

TEMPERATURE CONTROL IN DOMESTIC REFRIGERATORS AND FREEZERS

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ABSTRACT

Temperature control of food in the home is vitally important. In the past decade there have been 15 published surveys of temperatures in domestic refrigerators. The last detailed survey carried out in the UK was in 1991. Refrigerators are now fitted with lower power compressors and thicker insulation to enable them to achieve low energy consumption. Therefore there is a possibility that due to these changes, temperatures in domestic refrigerators have changed. This paper reports results from a survey of currently used domestic refrigerators and compares the results to those obtained in 1991.

In addition the paper examines temperatures in domestic freezers. Although freezers pose less of a food safety risk they do contribute to poor food quality and potential waste if the food is not maintained at low enough conditions. None of the surveys published to date examines temperatures in domestic freezers.

1. INTRODUCTION

Temperature control of food in the home is vitally important. Evidence suggests that over 70% of food poisoning cases originate in the home and if food is stored in less than optimal conditions the potential for growth of pathogenic organisms exists.

The temperature performance of domestic refrigerators and freezers is defined in EN/ISO test standards and must be achieved with low energy consumption at minimum cost. The market for domestic refrigerators and freezers is extremely competitive. It is therefore very important to design a refrigerator to produce the temperatures required by the standard at the lowest possible cost. The basic design of domestic refrigerators and freezers has changed little in the last 60 years. The lack of development within this market was highlighted by Cleland (2001) who proposed that if new integrated approaches to temperature control and sustainability were not developed the refrigeration industry would lose market share and consumer confidence. This would then allow totally new products and markets (e.g. organoleptically superior dried foods) to develop and replace refrigeration as the primary means of food conservation.

In the past decade there have been 15 published surveys of temperatures in domestic refrigerators (James, 2003). The results are very similar, with overall mean temperatures ranging from 4.5 to 6.6°C and maximum temperatures from 11 to 14°C. In analysing the data from most of the various surveys reported over the last 30 years Peck et al. (2006) concluded that 61.2% of refrigerator throughout the world run at temperatures above 5°C.

The amount of time spent above 5°C (the temperature most commonly quoted as being the maximum desirable for food in domestic refrigerators) varies in each of the surveys, but is commonly above 50%. Much of the variation in the figures is probably related to the method of measurements and the level of 'damping' of the sensors. Details of the surveys carried out within the past 10 years are summarised in Table 1.

Table 1. Temperatures measured in surveys of domestic refrigerators in homes.

Reference	Country	n=	Measurement	T _{min}	T _{mean}	T _{max}	% in temp range
ARS, 2004 *	New Zealand	53	Not known				33%>5°C
Bakalis et al., 2004	Greece	110	Data logger (3 levels: T, M, B and door)				26%<4°C, 28% 4 to 6°C, 23% 6 to 8°C, 15% 8 to 10°C, 8% 10 to 12°C
Derens et al, 2007	France		Inside yoghurt				47%>6°C
Derens et al, 2007	France		Meat				75%>4°C
Derens et al, 2007	France		Air in fridge				5%>10°C
Marklinder et al, 2004	Sweden	102 households (705 samples)	Data loggers	0.2-2.4 (product dependent)	6.2-7.4	12.3	83-94%>4°C; 22-44%>8°C; 5-19%>10°C
Kennedy et al., 2005	Ireland	100	Data logger (1 level M)	-7.9	5.4	20.7 ¹	59%>5°C
Azevedo et al., 2005	Portugal	86	Digital thermometer				70%>6°C
Rahman et al, 2005	Malaysia			-2.8	2.0	7.5	
Jol et al, 2005	USA		Not known				20%>10°C
Taoukis et al., 2005	Greece	250	Data logger	-2	6.3		50%>6°C, 10%>10°C
Terpstra et al., 2005	Netherlands	31	Glass thermometer	3.8		11.5	68%>7°C
Koutsoumanis & Taoukis, 2005	Greece	31	Glass thermometer	3.8		11.5	21%>7°C
Breen et al., 2006	UK	24	Glass thermometer in gel		5.0 (mode)		33%>5°C
Gilbert et al, 2007	New Zealand	127			5.2		34%>6°C, 55%>5°C
WRAP, 2009	UK	50	Air (T, M, B)		7		29% > 9°C, 29% < 5°C, 70% < 8°C
Landfeld et al, 2011	Czech Rep	108	RFID tag	-0.8	6.5	14.8	74%>5°C, 45.9%>6.1°C, 24.8%>8°C, 14.7%>10°C

* Cited by Anon (2007)

