# The Sea Fish Industry Authority
## Seafish Technology


# Trials to Compare the Thermal Performance of a New Design of Tri-pack Corrugated Plastic Non-reusable fish box with Expanded Polystyrene and Single Walled Fibreboard Boxes


Report No. CR192



M. Anyadiegwu
M. Archer



December 2002

**Sea Fish Industry Authority**
Seafish Technology

# Trials to Compare the Thermal Performance of a New Design of Tri-pack Corrugated Plastic Non-reusable fish box with Expanded Polystyrene and Single Walled Fibreboard Boxes

Confidential Report No. CR192

M. Anyadiegwu
M. Archer
December 2002


## Summary

Trials were carried out to compare the thermal properties of expanded polystyrene (EPS), single walled fibreboard (SWF) and corrugated plastic (CP) boxes. The boxes were tested in an environmental chamber and fish fillet temperature in each box was recorded for two time-temperature profiles.

The first profile represented an interrupted chilled chain distribution over 66 hours, such as by airfreight, and the second profile represented a controlled chilled distribution of 72 hours, such as by road transport. Fillets in each box were chilled using a single frozen gel-ice pack placed on top of the fillets, or using ice.

The EPS box was most effective at maintaining low fillet temperature for both temperature profiles and cooling methods. The CP box had similar but slightly better insulative properties than the SWF box. Ice chilling of fillets was more effective than a single gel-ice pack at maintaining low fillet temperatures for both temperature profiles.

At the end of the trials using ice, the amount of melt water produced exceeded the capacity of the absorbent pad used. The ratio of ice used and/or absorbent pad capacity needs careful consideration to prevent fillets from soaking in melt water in non-draining boxes.

Where fish is distributed in an uncontrolled chilled distribution chain, boxes with greater insulative properties, such as EPS would be advisable in order to maintain low product temperatures. Where fish is distributed in a strictly controlled distribution chain, it would be beneficial to use boxes with less insulation, to allow chill temperatures to influence product temperatures.

# Contents:



## Appendices:

# 1. Introduction

It is important to keep fish as close to temperature of melting ice as possible in order to maintain freshness quality. Packaging protects product integrity and may offer some protection against ambient temperatures and/or temperature abuse.

Six years ago, Seafish carried out trials to investigate the thermal properties of different types of non-reusable fish boxes. This work involved testing the insulative properties of expanded polystyrene boxes (EPS), single walled fibreboard (SWF), corrugated board and corrugated plastic (polypropylene) (CP) packaging. Tests were carried out using an environmental chamber to simulate typical handling and temperature profiles experienced in chilled fish distribution. Since that time, box designs have changed and new products have come into the market. The distribution chain has also seen some changes including the use of gel ice packs and improved temperature control. Hence there is a need to update information in this area.

Seafish was asked by Tri-pack Plastics who were involved in the original trials to test their latest CP fish box design. This report is concerned with a series of trials to compare the thermal performance of a recently developed Tri-pack CP box against EPS and SWF boxes that are commonly used in industry. The fish fillet temperature in each box was recorded for two time-temperature profiles. The first profile represented an interrupted chilled distribution chain over 66 hours, such as airfreight. The second profile represented a controlled chilled distribution chain of 72 hours, such as road transport. Fish in each box was chilled using a single frozen gel-ice pack, placed on top of the fillets. The trials were then repeated using ice as a coolant.

The trials were carried out in August and September 2002.

# 2. Common Equipment and Methodology

## 2.1 Trials Equipment

### Refrigeration and temperature monitoring

A Cee-Tel environmental chamber (model c/o 423) with a Eurotherm 421 control system was used to control the ambient temperature during the trials. A Grant Squirrel 1000 series, 8 channel data logger with type T thermocouples was used to record the data. All the probes were calibrated to $0^oC$ in melting ice prior to the trial. Following the trial, the data was transferred to a PC for analysis.

### Box details

In total, three types of non-reusable fish box were tested, comprising EPS, SWF and CP. The CP boxes were supplied by Tri-pack Plastics whilst SWF and EPS boxes were supplied by other packaging box manufacturers. All of the boxes were 6.5kg (1 stone) capacity and are described in Table 1.

