**DOMESTIC FOOD PRACTICES
IN NEW ZEALAND
FREEZER SURVEY**

FINAL REPORT

Prepared as part of a New Zealand Food Safety Authority
contract for scientific services

by

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IN NEW ZEALAND
FREEZER SURVEY

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SUMMARY

Campylobacteriosis is the most frequently reported gastrointestinal illness in New Zealand, with greater than 50% of cases being attributed to consumption of chicken (Eberhart-Phillips *et al.*, 1997). A recent commentary by Baker and colleagues (2006) on the rates of *Campylobacter* infection in New Zealand has suggested that all fresh poultry should be temporarily withdrawn from the food supply and replaced with frozen or processed alternatives. While scientific evidence supports some decline in *Campylobacter* numbers following freezing, this approach is not in itself a 100% effective intervention and does not take into account issues regarding thawing and potential undercooking. It also flies in the face of consumer preference for fresh poultry in New Zealand where 71% of consumers purchase 50% or more of their poultry fresh. However, given that 66.3% of consumers also freeze over half of this fresh poultry in the home, an investigation of domestic freezing conditions has merit.

This project was therefore initiated to provide baseline information on: (i) domestic freezer types commonly in use in New Zealand; (ii) typical domestic freezer temperatures; and (iii) freezing and thawing temperature profiles for chicken samples, with a view to generating information to support a more quantitative assessment of the effects of freezing.

An email survey using ESR staff was conducted to analyse the prevalence of freezer types in New Zealand. Fridge-freezers were most commonly reported (70.3%), of which bottom-loading freezer compartments were more prevalent than top-loading freezers by a factor of 2 to 1. A questionnaire and chicken samples fitted with data loggers were then distributed to 41 participants in a Christchurch-based survey of domestic freezers.

Using temperature profile data from the data loggers, it was found that surveyed freezers operated at a mean temperature of -16.56°C. Sample location and freezer loading both had an impact on freezer temperature, with the top section of freezers 2 to 2.5°C warmer than the middle or bottom sections, and three quarters to fully loaded freezers operating at temperatures 1 to 2°C warmer than less loaded freezers. Other factors including freezer type, age, defrost mechanism and dial/setting adjustment did not affect mean freezer temperatures.

Freezing temperature data for chicken portions were also analysed. Freezer type, sample location and freezer loading were all found to significantly influence the rate of freezing of samples over a defined temperature range (from 0 to -5°C). These parameters should therefore be considerations in the development of future experimental work to determine the quantitative decline in numbers of campylobacters during domestic freezing.

Thawing of chicken portions at different temperatures was also considered. Chicken samples thawed at room temperature took on average 686 minutes to reach ambient temperatures. This suggests that the period such food spends at ambient temperature under typical domestic thawing conditions is limited, and therefore so is the potential for bacterial growth. Thawing at refrigeration temperatures took considerably longer, from 18 hrs to nearly 3 days. While this is not a concern from a pathogen growth perspective it is an inconvenience that likely drives the more common practice of room temperature thawing.

This information will be valuable in supporting risk management initiatives by the New Zealand Food Safety Authority to control *Campylobacter* through the food chain, and

contribute valuable data to ongoing pathogen risk model developments in this area. Data will also be used to develop practical experiments to quantify the effect of domestic freezing on *Campylobacter* levels on poultry.

1 INTRODUCTION

Campylobacteriosis is the most frequently reported gastrointestinal illness in New Zealand, with greater than 50% of cases being attributed to consumption of chicken (Eberhart-Phillips *et al.*, 1997). A recent commentary by Baker and colleagues (2006) on the rates of *Campylobacter* infection in New Zealand has proposed that all fresh poultry should be withdrawn from the food supply and replaced with frozen or processed alternatives until industry interventions can reliably reduce *Campylobacter* levels to accepted regulatory levels. This suggestion, similar to interventions introduced in certain European countries, is based on scientific evidence that freezing can reduce *Campylobacter* loads. However, this approach is not in itself a 100% effective intervention and does not take into account issues regarding thawing, and the potential undercooking of incompletely thawed poultry. It also flies in the face of consumer purchasing practices in New Zealand. The domestic food handling survey conducted by ESR in 2005 reported that just 10% of respondents purchased only frozen chicken while 71% purchased 50% or more of their poultry fresh (Gilbert *et al.*, 2005; Gilbert *et al.*, 2007). This has been independently confirmed by both Tegel and Inghams, whose sales of frozen poultry portions have been in decline for a number of years. However, given that 66.3% of consumers also freeze over half of this fresh poultry in the home, a quantitative investigation of *Campylobacter* reduction under domestic freezing conditions has merit.

Freezing of foods is a common means of extending shelf life through the combined effects of low temperature and reduced water activity, although it is not in practice an absolute means of guaranteeing the safety of any food. Injury and death of microorganisms during freezing of foods is thought to be due to osmotic stress and/or dehydration rather than cell damage due to intracellular or extracellular ice formation (Gill, 2002). A previous review of literature conducted by ESR (Turner, 2004) reported that *Campylobacter* levels can be reduced by 0.5 to >2.5 logs by freezing. However these reductions vary depending on the rate and temperature of freezing, the duration of storage and the food matrix in question. For example, in research by Zhao *et al*. (2003), *Campylobacter* reductions of up to 4 logs were reported for chicken wings stored at -20ºC for up to 50 weeks, but lower reductions were reported for samples stored for short periods at the same temperature. Freezing at -86ºC had very little effect on *Campylobacter* numbers. A combination of pre-refrigeration prior to freezing for 14 days at -20ºC was the most effective treatment reported by Bhaduri & Cottrell (2004), with reductions greater on chicken skin than in ground chicken meat. There has also been some suggestion in the literature that there may be differences between campylobacters in terms of freezing tolerance, with Chan *et al.* (2001) reporting that clinical strains were more likely to remain viable after -20°C freezing than poultry-derived isolates. Further work by Wieland *et al.* (2006) investigating the genetic variability of *C. jejuni* isolates indicated that freezing does not specifically select for particular genotypes and that freezing tolerance is therefore not genotype-dependent.

There are reported differences in kill for rapid freezing versus slower freezing, with slower freezing being more effective due to the extended exposure of microorganisms to both osmotic shock and dehydration conditions (Gill, 2002). Therefore the way in which chicken is frozen, in particular the length of time that it is held at effective killing temperatures, is an important consideration regarding the possible application of freezing as a consumer-level intervention strategy for *Campylobacter*. Thawing is a related aspect that needs careful consideration in terms of its effect on bacterial levels, as on one hand microbes may be exposed to additional osmotic shock but temperature increases may promote their growth.

This project was therefore initiated to provide baseline information on: (i) domestic freezer types commonly in use in New Zealand; (ii) typical domestic freezer temperatures; and (iii) freezing and thawing temperature profiles for chicken samples. This information is essential to support risk management initiatives by the New Zealand Food Safety Authority to control *Campylobacter* through the food chain.

The project was split into three time-related parts:

- 2006: email survey to gather information on freezer types in common usage;
- 2007 (Part I): specific questionnaire regarding freezers and collection of temperature data for domestic freezing and room temperature thawing of chicken samples, together with ambient air temperature data;
- 2007 (Part II): collection of temperature data for domestic freezing and refrigerated thawing of chicken samples, together with ambient air temperature data.

This project builds on experience and information gained in previous work reported by ESR including:

- Whyte *et al.* (2005). The effect of low temperature on *Campylobacter* on poultry meat.
- Gilbert *et al.* (2005). Domestic Food Practices in New Zealand: refrigerator survey & meat handling survey.
- Gilbert *et al.* (2007). Fridge Survey. British Food Journal, volume 4 (accepted manuscript).
- Gilbert *et al*. Domestic Food Handling Survey (manuscript submitted).

2 METHODOLOGY DEVELOPMENT

2.1 Survey Instruments

For the purposes of investigating domestic food handling practices in New Zealand with regards to freezing of fresh chicken, it was decided to develop three survey instruments primarily based on previous experience conducting domestic food practices surveys (Gilbert *et al.*, 2005; Gilbert *et al.*, 2007):

1) A questionnaire about freezers;

2) Measurement of domestic freezer temperatures;

3) Measurement of temperatures of fresh chicken portions frozen under domestic conditions followed by thawing at either room temperature or refrigeration temperature (+2 to +4ºC).

Previous projects had found a high risk of loss of data loggers when these were sent out beyond the control of ESR. Consequently it was decided to retain control by locating participants via ESR staff. Therefore those involved were mostly ESR staff, friends, family and neighbours. There was no reason identified to indicate that this sample set would be atypical of New Zealanders in general.