The last detailed survey in the UK where temperatures were measured over time in different locations within 252 domestic refrigerators was carried out by Evans et al. (1991). In the work miniature data loggers with three air and two product sensors were placed into the refrigerators to monitor temperatures every 8 s and to record mean temperatures every 5 min for a period in excess of seven days. Air temperature sensors were positioned in the top, middle and bottom sections of the refrigerators and a simulated food product (87 mm diameter by 28 mm high disc of 'Tylose'; a food substitute; in a petri dish) placed on the middle shelves. Sensors were placed in the geometric centre and centrally on the surface of the Tylose discs. The study showed that the mean temperature over 7 days (evaluated from top, middle and bottom sensors) ranged from -1°C to 11°C. The overall mean air temperature for all the refrigerators in the survey was 6°C, with 70% of refrigerators operating at average temperatures above 5°C.

None of the published studies has examined temperatures in freezers. Although freezers are unlikely to constitute a food safety problem, the quality of food can be compromised if temperatures are not well controlled.

The work presented in this paper describes a new survey that examines temperatures in domestic refrigerators and freezers and compares the resulting temperatures measured in the refrigerators with the previous UK survey carried out by Evans et al (1991).

2. MATERIALS AND METHODS

2.1 Samples

Breakfast pot yogurts (135 g) were used as the refrigerator test samples and were obtained directly from the manufacturers (Yeo Valley). The yogurts consisted of 2 sections: a base pot of yogurt and an upper granola container clipped onto the lid. The samples were selected so that the temperatures sensors (Omega mini Nomad RFID tags) could be inserted between the yogurt and the lid without becoming detached and so that the sensors were measuring the temperature of the food rather than the air.

Mini tubs of ice cream (Yeo Valley) were used as samples in the freezer compartments. The same RFID tags as above were inserted between the lid and the ice cream.

All samples were stored in a temperature controlled refrigerator ($1\pm 1.5^{\circ}\text{C}$) or freezer ($-20\pm 1^{\circ}\text{C}$) prior to the samples being given to participants.

In all cases participants placed the yogurts in the centre of the top, middle and bottom shelves of their refrigerators and placed the ice cream at any position within their freezer.

2.2 Participants

One hundred and twelve households took part in the trial. All participants lived within a 100 mile radius of central Bristol. Samples were given to participants who then took them to their homes by whatever method they chose.

2.3 Data collected

The surveys were carried out during March and April 2014. Participants were asked to keep samples in their refrigerator and freezer for a minimum of 2 days and maximum of 14 days before returning the RFID loggers for analysis. Participants were asked to complete a questionnaire to provide information on the time it took them to take the food home, the type of refrigerator and freezer or fridge-freezer that they owned, the make and model of each appliance(s), the age of the appliance(s) and the location of the appliance(s). Information was offered to each participant on the operation of their refrigerator and freezer or fridge-freezer.

3. RESULTS

3.1 Temperatures measured in refrigerators

The overall mean temperature of all refrigerators measured in the survey was 4.4°C . The maximum overall mean temperature in a single refrigerator was 10.4°C and the overall minimum mean temperature was -0.6°C . Overall the refrigerators in the survey spent 38% of the time above 5°C (58% on the top shelf, 32% on the middle shelf and 26% on the bottom shelf). The amount of time spent on each shelf at 1°C temperature intervals is shown in Figure 1.