**Table 1. Description of the fish boxes used for trial studies**

| Fish Box | Description |
|---|---|
| EPS | The boxes and lids were made of moulded polystyrene beads comprising 98% air by volume. Internal dimensions were 380 (l) x 242 (w) x 125mm (h).<br>The base of the EPS box had studs (15 mm high) to support a plastic separator. |
| SWF | The boxes and lids were made from a water-resistant solid fibreboard lined with low density polyethylene film. The corners of the boxes were glued with water resistant glue. Internal box dimensions were 372 (l) x 245 (w) x 112mm (h)<br>The boxes were supplied as a fold flat box, a cardboard separator and underlying polystyrene chips. Each box used was assembled according to the manufacturer's guidelines. An assembled box was supplied for guidance. |
| CP | Boxes and lids were made from extruded corrugated plastic (polypropylene) sheet comprising thin skins over a central corrugate to create a layer of trapped air between the plastic sheets. Internal dimensions were 365 (l) x 240 (w) x 140mm (h).<br>Each box was supplied with a plastic separator with integral supports to enable fish to stand clear of the bottom of the box. |

Each box had a food grade plastic bag liner to prevent leakage, with an absorbent pad placed on the bottom followed by either a plastic or cardboard separator to keep the fish away from the pad. The absorbent pad consisted of an acrylate powder enveloped on one side by a non-stick plastic laminate, and on the other a non-woven polyester fabric for easy passage of fluids. Each absorbent pad (approximately 263 x 93mm) consisted of a single compartment (approximately 246 x 69mm) containing the acrylate polymer powder.

With the SWF box, some polystyrene chips were placed around the pad followed by the cardboard separator. The plastic bag liners and plastic separators were purchased from the fish box suppliers.

To replicate industry practice, either ice or a gel-ice pack was used as a chilling medium. Ice was produced using a Ziegra ice machine (Model ZBP 250), while gel-ice packs and absorbent pads were supplied by Styropack.

The gel-ice pack consisted of an acrylate polymer powder, enveloped on one side by a non-stick plastic laminate, and on the other a non-woven polyester fabric for easy passage of fluids. Each gel-ice pack (approximately 290 x 260mm) consisted of 12 small compartments (approximately 70 x 50mm), each containing a small quantity of acrylate polymer powder. The gel-ice packs were immersed in water for at least 30 minutes (to saturate with water) and were frozen at -18°C (laminated side down). The typical weight of the frozen gel-ice pack was 450g.

## 2.2 Common Experimental Method

Each box was packed according to current industry practice and was tested under two different time-temperature profiles to replicate two typical fish distribution chains. These were:

- 66 hours at varying ambient temperatures, with an average ambient temperature of 2.8°C and the fillets pre-conditioned to 4°C. This represented an interrupted chilled distribution chain, such as airfreight.
- 72 hours at a constant ambient temperature of 2°C, with the fillets pre-conditioned to 0°C. This represented a strictly controlled, chilled distribution chain such as road transport.

For each time-temperature profile, two different methods of direct cooling were used: ice and gel-ice packs. Therefore, each box was tested under the following four conditions:

- Trial 1 – Direct cooling by gel-ice whilst held at varying ambient storage temperatures for 66 hours
- Trial 2 – Direct cooling by top icing whilst held at varying ambient storage temperatures for 66 hours
- Trial 3 – Direct cooling by gel-ice whilst held at a constant ambient storage temperature of 2°C for 72 hours
- Trial 4 – Direct cooling by top icing whilst held at a constant ambient storage temperature of 2°C for 72 hours

Medium sized haddock fillets were either preconditioned in the environmental chamber to maintain a temperature of 4°C or held in melting ice to achieve a temperature of 0°C.

Each box was filled with 6Kg of haddock fillets placed on top of the separator. A thermocouple was inserted into a fillet located at the bottom-centre, middle-edge and top-centre of each box, to monitor the fillet temperature throughout the box.

To replicate industry practice, either a gel-ice pack or 2Kg of ice was placed directly on top of the fish. The plastic liner was then sealed using plastic adhesive tape. The box lid was then sealed in place using further adhesive tape. Another thermocouple was secured on top of the box to monitor ambient air temperature within the chamber.

Because of the limitations of the chamber and data logger, only 2 boxes could be tested at a time. Therefore, duplicate tests had to be carried out to make comparisons between the 3 box types. In practice the chamber replicated the demanded temperature conditions to within a fraction of a °C.

For trials with varying ambient temperature, the temperature of the environmental chamber was manually adjusted over a period of 66 hours, as shown in Table 2.