2.2 The Freezer Survey

The freezer survey was split into four key activities:

2.2.1 Email Survey

An email survey using voting buttons was conducted in December 2006 to establish the prevalence of different freezer types in the home. The survey was sent to an estimated 385 staff based on three ESR sites (Auckland, Christchurch and Porirua) and responses were filtered into different email folders based on the reply headings generated.

2.2.2 Questionnaire

A one page questionnaire containing eight questions to be filled out by the respondent was developed. The questions were in part based on a previous questionnaire used for the domestic refrigerator survey developed in collaboration with the NZFSA. The full questionnaire can be found in Appendix 1. These questionnaires were distributed with samples as outlined in section 2.2.3.

2.2.3 Collection of freeze-thaw temperature data

Skin-on chicken samples were purchased in two portion packs from Raeward Fresh, Christchurch, at regular intervals during the freezer survey. Samples were removed from their original packaging and the skin was removed from half the samples. Samples were then weighed prior to further preparation. Mean sample weights for skin-off and skin-on portions were 252.4 g (SD 31.6) and 295.0 g (SD 40.3) respectively.

Thermochron iButtons® (temperature range -40°C to +85°C) were used to record both the ambient air temperatures and the internal and external temperatures of two fresh chicken breast portions (both skin-on and skin-off) during freezing and thawing. The iButtons® were calibrated against a reference thermometer and found to record temperatures within ± 0.5°C of the reference thermometer. Temperatures adjustments based on calibration data were made as necessary prior to analysis.

Five data loggers were utilised per surveyed freezer – two per chicken breast (internal and external; Figure 1) plus a 5th data logger to record the air temperature in each freezer. The numbers of loggers available permitted a maximum of five freezers could be monitored at any one time. The loggers were programmed to switch on at 4 pm on the first day of testing and set to record at 1 minute intervals. Each participant was issued with a chilly bag containing two chicken breasts of similar weights with data loggers already attached (using rubber bands to keep them in place; Figure 1), placed in Ziploc bags to prevent any leakage or potential contamination, and a questionnaire containing instructions. An ice pack was placed in the bottom of each bag to ensure that all samples were at similar temperatures prior to freezing.

Figure 1: Placement of internal and external data loggers in skin-on and skin-off fresh chicken breast portions

Participants were instructed to place the bagged chicken portions and the 5th logger into their freezer as soon as possible after arriving home. If they owned more than one freezer, they were asked to use the freezer they would normally freeze chicken in. The placement position of the chicken samples was not specified (beyond placing them side-by-side in the same location) but placement of the 5th data logger was requested to be as close to the samples as possible to ensure that the ambient temperature being recorded would best represent the conditions the chicken portions were being exposed to in the freezer area selected. The 5th logger was either tied on with twist ties where appropriate shelf racks were present, or placed button-side up beside samples.

Participants were also instructed to remove the chicken portions and 5th logger from the freezer the following morning and allow samples to thaw at room temperature on the kitchen bench (or in another suitable location where cats, etc. would not be able to access samples). The thawing condition recommended was based on results from the domestic food handling survey where room temperature thawing was the most commonly reported means of thawing meat (Gilbert *et al*., 2005; Gilbert *et al*., 2007). Samples were then returned to ESR the following morning where data loggers were removed for data transfer and samples were re-weighed to quantify water loss prior to incinerated disposal.

2.2.4 Collection of freeze-thaw temperature data at NZFSA recommended freezer and fridge operating temperatures

A smaller study (as per section 2.2.3) was subsequently commissioned to collect freezing and thawing temperature data for chicken portions handled under existing NZFSA consumer guidelines for freezer temperature (-18ºC or colder) and thawing (in refrigerators operating at between +2 and +4ºC). Mean sample weights for skin-off and skin-on portions were 219.5 g (SD 47.1) and 250.9 g (SD 28.8) respectively.

Temperatures of freezers and fridges were monitored using data loggers, and any temperature adjustments made prior to data collection were re-checked to ensure that these had been successful. For the actual survey, a shorter questionnaire was administered (Appendix 2) and loggers were programmed to record data every 3 minutes over a 4 day period. This data will be reported separately from the larger survey in this report.

2.2.5 Statistical Analysis

Generalised linear models were used to investigate the relationship between freezing time and sample type, datalogger placement, freezer type, sample location and freezer loading. The general linear model is an extension of linear multiple regression for a single dependent variable. Statistical analyses were performed using SAS System V.9.1. A p-value of <0.05 was taken to be statistically significant.

2.3 Freezer Survey Participants

In total, 41 urban households across Christchurch and surrounding areas were recruited for the freezer survey (section 2.2.3). The survey began on the 15th January 2007 and was completed by 9th February 2007. The second survey (section 2.2.4) was conducted in March 2007, and involved six participants recruited from the original survey with freezers operating at temperatures at or below -18 º C.

3 RESULTS: EMAIL SURVEY AND QUESTIONNAIRE RESPONSES

3.1 Email Survey Responses

The email survey, conducted in December 2006, received a response rate of 57.4% (221/385). From the results presented in Table 1, the most commonly owned freezer was determined to be a combination fridge-freezer (70%) with either a top-mounted (25.3%) or, more usually, a bottom-mounted (45%) freezer section.

Table 1: Results of ESR-wide email freezer survey

Type of freezer	1 freezer only	>1 freezer	Total	% (of total freezers)
Chest freezer	13	31	44	16.1
Fridge-freezer (bottom)	95	28	123	45.0
Fridge-freezer (top)	51	18	69	25.3
Vertical	16	16	32	11.7
Other (side-by-side)	1	3	4	1.5
Other (ice box)	-	1	1	0.4

Of the 221 total responses, 176 respondents (79.6%) owned only one freezer, while 45 (20.4%) indicated that they had more than one. An email follow-up to the 45 respondents was conducted to gain further information on the numbers and types of freezers they owned. This revealed that 31 of the 45 respondents (68.9%) had a chest freezer in addition to one or more fridge-freezers, while the remaining 14 (31.1%) had two or more freezers of varying types (not including a chest freezer). Of the 45 respondents, 8 (17.8%) had at least 3 or more freezers.

3.2 Questionnaire Responses

Forty one questionnaires (and freezer surveys) were conducted in total, including one for a fridge with an ice box freezer compartment. However, due to the extreme differences encountered in terms of temperature data for the ice box, and its inappropriate use as a freezer for foods such as chicken, it will not be considered further in this report.

3.2.1 Makes of freezers

Of the 40 freezers surveyed, nearly half (19/40; 47.5%) were reported as being made by Fisher and Paykel (Table 2). Kelvinator accounted for 15% (6/40) of freezers while 11 other makes constituted the remaining 37.5%. Some uncertainty exists regarding the Kelvinator data, which was reported by different respondents as either a freezer make or a model (e.g. Fisher and Paykel Kelvinator). Responses were recorded as reported in the questionnaire but it is acknowledged that this might underreport the prevalence of other manufacturer/manufacturers as a consequence. Only 1 respondent failed to state the make of their freezer.

Table 2: Makes of freezers surveyed

Make	No. of respondents (%); n = 40
Fisher and Paykel	19 (47.5)
Kelvinator	6 (15)
Westinghouse	3 (7.5)
Simpson	2 (5)
Bonnaire	1 (2.5)
Bosch	1 (2.5)
Haier	1 (2.5)
Leonard	1 (2.5)
Liebherr	1 (2.5)
Mitsubishi	1 (2.5)
Samsung	1 (2.5)
Sharp	1 (2.5)
Trieste	1 (2.5)
Not stated	1 (2.5)

3.2.2 Ages of freezers

The reported ages of the freezers in the survey are shown in Table 3. Nearly three quarters (29/40; 72.5%) of the freezers surveyed were ≤ 10 years of age, with over half of these 5 years old or less. Fifteen percent (6/40) of freezers were 21 years old or greater.

Table 3: Age of freezers surveyed

Age of freezer (years)	No. of respondents (%); n=40
0 - 5	17 (42.5)
6 - 10	12 (30)
11 - 15	2 (5)
16 - 20	3 (7.5)
21+	6 (15)

3.2.3 Types of freezers

Fridge-freezers made up 65% (26/40) of the total surveyed, of which two thirds were bottom-mounted freezers (Table 4). Vertical and chest freezers were equally represented at 17.5% (7/40 each).