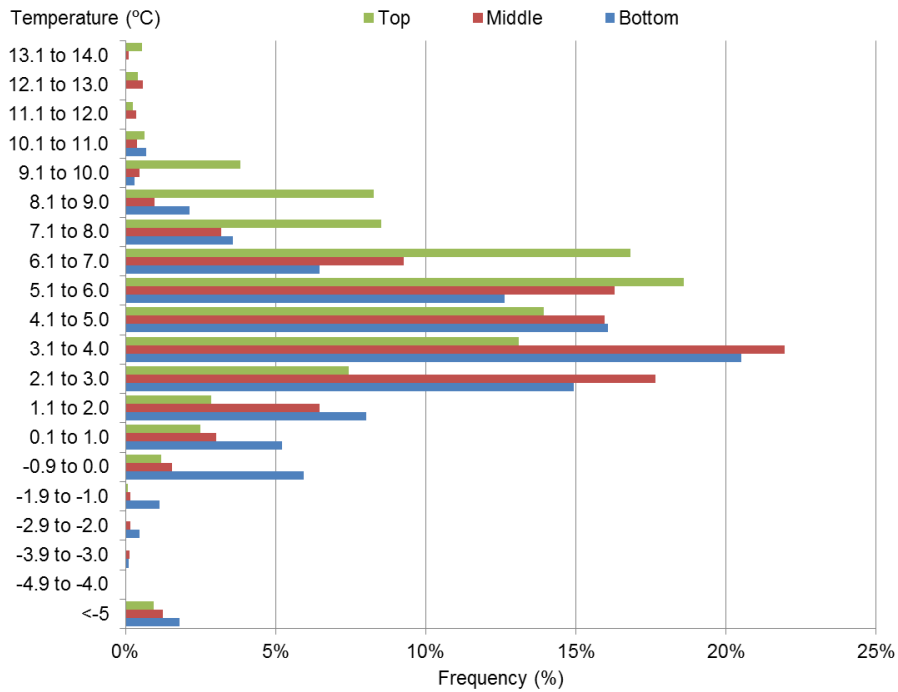


Figure 1. Frequency distribution of time and temperature for refrigerators in the survey.

3.2 Comparison between temperature performance in refrigerator with previous UK survey

Compared to the previous UK Survey (Evans et al, 1991) the temperatures measured in this survey were lower. Figure 2 shows the overall frequency distribution of time and mean temperature for all refrigerators in each survey.

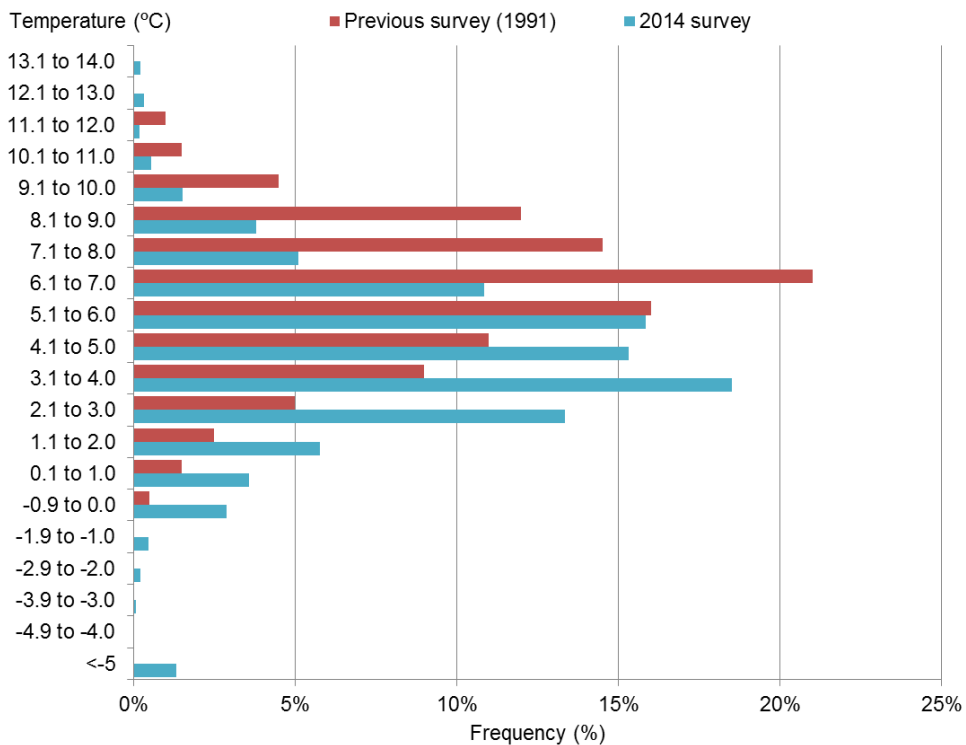


Figure 2. Frequency distribution of time and mean temperature for refrigerators in the current and previous surveys.

Table 2 shows a comparison between the positions of maximum and minimum temperature in the previous and current surveys. In both cases the highest mean temperatures were most often on the top shelf. In the previous survey the minimum mean temperature was most often found on the middle shelf whereas in the current survey the lowest minimum temperature was located on the bottom shelf. Table 3 shows the positions of lowest and highest mean temperatures divided by refrigerator type. The positions of highest and lowest mean temperatures are different in the 1991 and 2014 surveys but have a similar pattern for fridge freezers (maximum temperature on top shelf and minimum temperature on middle or bottom shelves). Differences between the 1991 and 2014 surveys are more apparent in the ice box and larder refrigerators. This is partly due to number of replicates. In the 1991 survey there were proportionally less larder refrigerators and a greater proportion of ice box refrigerators, whereas in the 2014 survey this trend was reversed (probably demonstrating the trend for the convenience of having a refrigerator that does not require defrosting).