**Table 2. Ambient temperature profile over a period of 66 hours.**

| Temperature (°C) | Duration (Hours) |
|---|---|
| 15 | START 1 |
| 4 | 15 |
| 10 | 1 |
| -0.5 | 4.5 |
| 8.2 | 0.5 |
| 3.5 | 18 |
| 2 | 6 |
| 5.3 | 0.5 |
| 2.7 | 0.25 |
| 8.8 | 1.25 |
| 1.7 | 17 |
| 11.8 | FINISH 1 |
| **Total** | **66** |

This time-temperature profile was adapted from previous Seafish work where a data logger was placed in a road transport vehicle to monitor typical temperatures reached during different distribution chains used by industry. The time-weighted average ambient temperature of this profile is calculated to be 3.3°C.

# 3. Results and general discussion

Summaries of the results of each trial are included in this section. The detailed time-temperature profiles for all the trials carried out are included in the Appendix I – IV.

## 3.1 Trials with a variable ambient temperature for 66 hours

### 3.1.1 Trial 1 – Gel-ice pack cooling at varying ambient storage temperature

The average fillet temperatures at the top, middle and bottom of each box and the overall average fillet temperatures for each of the different boxes are shown in Table 3 and Figure 1. Detailed results are presented graphically in Figures 1.1, 1.2 and1.3 of Appendix I.

**Table 3. Average fillet temperature in EPS, SWF and CP boxes stored in a variable ambient temperature for 66 hours with a gel-ice pack placed on top of fillets.**

| Box Material | Thermocouple placement | Average fillet temperature (°C) | Overall average fillet temperature (°C) |
|---|---|---|---|
| EPS | Top centre | 2.7 | 3.0 |
| | Middle edge | 3.2 | |
| | Bottom centre | 3.2 | |
| SWF | Top centre | 4.0 | 3.9 |
| | Middle edge | 3.8 | |
| | Bottom centre | 3.9 | |
| CP | Top centre | 3.6 | 3.7 |
| | Middle edge | 3.7 | |
| | Bottom centre | 3.8 | |

Overall, there was only a small difference between the average temperature of fillets at the top, middle and bottom of each box type (Table 3). From detailed results in Appendix I, it was apparent that fillet temperature at the top of EPS and CP boxes were up to 2 and 1°C (respectively) colder than those at other parts of the box. This was due to the direct cooling effect of the frozen gel-ice pack. The difference in temperature lasted for 22 and 16 hours for EPS and CP boxes respectively, until fillet temperature in all parts equilibrated. This trend was not observed in the SWF box which showed only a marginal difference in fillet temperature (maximum of 0.5°C) at the top, middle and bottom of the box throughout the trial.