Table 4: Types of freezers surveyed

Descriptions	No. of respondents (%); n=40
Front opening fridge-freezer with the freezer on top (fft)	9 (22.5)
Front opening fridge-freezer with the freezer on the bottom (ffb)	17 (42.5)
Front opening vertical freezer (v)	7 (17.5)
Top opening chest freezer (c)	7 (17.5)

3.2.4 Automatic defrost function

Just over half (22/40; 55%) of the 40 freezers under consideration had an automatic defrost function.

3.2.5 Placement of samples in freezers

Participants were asked to comment on the experimental location of the chicken samples in their freezers. This was fairly evenly split with 37.5% (15/40) of samples placed on the top shelf, 35% (14/40) on the middle shelf and 27.5% (11/40) on the bottom shelf.

3.2.6 Loadings of freezers

To determine whether existing freezer contents would influence the rate of freezing of samples, participants were also asked to comment on the loading of their freezer (Table 5). Nearly three quarters (29/40; 72.5%) of respondents had either a full or three quarters full freezer while only 10% (4/40) had a freezer quarter full. No one indicated freezer contents less than one quarter full.

Table 5: Relative loadings of freezers surveyed

Loading of freezer	No. of respondents (%); n=40
Full	10 (25)
Three quarters full	19 (47.5)
Half full	7 (17.5)
Quarter full	4 (10)
Less than quarter full	0

3.2.7 Dial/settings, their range and adjustment frequency

Only 40% (16/40) of respondents indicated that their freezer had some sort of dial setting to control internal temperature. One respondent (2.5%) was unsure, while the remaining 57.5% 23/40) did not have a dial setting.

There was great variation in the type and range of settings reported, with settings ranging from 1 to 5, 6, 7 or 8 depending on the make of freezer. In order to compare these more easily, each setting was converted into an equivalent setting out of 10 with each setting representing a 10% portion of the freezer's capacity. For example, a setting of 4 out of a range of 7 settings corresponds to a percentage of 57%, and would approximate a 6 out of 10 equivalent setting. Most freezers had a setting of between 3 and 4, and the most common maximum setting was 7. This calculation assumes that there is equal division of power capacity between each setting number. No settings were found to start at 0. Therefore setting 1 is the lowest setting.

Table 6 shows the number of freezers (total 16 respondents) operating within the 1 to 10 range of power settings. Additionally, the respective comments regarding adjustments of the dial settings are given for these respondents (i.e. never, sometimes or often adjusted).

Table 6: Converted freezer power setting (out of max 10) and dial adjustment comments

Power setting (lowest 1 to highest 10)	Number of freezers at each power setting; n=16 (%)	Dial adjustments		
		Never	Sometimes	Often
1 (1-10%)	0 (0)	0	0	0
2 (11-20%)	1 (6.3)	0	1	0
3 (21-30%)	2 (12.5)	2	0	0
4 (31-40%)	1 (6.3)	1	0	0
5 (41-50%)	3 (18.8)	3	0	0
6 (51-60%)	5 (31.3)	4	1	0
7 (61-70%)	1 (6.3)	0	1	0
8 (71-80%)	2 (12.5)	2	0	0
9 (81-90%)	0 (0)	0	0	0
10 (91-100%)	1 (6.3)	1	0	0

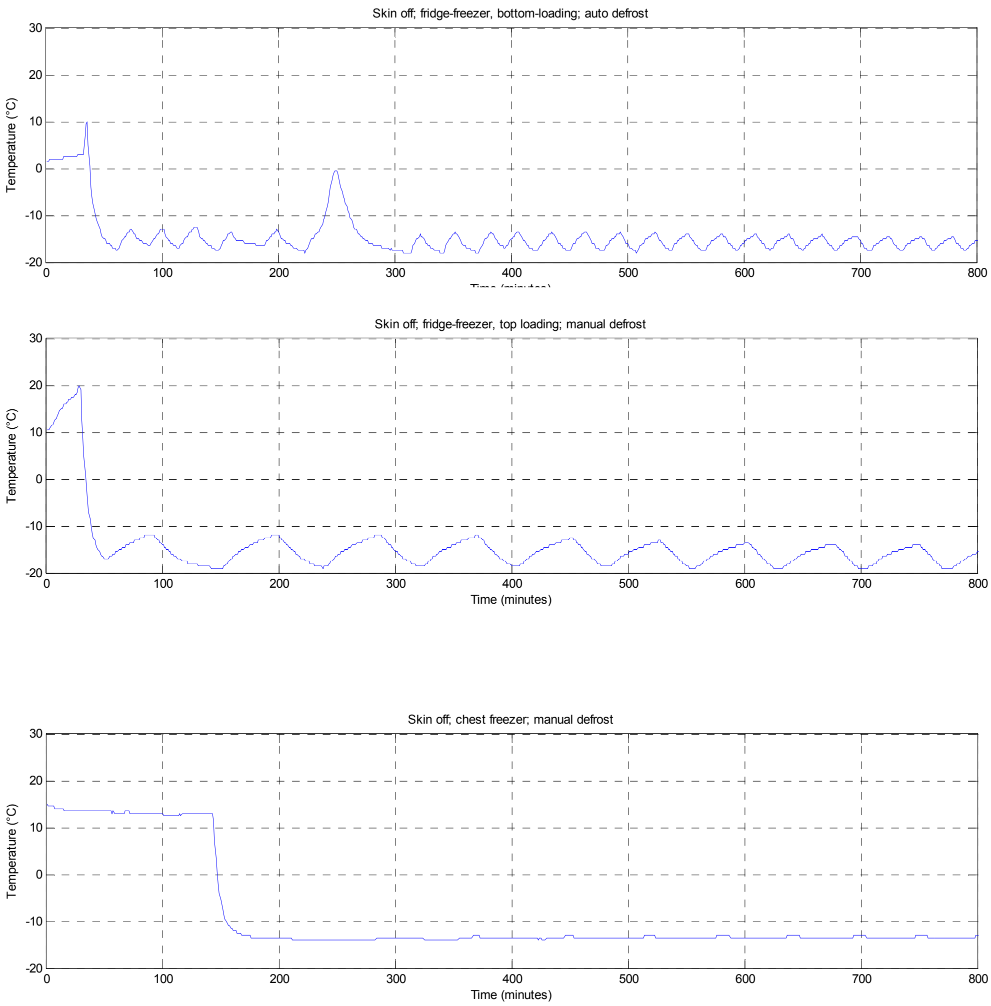
Only 12.6% of freezers were operating at the lowest (1, 2) or highest (9, 10) power settings, with 50.1% indicating a power setting equivalent to 5 or 6 out of 10. Adjustment of freezer settings only occurred sometimes in 18.8% of cases with all 3 respondents operating freezers at different power settings. Please note that due to rounding errors, the total percentage presented here is slightly over 100%.

4 RESULTS: FREEZER TEMPERATURES

4.1 Temperature Profiles

The air temperature of surveyed freezers was measured using a data logger located in the same part of the freezer as the chicken samples. Figure 2 provides examples of temperature profiles plotted in MATLAB, obtained for three different types of freezers with either automatic or manual defrost functions. Data loggers took between 50 and 150 minutes to reflect the temperature of the air in freezers, due to differences in the time taken for participants to arrive at home and place samples and data loggers into the freezer. The temperature drop recorded by the data logger after placement into the freezer was however rapid.

Figure 2: Air temperature profiles for three freezer types



Both fridge-freezer profiles demonstrate cyclical fluctuations in ambient freezer air temperature. These fluctuations were larger and more infrequent in the top-loading fridge-freezer compared with the bottom-loading fridge-freezer (7°C over an 80 minute period versus 4°C over a 28 minute period respectively). In contrast, the chest freezer temperature profile fluctuated by no more than 0.5°C after stabilising at ambient freezer temperature.

A temperature spike occurring 223 minutes into the bottom-loading fridge-freezer profile illustrates an automatic defrost cycle. In this particular example the air temperature increased by 17.5°C (from -18°C to -0.5°C) over a 27 minute period before dropping back down to -18°C over a longer 64 minute period. Smaller temperature spikes and more than one spike during the freezing cycle were also observed for other automatic defrost freezers (not shown). Mean air temperature data for each freezer were extracted from the data logger temperature profiles over a 400 minute period of constant ambient temperature measurements.

4.2 Mean Domestic Freezer Temperatures

Figure 3 illustrates the fitted distribution of mean air temperatures obtained for 39 domestic freezers (data were irretrievable for one freezer). Mean temperatures ranged from -11.47°C to -23.26°C with an overall mean value of -16.56°C. Only 28% of freezers operated at -18ºC or lower, with 68% operating between -13 and -18ºC.