Table 2. Position of highest temperature within refrigerators investigated.

Position	1991 survey (% of refrigerators)		2014 survey (% of refrigerators)	
	Highest mean temperature	Lowest mean temperature	Highest mean temperature	Lowest mean temperature
Top	69.9	20.3	68.2	13.6
Middle	8.1	45.1	19.1	31.8
Bottom	22.0	34.6	12.7	54.5

Table 3. Positions of lowest and highest mean temperatures in refrigerators investigated.

	% of lowest mean temperatures in:							
	1991 survey				2014 survey			
	Top	Middle	Bottom	Number (%)	Top	Middle	Bottom	Number (%)
Refrigerator type:								
Ice box	48.1	41.6	10.4	81 (32)	33.3	33.3	33.3	3 (3)
Fridge-freezer	10.6	45.5	43.9	126 (50)	14.5	32.3	53.2	62 (58)
Larder	0.0	50.0	50.0	45 (28)	11.9	28.6	59.5	42 (39)
	% of highest mean temperatures in:							
	1991 survey				2014 survey			
	Top	Middle	Bottom	Number	Top	Middle	Bottom	Number
Refrigerator type:								
Ice box	28.6	11.7	59.7	81	66.7	0.0	33.3	3
Fridge-freezer	84.6	8.9	6.5	126	62.9	27.4	9.7	62
Larder	100.0	0.0	0.0	45	76.2	9.5	14.3	42

3.3 Performance of domestic freezers

The overall mean temperature of freezers in the survey was -20.1°C (maximum mean temperature was -11.1°C and minimum mean was -41.1°C). The frequency distribution of time and mean temperature for all freezers in the survey is shown in Figure 3.

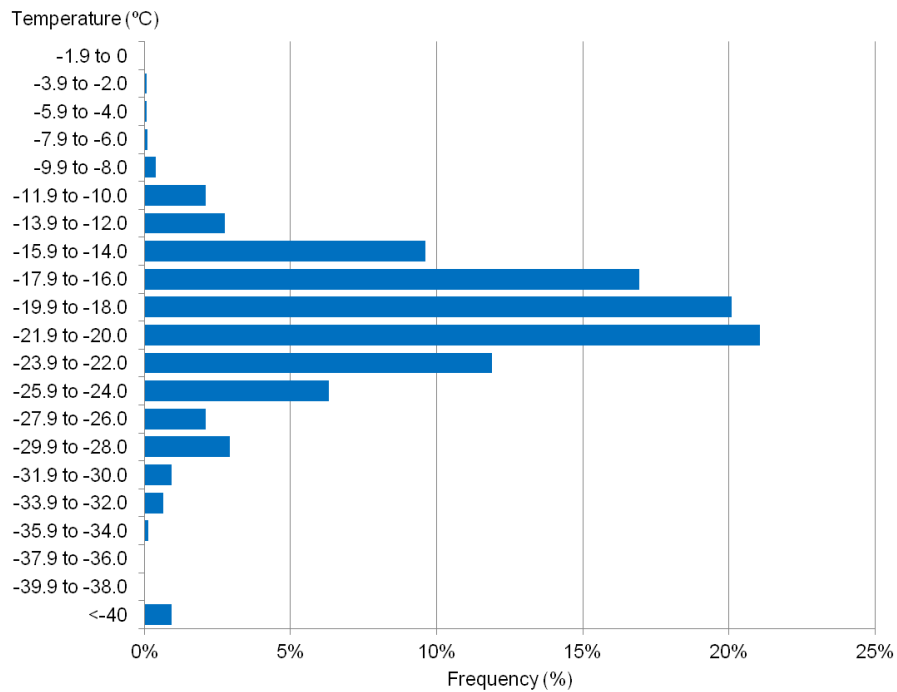


Figure 3. Frequency distribution of time and temperature for freezers in the survey.

Overall there was very little difference between overall mean temperatures in upright freezers, chest freezers and the freezer section of the fridge-freezers (Table 4). Data was collected from one refrigerator with an ice box freezer where the overall mean temperature was -11.1°C . However, this provides insufficient replicates to be able to suggest that ice box freezers operate at a higher temperature than the other freezer types assessed.

Table 4. Positions of lowest and highest mean temperatures in freezers investigated.