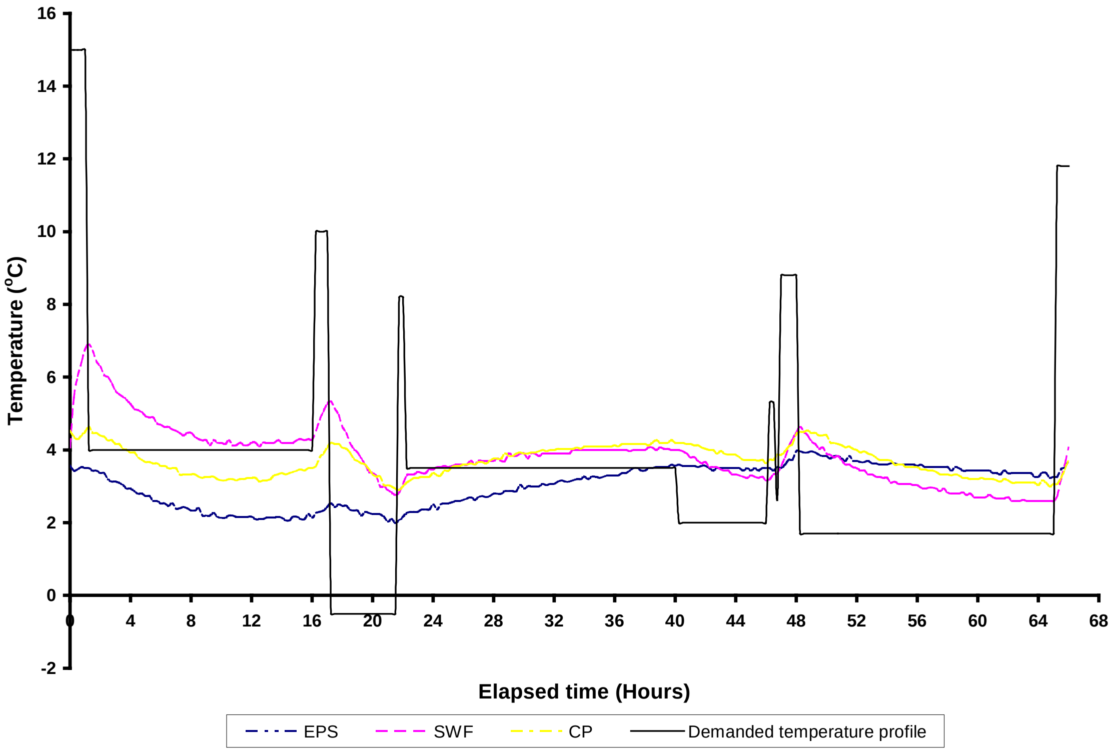


**Figure 1. Average fillet temperature in EPS, CP and SWF fish boxes held in a variable ambient temperature for 66 hours (gel-ice cooling of fillets)**

In all cases, average fillet temperature followed a similar trend in response to changes in ambient temperature.

During periods of elevated temperature (at hours 1, 16 - 18 and 46 - 48) the temperature of fillets in the SWF box increased faster than that in the CP box. Fillets in the EPS box showed a very small gradual rise in temperature during these periods. Conversely, a similar pattern is apparent during periods of cold ambient temperature (at hours 17 – 22 and 40 – 46). Fillet temperatures in the SWF and CP boxes fell, while fillets in the EPS box showed very little change in temperature. This reflects the high insulative properties of EPS compared to CP and SWF materials.

Overall, the EPS box held fillet temperature lowest, followed by CP and the SWF box.

### 3.1.2 Trial 2 – Top ice cooling at varying ambient storage temperature

The average fillet temperatures at the top, middle and bottom of each box and the overall average fillet temperature for each of the different boxes are shown in Table 4 and Figure 2. Detailed results are presented graphically in Figures 2.1, 2.2, and 2.3 of Appendix II.

**Table 4. Average fillet temperature in EPS, SWF and CP boxes stored in a variable ambient temperature for 66 hours with top icing of fillets.**

| Box Material | Thermocouple placement | Average fillet temperature (°C) | Overall average fillet temperature (°C) |
|---|---|---|---|
| EPS | Top centre | 0.1 | 0.5 |
| | Middle edge | 0.4 | |
| | Bottom centre | 1.1 | |
| SWF | Top centre | 1.0 | 1.8 |
| | Middle edge | 1.8 | |
| | Bottom centre | 2.6 | |
| CP | Top centre | 0.4 | 1.0 |
| | Middle edge | 0.9 | |
| | Bottom centre | 1.8 | |

Overall, there was a significant difference between the average temperature of fillet at the top, middle and bottom of each box. From detailed results in Appendix II, fillet temperatures at the top of EPS, SWF and CP boxes were significantly lower than that for fillet at lower sections of the box. This reflects the time it took for the ice to melt and cool all fillets during the trial. When using ice, Seafish recommends top and bottom icing which reduces this problem. There was only a marginal difference in fillet temperature at the top, middle and bottom of all boxes at the end of the trial.

During the first hour of elevated ambient temperature, average fillet temperatures in EPS, SWF and CP boxes fell. After 32 hours, the temperature of fillets in the SWF box increased slightly faster than that in the CP box. Fillets in the EPS box showed very little change.

Overall, the EPS box was best at holding fillet temperatures close to that of melting ice, followed closely by the CP box and then the SWF box. However, all boxes held the fillet temperature at low levels.