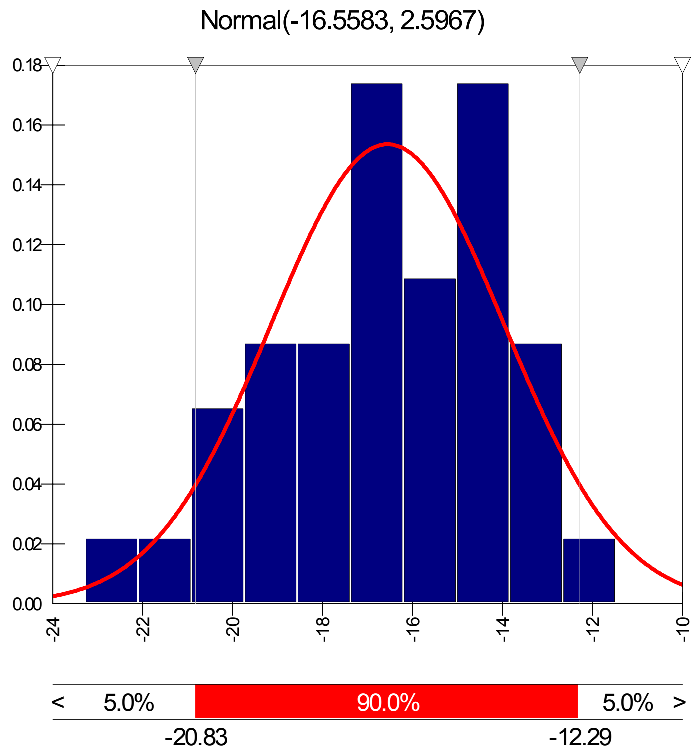


Figure 3: Fitted distribution of mean domestic freezer temperature ranges

The next sections present analyses of mean freezer temperatures in relation to the responses obtained from the survey questionnaire.

4.3 Effect of Freezer Type on Mean Freezer Temperatures

Freezer type did not influence mean air temperature values recorded during the freezer survey (Table 7). These ranged from -16.35 to -16.65°C, irrespective of other considerations such as data logger location and freezer loading. The warmest freezer temperature encountered was in a top-loading fridge-freezer, while the coldest was in a vertical freezer.

Table 7: Effect of freezer type on mean freezer temperatures

Descriptions	n	Max	Min	Mean	SD
Fridge-freezer (top)	9	-11.47	-21.69	-16.64	1.409
Fridge-freezer (bottom)	16	-14.09	-20.53	-16.65	1.195
Vertical	7	-13.13	-23.26	-16.45	0.651
Chest freezer	7	-13.81	-19.00	-16.35	0.912

4.4 Effect of Freezer Age on Mean Freezer Temperatures

Freezers ≤ 10 years old and freezers ≥ 21 years old had similar mean temperature values (Table 8). Freezers of 11 to 15 and 16 to 20 years of age had respective mean air temperatures approximately 3°C lower and 2°C higher than the other freezer age groups but came from small sample sizes (n=2 and n=3 respectively).

Table 8: Effect of freezer age on mean freezer temperatures

Descriptions	n	Max	Min	Mean	SD
0-5	17	-11.47	-21.69	-16.64	1.077
6-10	12	-13.57	-19.98	-16.59	1.291
11-15	2	-15.21	-23.26	-19.24	0.900
16-20	3	-14.09	-15.58	-14.71	0.710
≥ 21	5	-13.42	-19.00	-16.23	0.999

4.5 Effect of Defrost Mechanism on Mean Freezer Temperatures

Mean freezer temperatures were not affected by the type of defrost mechanism employed by the various freezer types surveyed (Table 9).

Table 9: Effect of defrost method on mean freezer temperatures

Descriptions	n	Max	Min	Mean	SD
Manual defrost	17	-13.42	-23.26	-16.69	1.100
Automatic defrost	22	-11.47	-20.53	-16.45	1.093

4.6 Effect of Temperature Measurement Location on Mean Freezer Temperatures

To determine whether the location of food within a freezer is an important factor in terms of the freezing process, respondents were asked to indicate in the questionnaire where samples and data loggers were placed within their freezer. Based on data presented in Table 10, the mean air temperature recorded in the top sections of surveyed freezers was on average 2 – 2.5°C warmer than the middle and bottom sections respectively, which suggests that freezing could be slightly slower in the upper areas of the freezer compartment.

Table 10: Effect of temperature measurement location on mean freezer temperatures

Descriptions	n	Max	Min	Mean	SD
Top	15	-11.47	-20.53	-15.13	1.085
Middle	12	-13.81	-23.26	-17.21	1.136
Bottom	12	-13.13	-21.69	-17.69	1.070

4.7 Effect of Freezer Loading on Mean Freezer Temperatures

Freezer loading is another factor that could potentially impact on freezing, and was again a question asked of survey respondents. Based on the air temperature data collected, one quarter full and half full freezers operated at temperatures on average 2°C colder than fully loaded freezers, and over 1°C colder than three quarters full freezers (Table 11).

Table 11: Effect of freezer loading on mean freezer temperatures

Descriptions	n	Max	Min	Mean	SD
Full	10	-13.13	-19.98	-15.53	1.071
¾ full	18	-13.42	-20.53	-16.21	1.193
½ full	6	-11.47	-19.78	-17.53	1.098
¼ full	5	-14.11	-23.26	-17.57	0.863

4.8 Effect of Temperature Adjustment Capability on Mean Freezer Temperatures

The mean temperature of freezers with dial settings was approximately 0.5°C different from freezers with pre-set temperatures (Table 12) with larger standard deviations.

Table 12: Mean freezer temperatures for freezers with and without temperature adjustment settings

Descriptions	n	Max	Min	Mean	SD
With adjustment setting	16	-13.13	-21.69	-16.27	1.169
Without adjustment setting	23	-11.47	-23.26	-16.76	1.045

5 RESULTS: CHICKEN PORTION TEMPERATURES

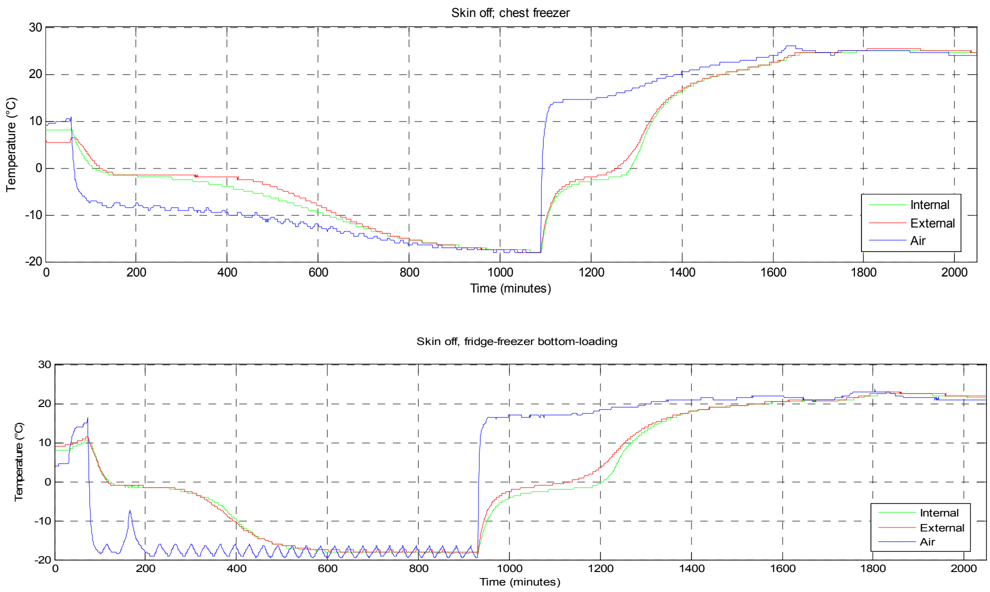
5.1 Chicken Portion Temperature Profiles

To determine freezing rates of chicken portions in domestic freezers, temperature profile data were collected for four freezer types during the freezing process as well as during thawing at room temperature. Examples of temperature profiles obtained are shown in Figure 4. These show skin-off chicken temperatures (both internal and external) and air temperatures measured during freezing and thawing for a chest and bottom-loading fridge-freezer.

Freezing data were analysed by comparing the time required to reduce the temperature of chicken over a fixed range (from 0 to -5°C) with freezer information from the questionnaire. This temperature range was chosen as it reflects the most dynamic part of the freezing process where the ice fraction increases to 74% (Gill, 2002). The temperature plateaus coinciding with this temperature range in Figure 4 are related to the release of latent heat from samples and can vary in duration as shown.

