 5°C | none |
| Gilbert et al. (2007) | New Zealand | Every 10 minutes for 72hrs | 127 | Data Logger –2 points (T, B shelf) | 55% | 5.2°C | |
| NSW (2009) | Australia | Every 10 minutes for 72hrs | 57 | Data Logger – 1 point (M shelf) | 23% | 3.4°C | Household diary |
| George et al. (2010) | UK (WRAP food waste study) | 1 min intervals for a min. of 4 days | 50 | Miniature Data logger (Logtag Trex 8) – 3 points (T, M, B shelf) | 29% | 7°C | Recommendation that a fridge activity diary is kept by participating households. |

**Figure 7.1: Factors affecting refrigerator ability to operate within the recommended refrigerator temperatures range of 0-5⁰C**



**Household**

1. Household profile (SR)
2. Fridge temperature knowledge (SR)
3. Fridge temperature checks (SR)
4. Fridge usage (activity) (ART)
5. utilised capacity of fridge (Obs)

**Refrigerator**

1. Age of fridge (SR + Obs)
2. Type of fridge (SR + Obs)
3. shelf type (solid or wire) (SR + Obs)
4. Fridge door seals (SR + Obs)
5. Location of fridge (Obs)
6. Energy efficiency (SR + Obs)
7. Presence and type of fridge thermometer (Obs)

**Median Operating Refrigerator temperature (ART)**
Recommended 0-5⁰C

**Environment**

1. Ambient temperature (ART)
2. Fridge usage (ART)

**Food**

1. Type and quantity of food (Obs)
2. Impact on Temperature of food entering the fridge (ART)
3. Presence and type of food packaging/containers (Obs)

*Key: The codes used refer to: self-reported (sr); ART (via ART devices) and observational (obs) data.*

The FSA is advised to consider all these factors in any future temperature monitoring studies. To achieve this, the strong recommendation is that ART data should be collected in conjunction with other data streams (i.e. self-reported & observational (photographic/checklists) to support multivariate analyses of these interrelated factors.

With a sufficient sample size, such analyses could help to establish how, if at all, this array of factors influence median operating refrigerator temperatures and whether there are statistically significant relationships between operating temperature and the array of different factors outlined. Exploratory analysis in the feasibility study identified potential relationships between refrigerator temperature & activity and the: number of household occupants; regular use of an eating area in the kitchen, the presence of pets and children; number of refrigerator activities; home ownership; and type of refrigerator. In addition, previous temperature performance studies have highlighted other potential relationships between refrigerator temperature performance and: ambient kitchen temperature; age, capacity and condition of refrigerator; use and type of refrigerator thermometer and the positioning of the refrigerator within the kitchen (See Table 4.3). It is recommended that a broad range of hypotheses is developed and tested as part of a scaled up ART study in order to establish which factors, if any, are the primary influencers of median refrigerator operating temperature. Such analysis (and the emerging insights) will provide both valuable objective and contextual evidence for a range of stakeholders interested in the

temperature performance of domestic refrigerators and in particular those tasked with reducing the incidence of foodborne disease associated with inadequate chilling.

The sensitivity and sychronisability of ART data makes it possible to identify small changes in refrigerator temperature (at 1 second intervals) and directly relate any changes to refrigerator events. However, the importance of periodic temperature increases within the refrigerator as a result of such events remains unclear. The feasibility study has demonstrated how ARTs can provide a data capture mechanism to facilitate further, more intensive time-temperature analysis of domestic refrigerators (number of minutes a refrigerator is operating out of the recommended range (see Chapter 4)) which may help improve understanding of the importance of such temperature changes for the growth of foodborne pathogens and in particular cold liking pathogens (such as *Listeria monocytogenes)* within the refrigerator. This type of analysis may be of significant value to researchers and policy makers involved in refrigerator temperature and microbiological research/policy development (in particular those involved in modelling refrigerator temperature performance and microbial growth) and inform foodborne disease strategies.

## 7.4 Conclusion

ARTs have demonstrated greater technical proficiency in recording refrigerator temperature and activity data, are simple to deploy, unobtrusive when installed, and have superior reading and memory capacity compared to other temperature logging devices. The feasibility of using ARTs in future large scale refrigerator studies is therefore demonstrated.

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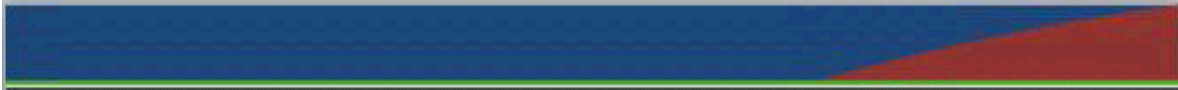
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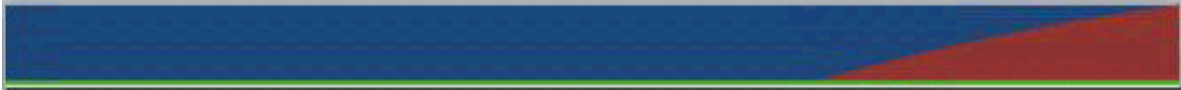
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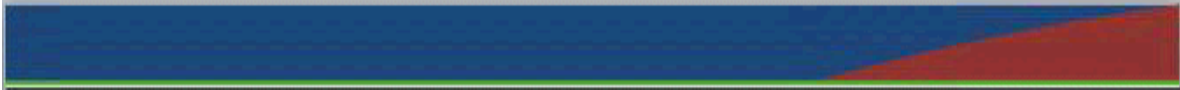
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