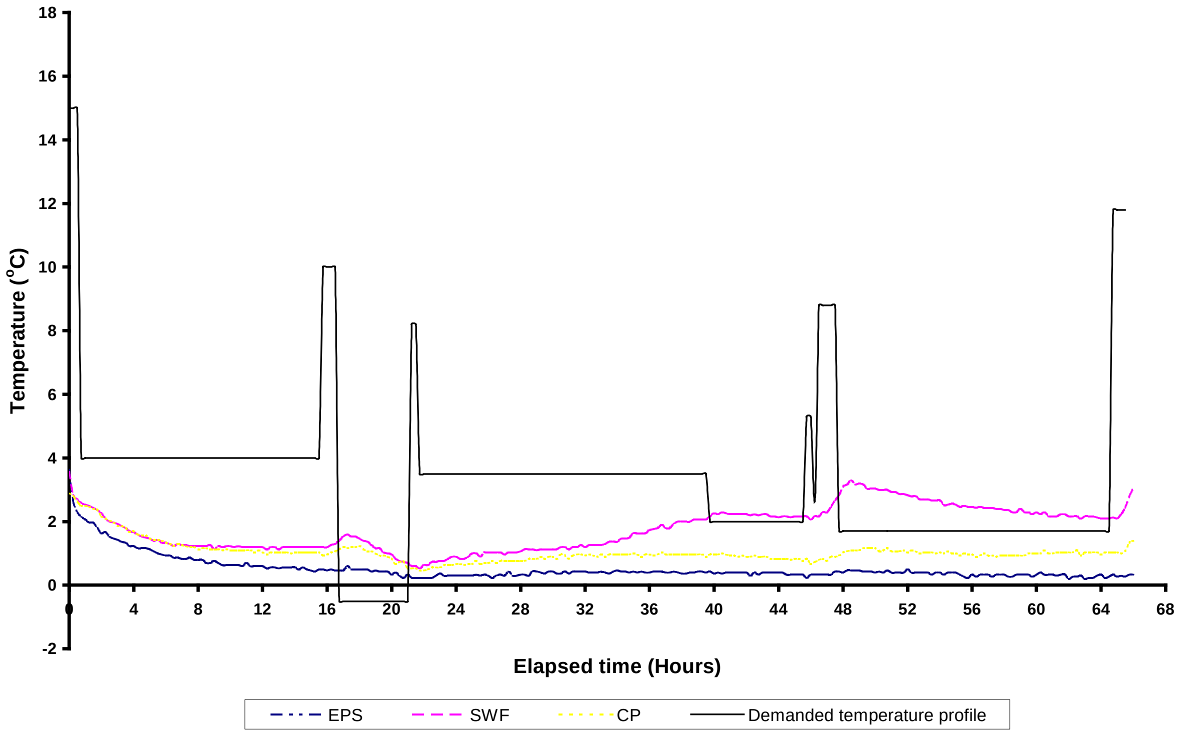


**Figure 2. Average fillet temperature in EPS, CP and SWF boxes held in a variable ambient temperature for 66 hours (top icing of fillets)**

In all cases, average fillet temperatures were significantly lower than in the trial using a single gel-ice pack, showing that the ice was a more effective cooling medium than a single gel-ice pack.

At the end of the trial period, some ice remained in EPS and CP boxes but not in the SWF box. However, a major problem observed with top icing using this box arrangement was that the absorbent pad at the bottom of each box could not soak up the volume of melt water produced. As a result, fish fillets were left standing in the melt water that was retained in the bottom of the box.

## 3.2 Trials with a constant ambient temperature of 2°C for 72 hours

### 3.2.1 Trial 3 – Gel-ice pack cooling at constant ambient storage temperature

The average fillet temperatures at the top, middle and bottom of each box and the overall average fillet temperature for each of the different boxes are shown in Table 5 and Figure 3. Detailed results are presented graphically in Figures 3.1, 3.2 and 3.3 of Appendix III.

**Table 5. Average fillet temperature in EPS, SWF and CP boxes stored at a constant ambient temperature of 2°C for 72 hours with a gel-ice pack placed on top of fillets.**

| Box Material | Thermocouple placement | Average fillet temperature (°C) | Overall average fillet temperature (°C) |
|---|---|---|---|
| EPS | Top centre | 0.9 | 1.1 |
| | Middle edge | 1.3 | |
| | Bottom centre | 1.2 | |
| SWF | Top centre | 1.5 | 1.7 |
| | Middle edge | 1.8 | |
| | Bottom centre | 1.8 | |
| CP | Top centre | 0.9 | 1.3 |
| | Middle edge | 1.4 | |
| | Bottom centre | 1.5 | |

Overall, there was only a small difference between the average fillet temperature at the top, middle and bottom of the different box types. Fillet temperatures in all boxes increased slowly during the trial. Fillet temperatures in both SWF and CP boxes appeared to increase at a similar rate. Average fillet temperature in the SWF and CP boxes reached 2°C after 44 and 58 hours, respectively. This difference could have been due to the slightly different initial fillet temperatures. Fillet temperature in the EPS box remained under 2°C throughout the trial.