Thawing data were analysed by determining external sample temperatures for skin off samples at the beginning and end of thawing versus time as these were expected to represent the fastest thawing profile. The conclusion of thawing was defined as the highest temperature reached (approximately equivalent to ambient air temperature).

Figure 4: Chicken portion (skin off; internal and external) and air temperatures for two different freezer types



5.2 Mean Freezing Times for Chicken Portions

Skin did not influence internal temperature changes but did appear to have some effect on reductions in external temperatures (Table 13) where skin-off external temperatures reduced on average 15 minutes faster than for skin-on samples. This is likely due to the difference in freezing characteristics of the chicken flesh (represented by skin-off external measurements) as compared to chicken skin (skin-on external measurements). The effect of data logger placement within samples and the presence of skin were not however found to be statistically different based on regression analysis ($p>0.05$), therefore all data were grouped for subsequent analyses. The total number of measurements in each description (here and in subsequent sections) is not equal due to some failures of data loggers.

Table 13: Mean freezing times (minutes) required to reduce chicken portion temperatures from 0 to -5°C

Descriptions	n	Min	Max	Mean	SD
Skin-off, internal	38	214	629	372.6	111.295
Skin-off, external	38	186	645	363.7	111.066
Skin-on, internal	39	192	584	373.8	102.860
Skin-on, external	40	209	659	378.9	108.765

Based on these data, freezing rates were calculated (Table 14). Mean freezing rates ranged from 0.014 to 0.015°C per minute over the 0 to -5°C range.

Table 14: Mean freezing rates (°C/minute) for chicken portions from 0 to -5°C

Descriptions	n	Min	Max	Mean	SD
Skin-off, internal	38	0.008	0.023	0.015	0.004
Skin-off, external	38	0.008	0.027	0.015	0.005
Skin-on, internal	39	0.009	0.026	0.015	0.004
Skin-on, external	40	0.008	0.024	0.014	0.004

5.3 Effect of Freezer Type on Mean Freezing Times of Chicken Portions

Fridge-freezers with top-loading freezer compartments reduced chicken portion temperatures from 0 to -5°C in a shorter period of time than other freezers (Table 15). Statistically, there was a significant difference ($p=0.029$) between top-loading and bottom-loading fridge-freezers, but top-loading fridge-freezers were not statistically different in behaviour to vertical ($p=0.104$) and chest ($p=0.729$) freezers. Freezer type was identified as a significant factor overall ($p<0.0001$).

Table 15: Effect of freezer type on mean freezing times (minutes) required to reduce chicken portion temperatures from 0 to -5°C

Descriptions	n	Min	Max	Mean	SD
Fridge-freezer (top)	9	186	659	338.1	124.807
Fridge-freezer (bottom)	17	192	619	391.8	101.759
Vertical	7	214	542	383.2	116.303
Chest freezer	7	217	485	355.0	76.576

5.4 Effect of Freezer Age on Mean Freezing Times for Chicken Portions

Mean freezing times and standard deviations for freezers of different ages were variable, ranging from 338.8 to 416.6 minutes (Table 16). Although mean air temperature differences were previously noted (Section 4.4), this factor was not considered further in the regression analysis performed due to the variable sample sizes encountered.

Table 16: Effect of freezer age on mean freezing times (minutes) required to reduce chicken portion temperatures from 0 to -5°C

Descriptions	n	Min	Max	Mean	SD
0-5	17	186	659	379.9	125.888
6-10	12	214	561	372.6	91.073
11-15	2	218	457	345.4	100.861
16-20	3	292	496	416.6	67.419
>21	6	192	520	338.8	96.555

5.5 Effect of Defrost Method on Mean Freezing Times for Chicken Portions

Freezers with an automatic defrost cycle took on average 33.8 minutes longer to reduce chicken portion temperatures from 0 to -5°C than manually defrosted freezers (Table 17) but larger standard deviations were obtained. Given the infrequency of the defrost cycle and the similar air temperatures previously determined for the two freezer groups (Section 4.5), this factor was not considered to be important and was not therefore included in the regression analysis.

Table 17: Effect of defrost method on mean freezing times (minutes) required to reduce chicken portion temperatures from 0 to -5°C

Descriptions	n	Min	Max	Mean	SD
Manual defrost	18	186	509	353.6	90.630
Automatic defrost	22	195	659	387.4	117.856

5.6 Effect of Sample Location on Mean Freezing Times for Chicken Portions

Chicken portions placed in the top section of domestic freezers took significantly longer to decline in temperature from 0 to -5°C (Table 18) than portions placed in either the middle ($p<0.0001$) or bottom sections of freezers ($p=0.015$). However, there was no significant difference between the middle and bottom sections of freezers in terms of freezing times ($p=0.359$). Based on regression analysis, sample location was a significant factor overall ($p<0.0001$) and there was a significant interaction between location and freezer type ($p=0.033$).

It is acknowledged that "top", "middle" and "bottom" may have been more difficult to determine in the context of chest freezers where baskets/shelving are not always present and food items are stacked on top of each other.

Table 18: Effect of sample location on mean freezing times (minutes) required to reduce chicken portion temperatures from 0 to -5°C

Descriptions	n	Min	Max	Mean	SD
Top	15	208	659	418.4	95.071
Middle	14	192	645	338.5	107.960
Bottom	11	186	542	351.5	102.901

5.7 Effect of Freezer Loading on Mean Freezing Times for Chicken Portions

The lower the freezer loading, the faster the reduction in temperature of chicken portions from 0 to -5°C as demonstrated by the reduction in mean freezing time from 426 to 306.4 minutes (Table 19). Freezers loaded only one quarter full froze samples significantly faster than freezers completely full ($p=0.011$). Freezers loaded half full also froze samples significantly more quickly than fully loaded freezers ($p=0.025$). Freezers three quarters full were not statistically different in behaviour to fully loaded freezers ($p=0.063$).

Table 19: Effect of freezer loading on mean freezing times (minutes) required to reduce chicken portion temperatures from 0 to -5°C

Descriptions	n	Min	Max	Mean	SD
Full	10	243	552	426.0	87.840
¾ full	19	186	645	376.0	101.352
½ full	7	192	659	331.6	123.187
¼ full	4	212	466	306.4	87.856

5.8 Rate of Thawing of Chicken Portions at Room Temperature

Chicken portions were removed from the freezer in the morning after overnight freezing and were thawed at room temperature all day. Two distinct phases – from frozen up to 0°C and from 0°C to ambient air temperature – were evident from the thawing profiles (Figure 4). Temperature changes and the duration of thawing were however variable due to differences in initial starting temperature of samples (ranging from -22°C to -7°C) and ambient "room" temperatures (19°C to 28°C).

To allow comparisons to be made, external thawing rates for skin-off samples were calculated over the whole thawing profile from the point of removal of samples from the freezer to the point where sample temperatures were approximating ambient air temperature (Table 20). A mean thawing rate of 0.06°C per minute was determined, ranging from 0.03 to 0.08°C/minute.

Table 20: Temperature changes (°C), duration of thawing (minutes) and thawing rates (°C/minute) for skin-off chicken portions held at room temperature

Descriptions	n	Min	Max	Mean	SD
Temperature changes occurring during thawing	38	29.0	46.5	37.5	4.559
Duration of thawing	38	466	1016	686	119.770
Mean thawing rates	38	0.03	0.08	0.06	0.011

5.9 Water Loss Associated with the Freeze-Thaw Cycle

Samples were weighed prior to freezing and again at the end of the thawing process to quantify the water loss associated with the freeze-thaw cycle. The % water loss was calculated from the original weight of each sample, and a data summary is presented in Table 21. Mean water loss was similar for both skin-on and skin-off samples at 6.9 and 6.3% respectively, with skin-on samples displaying a slightly narrower range of water loss values.

Table 21: Water loss (%) from skin-on and skin-off chicken breast portions after room temperature thawing

Descriptions	n	Min	Max	Mean	SD
Skin-on	40	4.0	11.8	6.9	1.6
Skin-off	40	2.6	12.6	6.3	2.2

6 RESULTS: FREEZING AND THAWING AT NZFSA RECOMMENDED TEMPERATURES

A smaller scale survey (n=6) was commissioned to investigate freezing and thawing at NZFSA recommended temperatures of -18ºC and +2 to +4ºC respectively. Limited questionnaire data are presented in Table 22. Prior to collection of data, loggers were distributed to participants to record the operating temperatures of both freezers and fridges. Four out of the six participants had combined fridge-freezers, with 1 top-loading (fft) and 3 bottom-loading (ffb) freezer compartments. Two participants used chest freezers (c) and separate fridges (Table 22). Temperature adjustment was required for five fridges operating at temperatures above +4ºC. Given the lack of control over adjustments made by participants, despite our best efforts several fridge and freezer temperatures either deviated from the desired temperature settings (Tables 23 & 24) or were not reflective of previous temperature data. This was compounded by the fact that only two participants reported adjustable freezer settings (Table 22).