	Overall mean	Maximum mean	Minimum mean	Number (%)
Upright freezer	-21.9	-15.5	-41.1	20 (20)
Chest freezer	-20.1	-14.0	-32.9	21 (21)
Fridge-freezer	-19.6	-11.4	-29.7	60 (59)
Under counter refrigerator with ice box	-11.1	-11.1	-11.1	1 (1)

3.4 Impact of age on temperature performance of refrigerators and freezers

The impact of age on refrigerator and freezer performance was investigated. As the energy efficiency of refrigerators has improved due to energy labelling it might be expected that this could affect temperatures within the refrigerators. To make refrigerators more energy efficient manufacturers have increased insulation thickness, fitted smaller (but more efficient) compressors and fitted better controls. As the testing of refrigerators is carried out with the doors closed it might be expected that the refrigerators might operate well in a test situation but may have less ability to extract heat in real life use where the refrigerator and freezer doors are opened regularly. Figure 4 shows a comparison between appliance age and mean temperature in the appliance. Within the survey refrigerators and freezers ranged in age between almost new to 30 years of age. The results showed that there was no clear indication that temperature control in appliances was related to age of the appliance.

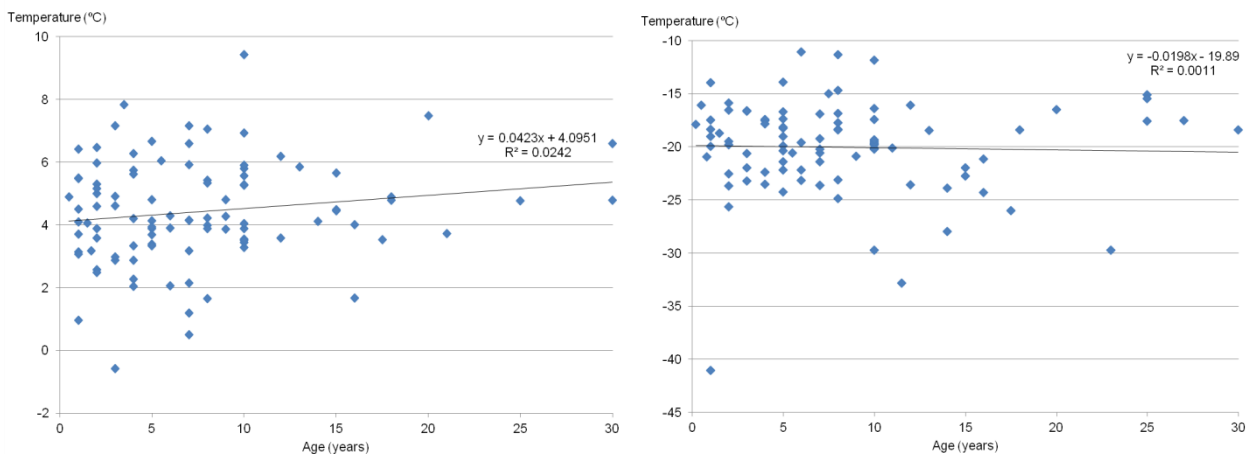


Figure 4. Comparison between age of refrigerators (left) and freezers (right) and the mean temperature measured in the appliance.

4. DISCUSSION

The data collected in the 2014 survey indicates that performance of domestic refrigerators has improved since the 1991 survey was carried out. In the 1991 survey the overall mean temperature of refrigerators was 6.0°C whereas in the 2014 survey the overall mean was 4.4°C. Time spent by all refrigerators above 5°C was 71% in the 1991 survey whereas in the 2014 survey it was 58%. The range in mean temperatures however, was not so dissimilar. In the 1991 survey the maximum mean was 11.4°C and the lowest mean was -0.9°C. In the 2014 survey the maximum mean was 10.4°C and the minimum mean was -0.6°C.

The overall mean temperature in domestic freezers was found to be -20.1°C. The freezers examined spent 32% of their time above -18°C and 2.7% of their time above -12°C. This indicates that almost all the freezers examined operated at a temperature that would keep frozen food in reasonable condition. The periods where temperatures rose above -12°C were mainly due to defrosts. It was quite noticeable that temperatures in some freezers rose, often quite regularly, for short periods to facilitate defrosting.

5. CONCLUSION

Temperatures in domestic refrigerators were found on average to be lower in the current survey than previous surveys carried out in the UK. Mean temperatures in domestic freezers were generally found to be acceptable and none exhibited any food safety issues. There was no indication that there has been any change in temperature control in either domestic refrigerators or freezers over the past 20-30 years.

6. ACKNOWLEDGEMENT

This publication has been produced with the financial support of the European Union (grant agreement FP7/2007-2013 – Frisbee). The opinions expressed in this document do by no means reflect the official opinion of the European Union or its representatives.

7. REFERENCES

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