Overall, the EPS box held fillets at the lowest temperatures for the longest period.

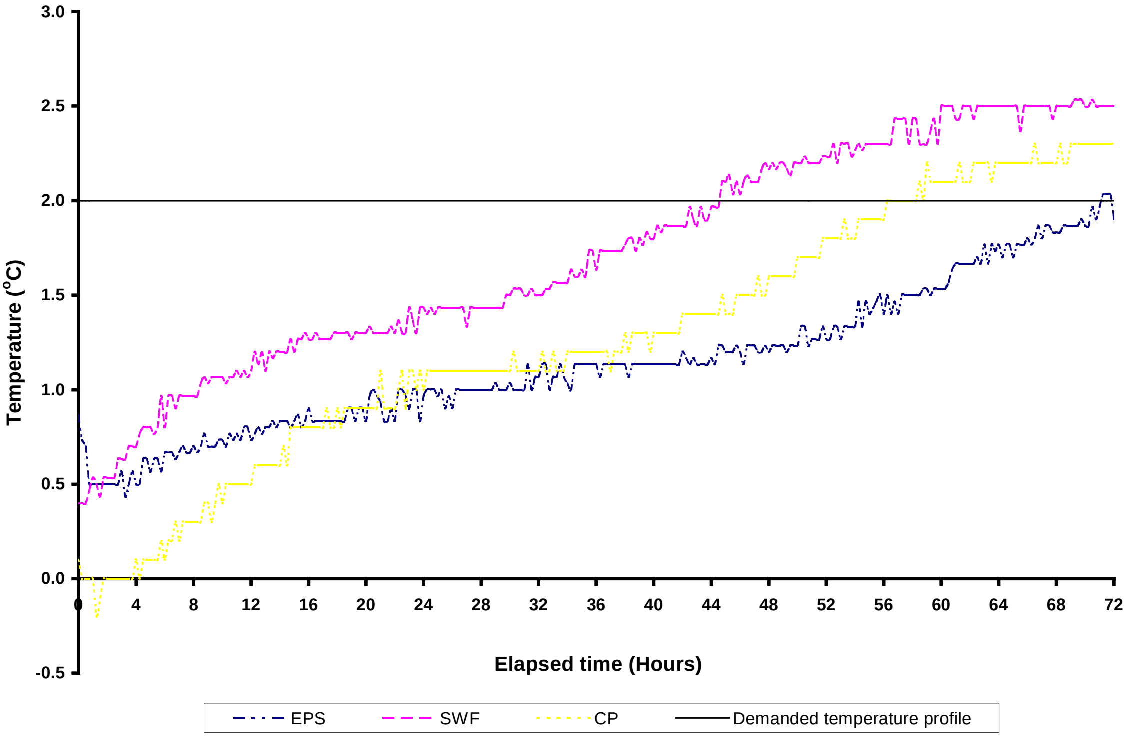


**Figure 3. Average fillet temperature in EPS, SWF and CP boxes held in a constant ambient temperature of 2°C for 72 hours (gel-ice cooling of fillets)**

### 3.2.2 Trial 4 – Top ice cooling at a constant ambient storage temperature

The average fillet temperatures at the top, middle and bottom of each box and the overall average fillet temperature for each of the different boxes are shown in Table 6 and Figure 4. Detailed results are presented graphically in Figures 4.1, 4.2 and 4.3 of Appendix IV.

**Table 6. Average fillet temperature in EPS, SWF and CP boxes stored at a constant ambient temperature of 2°C for 72 hours with top icing of fillets.**

| Box Material | Thermocouple placement | Average fillet temperature (°C) | Overall average fillet temperature(°C) |
|---|---|---|---|
| EPS | Top centre | -0.1 | 0 |
| | Middle edge | 0 | |
| | Bottom centre | 0.1 | |
| SWF | Top centre | -0.1 | 0.6 |
| | Middle edge | 1.0 | |
| | Bottom centre | 0.8 | |
| CP | Top centre | 0 | 0.4 |
| | Middle edge | 0.6 | |
| | Bottom centre | 0.6 | |

Overall, there was a small difference between the fillet temperature at the top, middle and bottom of the different box types. An initial fall in average fillet temperature was observed in all boxes. Subsequently, average fillet temperature in the SWF and CP boxes appeared to rise at the same rate. Average fillet temperature in the SWF box was slightly higher than that in the CP box throughout the trial. Average fillet temperatures in the EPS, SWF and CP boxes reached maximum temperatures of 0.2, 0.9 and 0.8°C, respectively by the end of the trial.