No attempt was made to control the sample location chosen for freezing or thawing. Freezer locations were equally represented while participants selected either the middle or bottom shelf of the fridge for thawing (Table 22).

Table 22: Questionnaire data collected from domestic freezing and refrigerated thawing study

	1	2	3	4	5	6
Freezer type	ffb	ffb	c	fft	ffb	c
Sample location	Middle	Top	Bottom	Top	Bottom	Middle
Freezer loading	Full	¾ full	½ full	¾ full	¾ full	½ full
Freezer setting	1/6	5/5	N/A*	N/A	N/A	N/A
Thawing location	Bottom	Bottom	Bottom	Middle (back)	Middle	Middle (back)

*N/A: not applicable

As with the previous survey, mean freezer temperature and chicken freezing data were collected (Table 23). Chicken data were again analysed by investigating the time required to reduce the temperature of the chicken portions from 0 to -5ºC. Mean freezer temperatures measured over a 7 hr period following stabilisation ranged from -16.4 to -22.23ºC, with two freezers (1 fft and 1 ffb) above the required temperature. However, in both cases individual temperature readings regularly dropped to -18ºC or below in a cyclical fashion. The top-loading freezer exhibited the largest fluctuation in temperatures (SD 1.718), ranging from -14 to -18ºC.

The mean freezing times required to reduce sample temperatures from 0 to -5ºC ranged from 272.8 to 310 minutes, which were 53.7 to 103.7 minutes faster than the mean times recorded in the original survey (Table 13). This is not unexpected given that these freezers were operating at a lower mean temperature of -19.46ºC (versus -16.56ºC; Figure 3) and the samples used here were slightly smaller (33 – 44 g weight difference from previous survey for skin-off and skin-on samples respectively).

Table 23: Freezer temperatures and respective freezing times (minutes) for skin-on and skin-off chicken breast samples

Freezer type	Mean Temp. (°C)	SD	Freezing time (0 to -5°C)			
			Skin-on, internal	Skin-on external	Skin-off, internal	Skin-off external
1 (ffb)	-17.38	0.412	246	339	366	417
2 (ffb)	-22.23	0.929	174	264	210	318
3 (c)	-18.56	0.556	372	295.2	381	363
4 (fft)	-16.40	1.718	250.8	237	204	198
5 (ffb)	-21.73	0.750	318	297	318	273
6 (c)	-20.46	0.140	276	219	291	291
Mean values:			272.8	275.2	295	310

Samples were thawed in fridges operating at mean temperatures ranging from -0.92 to +3.51ºC. The thawing period was defined as the time required for frozen samples to reach 0ºC (Table 24). As with the freezer data, some fluctuations in temperature were evident from the profiles and standard deviations, particularly for fridge 6. Only two of the six fridges operated at a mean temperature within the +2 to +4ºC range, with the remaining four fridges operating at temperatures below this. Thawing times were variable, ranging from 1104 to 4317 minutes (18.4 – 71.95 hrs), due mainly to differences in fridge temperatures. Thawing rates were therefore calculated to make further comparisons.

Table 24: Fridge temperatures, thawing rates and water loss for skin-on and skin-off chicken breast samples

Fridge	Mean Temp. (°C)	SD	Thawing rate from frozen to 0°C (°C/min)				Water loss (%)	
			Skin-on, internal	Skin-on external	Skin-off, internal	Skin-off external	Skin-on	Skin-off
1	2.51	0.808	0.015	0.017	0.013	0.012	6.9	6.7
2	0.09	1.195	0.016	0.015	0.019	0.016	7.2	7.1
3	0.93	1.145	0.013	0.014	0.016	0.015	8.6	8.6
4	1.17	0.692	0.014	0.011	0.011	0.010	6.9	5.7
5	-0.92	0.719	0.006	0.005	0.006	0.006	5.4	8.4
6	3.51	1.505	0.009	0.009	0.015	0.013	8.0	11.0
Mean values:			0.012	0.012	0.013	0.012	7.2	7.9

Thawing rates during refrigerated storage ranged from 0.005 to 0.019ºC/min, with the slowest rates recorded for fridges 5 and 6. Unfortunately these rates cannot be compared directly with previous thawing data as they only address thawing to a final temperature of 0ºC as opposed to ambient air temperature (Table 20). This difference in analysis was applied primarily because several samples did not reach ambient temperature during the measurement period, despite prolonged storage. However it is reasonable to comment that the rates shown in Table 24 would be somewhat slower than the rates recorded during room temperature thawing, particularly if the entire thawing curve to ambient temperature was analysed. Water losses from samples thawed at refrigerator temperatures were within the same range as those thawed at room temperature (Table 21).

The two samples thawed in fridge 6 were not consistent in terms of thawing rates with the skin-on sample taking almost a day longer to thaw than the skin-off samples. It is possible that one of the samples was located closer to the back of the fridge than the other, hence was possibly exposed to a colder temperature than the sample closer to the middle of the fridge. In the case of fridge 5, a very low ambient temperature of -0.92ºC clearly slowed the thawing rate of both samples substantially.

7 DISCUSSION

Email Survey

The email survey was a fast and relatively simple means of accessing information regarding ownership of different freezer types amongst ESR staff. The response rate of approximately 57% was however lower than expected. The use of voting buttons and sorting rules enabled responses to be automatically filtered into respective folders and counted upon completion of the survey. Of the 221 responses, 45 emails required follow-up to acquire additional information regarding their "more than one freezer" responses.

Based on the results of the email survey, fridge-freezers were found to be the most common freezer type found in domestic homes, accounting for 70.3% of all freezers considered. Upright fridge-freezers with bottom-loading freezer compartments outnumbered top-loading freezer compartments by a ratio of 2:1. This is slightly lower than Fisher and Paykel sales data suggesting a ratio of 3:1 (Angela Johnston, personal communication). Other freezer types reported included vertical and chest freezers, and side-by-side fridge-freezers.

Freezer Questionnaire

The subsequent questionnaire developed for the domestic freezer survey took into account all the freezer types identified in the email survey, and was distributed to 41 volunteers in the Christchurch area. One fridge with an ice box freezer section was included in the survey but the results obtained were not included in the overall analysis due to the substantially different behaviour of this freezer type. We were unable to survey side-by-side fridge-freezers as the 4 respondents with this uncommon freezer type were based on other sites.

Overall, fridge-freezers accounted for 65% of the 40 freezer types surveyed (22.5% top-loading; 42.5% bottom-loading) with the remaining 35% split evenly between vertical and chest freezers. These percentages and ratios are similar to those observed in the ESR-wide email survey, indicating that the freezer survey accurately represented these freezers in terms of prevalence. However, Fisher and Paykel sales data for chest versus vertical freezers (2:1) suggest that vertical freezers were slightly overrepresented in the survey (Angela Johnston, personal communication).

Fisher and Paykel freezers dominated the survey (47.5%) in terms of manufacturer, with 13 different makes reported in total. Just under half of the freezers (42.5%) were ≤ 5 years old while 15% were 21 years old or older. Although nearly three quarters of the freezers surveyed were relatively new (≤ 10 years old), only 55% of freezers were reported to have an automatic defrost function. According to Fisher and Paykel, all of their freezer types excluding chest freezers have automatic defrost functions, which started being incorporated approximately 20 years ago (Angela Johnston, personal communication). A higher positive response rate was expected, however there may have been confusion regarding freezer models other than Fisher and Paykel. The brands, ages, and configuration of the freezers observed in this study are in agreement with the data collected for the refrigerator survey in late 2004 (Gilbert *et al*., 2005; Gilbert *et al*., 2007).

Other factors for consideration in the questionnaire, particularly in relation to the freezing of chicken samples, were sample placement, existing freezer loading and dial/setting mechanism, all of which would be potentially expected to affect comparisons of freezer temperatures and freezing rates. Dial/setting mechanisms, which were commonly reported (96.1%) for refrigerators assessed in the domestic food practices survey (Gilbert *et al*., 2005; Gilbert *et al*., 2007) were less frequently reported for freezers. Only 40% of freezers had some form of mechanism to adjust temperature, with only 3 of the 16 respondents indicating that they "sometimes" adjusted the temperature.

Freezer Temperatures

The results of the questionnaire were then considered in relation to both the freezer air temperature and the temperature profiles of chicken portions subjected to a freeze-thaw cycle as defined in Section 2.2.3.

The mean temperature for all domestic freezers was -16.56°C, and was not influenced by freezer type, age, the type of defrost mechanism or whether the freezer temperature could be adjusted. Individually, freezer temperatures ranged from -11.47°C to -23.26°C (Figure 3) with only 27.5% of surveyed freezers operating at or below the commonly recommended freezer storage temperature of -18°C. Based on industry standards, up to 30.8% of freezers would fail to meet the minimum required temperature of -15ºC in any part of the freezer fully loaded (Angela Johnston, personal communication). Freezers selected for the second survey investigating refrigerated thawing had a mean temperature of -19.46ºC, but this was a small sample size (n=6) of freezers specifically chosen due to their colder operating temperatures.

Sample location and freezer loading both affected freezer temperature, with the top section of freezers 2 – 2.5°C warmer than the middle or bottom sections, and three quarters to fully loaded freezers operating at temperatures 1 to 2°C warmer than less loaded freezers. The effect of sample location makes sense in the context of cold air falling to the bottom of freezers; the lower compartments would therefore be expected to be colder. This effect was also observed in the refrigerator survey (Gilbert *et al.,* 2005; Gilbert *et al*., 2007) where mean temperatures were higher on top shelves than on bottom shelves. The effect of higher loadings on temperature suggests that freezers lose some efficiency as the loading increases.

Chicken Freezing Data

Freeze-thaw data were collected for fresh skin-on and skin-off chicken breast portions frozen in domestic freezers overnight and then thawed at room temperature. Temperature profiles plotted in MATLAB showed several reproducible phases of temperature change and stabilisation associated with changes in ambient conditions and the formation/melting of the ice fraction within samples for all freezers.

To compare freezing results, the time required for samples to pass through a fixed temperature change from 0°C to -5°C was selected to facilitate analysis. The assumption made was that samples in freezers with slower rates of freezing would take longer to pass through this temperature range than those in freezers with faster rates of freezing.

No significant differences in freezing time were observed for skin-on versus skin-off samples, or internal versus external temperature measurements. Mean freezing rates over this period ranged from 0.014 to 0.015°C per minute, significantly slower than the 1°C per minute slow freezing rate defined in literature. However, the freezing rates calculated here represent only a portion of the overall freezing process. Mean freezing times calculated from the second survey were faster than in the first survey, which is not unexpected given that the freezers were operating at lower temperatures and the sample sizes were smaller.

Fridge-freezers with top-loading freezer compartments lowered the temperature of chicken portions significantly faster than their bottom-loading equivalents, but were not significantly different to chest and vertical freezers overall.

As expected, the freezer temperature differences noted for different sample locations and freezer loadings translated into significant differences when chicken portions were frozen. Samples loaded into top sections of freezers or into highly loaded freezers took significantly longer to freeze, due presumably to the higher freezer air temperatures encountered under these conditions.

Although not considered in the statistical analysis, freezers with an automatic defrost mechanism took approximately 0.5 hours longer to freeze chicken samples than manual defrost freezers. This delayed freezing could be due to the occurrence of automatic defrost cycles during the early stages of the freezing process (as illustrated in Figure 4) which would increase air temperatures for short periods of time. However, further analysis of defrost spike locations in the automatic defrost freezer data did not show significant differences based on when during freezing the defrost spike(s) actually occurred.

Information on the effect of freezing on bacteria in general and *Campylobacter* in particular has been assembled by two previous ESR projects (Turner, 2004; Lake *et al*., 2006). The literature indicates that the survival of bacteria is related to the rate of freezing. Bacterial destruction in foods frozen at slow rates (e.g. 1°C per minute) is mainly due to osmotic stress and/or dehydration rather than mechanical damage caused by extracellular ice formation. The formation of intracellular ice crystals occurs only at higher rates of freezing (>10°C per minute) and is therefore of limited importance in terms of frozen foods (Gill, 2002). Experiments with *Campylobacter* on frozen meat or poultry indicate that most destruction occurs early in the process (days), and prolonged storage (weeks) does not markedly reduce numbers further. It seems reasonable to anticipate that most destruction caused by storage in domestic freezers also occurs early in the process.

The New Zealand risk model for *Campylobacter* in poultry assumed that both commercial and domestic freezing would result in a 2 $\log_{10}$ cfu per carcass reduction in bacterial numbers. The model developed in the Netherlands (Nauta *et al*., 2005), using unpublished data, differentiated between commercial freezing (14 days freezing period, pessimistic:best:optimistic reductions of 0.9:1.7:3.2 logs respectively from experimental data) and domestic freezing (estimated as being only for 2 days and therefore 1/7 of the reduction in the commercial setting). However, if most of the bacterial destruction occurs early in the freezing process (within 1 day of storage) as appears to be the case (Georgsson *et al*., 2006) then the lower reduction assumed for domestic freezing may be an underestimate.

Chicken Thawing Data

The temperature changes associated with thawing at room temperature were highly variable due to differences in the starting temperatures of frozen chicken portions and also changeable weather conditions which would impact on "room temperature". Rates of thawing were therefore calculated over the entire freezing profile (although thawing does not occur at a uniform rate) to allow comparisons to be made.

The external surface thawing rates for skin-off samples varied from 0.03°C to 0.08°C per minute (mean rate of 0.06). Thawing location and the ambient temperature on the day of testing would have influenced these results. For example, the sample with the slowest thawing rate was defrosted in a microwave oven (not switched on) where the final ambient air temperature only reached 19°C. On the other hand, the sample with the highest rate of thawing was defrosted on top of the freezer in a garage on a day when the ambient air temperature reached 27°C.

In certain cases, it was difficult to establish from the temperature profiles whether the external temperatures had stabilised or not as some survey participants placed samples into fridges after thawing before the end of the data logger temperature-recording period. Maximum temperatures were used for analysis in this situation but given that these may not have been true final temperatures, they may have artificially inflated thawing rates.

Thawing at refrigeration temperatures was as expected slower, with samples taking from 18 hrs to nearly 3 days to reach 0ºC. This variation would be primarily due to differences in fridge temperature although the location of samples within the fridge may have had some influence as well. Difficulties were encountered in applying the same approach to data analysis as described for the room temperature thawed samples, therefore a direct comparison of thawing rates cannot be applied. This was mainly due to the fact that several samples failed to reach the ambient temperature of the fridge in which they were being thawed over the 3 day survey duration.

It should be noted that temperature adjustments were required for five of the six fridges used for the refrigerated thawing survey, as all were operating at temperatures above +4ºC. This was unsurprising given that the refrigerator survey identified about 55% (70/127) of consumer fridges operating at temperatures greater than 5ºC (Gilbert *et al*., 2005; Gilbert *et al*., 2007). It is likely (based on anecdotal evidence) that consumers adjust their fridges to temperatures above 4ºC to prevent freeze damage to more sensitive foods, particularly salad vegetables such as cucumbers. Giving specific advice to consumers regarding storage temperatures should take this aspect into consideration. It was also noted that individual adjustments made to the fridge of combined fridge-freezers had an impact on the operating temperature of the freezer compartment. It is possible that some of the warmer freezer temperatures encountered in these surveys are a consequence of warmer fridge operating temperatures, and that consumers are unaware of this relationship.

In the survey of domestic food handling practices (Gilbert *et al*., 2005) the most commonly reported thawing procedure for meat/poultry (a small chicken was given as an example) was "all day or all night" at room temperature. This suggests 8 to 12 hours, i.e. 480 - 720 minutes. The data in Table 20 indicate that the period required for the chicken breast portions to reach temperatures approaching ambient had a mean of 686 minutes (standard deviation 119.077 minutes). Based on the temperature profile for the bottom-loading freezer in Figure 4, at least 186 to 252 minutes elapsed before samples reached 0ºC, and the increase in sample temperature thereafter was approximately 3ºC every 60 minutes up to a final ambient temperature of +18ºC. This information suggests that the period such food spends at ambient temperature is limited, as therefore is the potential for bacterial growth. This supports the conclusions from experimental studies with *Salmonella*, *E. coli* and *Staphylococcus aureus* on thawing chicken or minced beef (Ingham *et al*., 2005) where the thawing of food at room temperature was described as not particularly hazardous. In terms of *Campylobacter*, the thawing temperature will not affect cell numbers from a potential growth perspective, but its effect on survival is not clear (Georgsson *et al*., 2006) and warrants further investigation.

Thawing at refrigeration temperatures does not expose foods to temperatures where significant pathogen growth would be an issue, but it may introduce other issues such as the potential undercooking of only partially thawed meat. From a consumer perspective, thawing in the fridge is too slow and requires more "forward thinking" in terms of removing frozen meats well in advance of requirements. It seems likely that the inconvenience of refrigerated thawing is the main driver for the common practice of room temperature thawing.

Sample water loss was also calculated after the freeze-thaw cycle. Skin-on and skin-off samples had mean water loss percentages of 6.9 and 6.3 respectively following room temperature thawing, ranging from 2.6 – 12.6% for individual samples. Refrigerated thawing produced similar water loss values within this range, from 5.4 – 11.0%, suggesting that thawing at different temperatures does not influence the amount of water loss occurring.

8 CONCLUSIONS

This report describes both the results of an email survey regarding the prevalence of different freezer types in New Zealand, and quantitative temperature data regarding the air temperature and freezing behaviour of domestic freezers. Freezer type, sample location and freezer loading were identified as statistically significant and interactive factors affecting the freezing of chicken portions in a variety of domestic freezers. These warrant further investigation regarding their significance in terms of reductions in levels of *Campylobacter*.

The data collected by this survey will provide valuable information on the temperatures encountered by food during domestic freezing and thawing that can be used for a variety of risk models. The information on the temperatures at the surface and within poultry placed in such freezers will also allow a more detailed experimental examination of the effect of freezing as a potential consumer-level intervention strategy to tackle the *Campylobacter* problem in New Zealand.

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APPENDIX 1: FREEZER SURVEY INSTRUCTIONS AND QUESTIONNAIRE – ROOM TEMPERATURE THAWING

Freezer survey: determining the freezing and thawing rates of chicken portions in domestic situations

Hi. We are carrying out some research for the New Zealand Food Safety Authority into freezers, their temperatures, rates of freezing and also the rate of thawing. We are using chicken portions, skin on and skin off as our test food. We are asking members of staff at ESR to take part. We need information from 40 freezers in total.

The study involves taking two chicken portions home with you. Four "i-Button" temperature data loggers will be attached to the chicken portions to measure sample freezing and thawing temperatures. A fifth logger will be used to measure the temperature of your freezer and later to measure the ambient temperature of your kitchen while the chicken is defrosting on your bench. Please follow the instructions below. We advise that you read them twice through to avoid any misunderstandings!

Instructions:

- COMPLETE THE QUESTIONNAIRE ATTACHED AND ALSO DON'T DELAY PUTTING THE CHICKEN INTO THE FREEZER WHEN YOU REACH HOME
- You will be given two packs of chicken portions in a chilly bag in the afternoon (around 4pm). Each portion will have 2 data loggers attached (on the surface and internally). In the evening when you return home (preferably before 6pm) remove the samples from the chilly bag and place them as is into your freezer, in a position where you would normally freeze raw chicken. Ensure the surface data loggers are fully in contact with the surface.
- Take the 5th data logger out of its own bag and tie or place the logger (metal side up) on a shelf or basket as near as possible to the chicken – we want to measure the air temperature so avoid placing the metal button next to insulated walls or directly against food items.
- The data loggers will automatically turn on at 4pm and will record continuously for the next two days.
- PLEASE DO NOT DEFROST YOUR FREEZER and if possible avoid opening it once the chicken samples have been placed inside!
- The following morning, just before you come to work to allow maximum freezing time, take the bagged chicken portions and the 5th data logger out of the freezer and place the chicken as is on your kitchen

bench. It is advisable to place a plate beneath to catch the drips. Make sure the chicken will not be in direct sunlight. Place the 5th data logger near by (metal side up) (again not in direct sunlight – it will send the i-button crazy!) – this will record the ambient temperature of the kitchen while the chicken defrosts.

- If you have inquisitive pets, place the chicken and the 5th logger into a room that can be closed off from them, such as a laundry.
- If you use any other location other the kitchen/laundry benchtop, i.e. cupboard, microwave oven (used solely as a cupboard!) then please write location on the questionnaire. We would prefer room temperature bench top defrosting where possible, followed by cupboards.
- Leave the chicken defrosting until the following morning*, then place the chicken portions and the 5th data logger in the chilly bag. To contain the drip in the chilly bags, please place the samples into a plastic carrier bag before placing back into the bag. Return the bags with questionnaires please to Sue Gilbert or Glenn Bayne (Room 240) as soon as you arrive at work.

* The experiment finishes when the chicken has fully defrosted, therefore if you wish to place the chicken back into refrigeration overnight or place in the chilly bag with the frozen icepack overnight before bringing the bag back in, this will be ok. Leave the questionnaire beneath the bag so that it is clear which questionnaire belongs to which chicken.

All information collected will be anonymised, there are no questions asking for your name or address. We have assigned numbers only to link the questionnaire and the i-Buttons.

THANKS FOR TAKING PART IN THE STUDY

Domestic freezers: Questionnaire No………………………………..

Question 1: Please tell us the make and model of your freezer: ……

Question 2: We'd like to know the approximate age of your freezer; please tick **one** of the following boxes:

0 - 5 years	6-10 years	11-15 years	16-20 years	More than 21

Question 3: Which description below best describes your freezer?

Descriptions	Please tick **one**
Front opening fridge-freezer with the freezer on top	
Front opening fridge-freezer with the freezer on the bottom	
Front opening vertical freezer	
Top opening chest freezer	
Front opening side-by-side fridge-freezer	
Ice box inside fridge	

Question 4: Does your freezer have an automatic defrost function? YES ☐

NO (manual defrost) ☐

Question 5: Where in your freezer are you placing the chicken to be frozen?

Top ☐ Middle ☐ Bottom ☐

Question 6: How fully loaded is your freezer?

Full ☐ ¾ full ☐ ½ full ☐ ¼ full ☐ Less than ¼ full ☐

Question 7: If you have a dial or setting mechanism to make your freezer hotter or colder, what is the dial currently set to out of what range?. For example, "no. 5 out of settings 1 to 6" ……………………………………………………………

Do you ever change the settings? Never ☐ Sometimes ☐ Often ☐

Question 8: Did you open the freezer door while the chicken was freezing?

YES ☐ please give approximate times……………………………………………NO ☐

Important: Location of defrosting if not on the benchtop……………………………

APPENDIX 2: FREEZER SURVEY INSTRUCTIONS AND QUESTIONNAIRE – REFRIGERATED THAWING

Freezer and defrosting survey: determining the freezing and thawing rates of chicken portions in domestic freezers and refrigerators

Congratulations – you are one of six households selected for the second part of this research.

By now you will be aware that we have been tweaking your fridges and freezers to operate at air temperatures between 2 & 4°C and –18°C respectively. This is for research we are conducting for the New Zealand Food Safety Authority into rates of freezing and thawing at these specific temperatures in domestic appliances. We are using two chicken portions per appliance as our test food.

The study involves taking two chicken portions home with you on Friday night (30th March). The dataloggers will already be inserted and will turn on at around 5pm. You will also be provided with a datalogger in a separate small bag (do not take out of the bag) to measure the air temperature alongside the chicken.

THINGS TO REMEMBER!
PLEASE DO NOT DEFROST YOUR FREEZER OR MAKE TEMPERATURE ADJUSTMENTS DURING THE SURVEY.

INSTRUCTIONS

1. FRIDAY AFTERNOON: PUT THE CHICKEN PORTIONS AND DATALOGGER INTO THE FREEZER BETWEEN 5PM AND 6PM

2. SATURDAY MIDDAY: TAKE THE CHICKEN & DATALOGGER OUT OF THE FREEZER AND PLACE IN THE BOTTOM OF YOUR REFRIGERATOR (ON A PLATE TO PREVENT DRIPS), WITH THE DATALOGGER ALONGSIDE

3. WEDNESDAY MORNING: REMOVE THE CHICKEN SAMPLES AND LOGGERS FROM THE FRIDGE AND RETURN TO ESR.

We already know quite a lot about your fridge and freezer so unless you've changed your freezer since the last survey we only have a few questions this time around:

P.T.O.

Name……………………………………..

Question 1: Where in your freezer are you placing the chicken to be frozen?

Top ☐ Middle ☐ Bottom ☐

Question 2: How fully loaded is your freezer?

Full ☐ ¾ full ☐ ½ full ☐ ¼ full ☐ Less than ¼ full ☐

Question 3: If you have a dial or setting mechanism to make your freezer hotter or colder, what is the dial currently set to out of what range? For example, "no. 5 out of settings 1 to 6"

THANKS FOR TAKING PART IN THE STUDY