Overall, the EPS box was best at holding fillet temperature close to temperature of melting ice (0°C), closely followed by CP and SWF boxes. All fish boxes held fillet temperature at a level that will cause little adverse effects on fish quality. Overall, fillet temperatures were lower when ice was used compared to trials using a single gel ice pack.

At the end of the trial, more ice than that observed during trials at a variable ambient temperature remained in all fish boxes. Fillets at the bottom of the boxes were in direct contact with melt water.

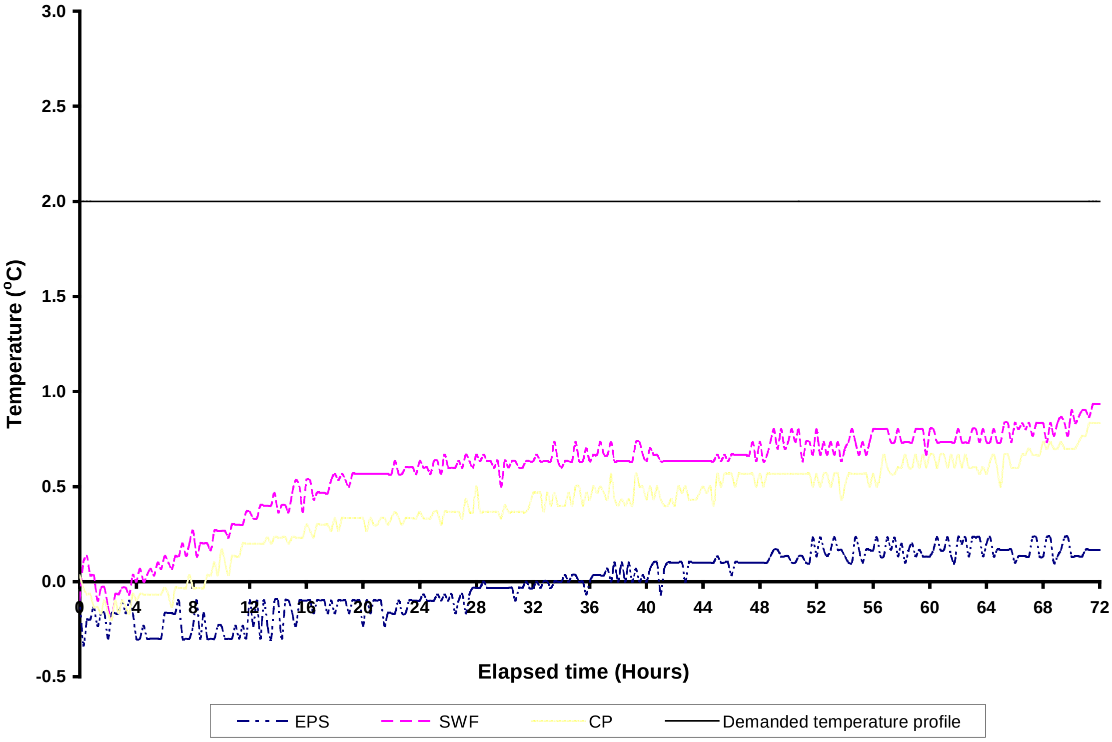


**Figure 4. Average fillet temperature in EPS, SWF and CP fish boxes held in a constant ambient temperature of 2°C for 72hours (top icing of fillets).**

# 4. Overall Discussion and Conclusions

**Trials with a variable ambient temperature for 66 hours**

- The EPS box was best at maintaining low average fillet temperature for both cooling methods.
- When using gel-ice, there was little difference in thermal performance between CP and SWF boxes, although the CP box was more effective than SWF at maintaining low average fillet temperature over the first 20 hours of the trial. A single gel-ice pack did not provide effective chilling.
- When using ice, the CP box was more effective than SWF at maintaining lower average fillet temperatures through the duration of the trial. Ice chilling was more effective.
- All fish boxes were influenced to various degrees by changes in ambient temperature but the response of the EPS box was relatively small because of its insulative properties.

**Trials with a constant ambient temperature of 2°C for 72 hours**

- The EPS box was most effective at maintaining a low average fillet temperature for both cooling methods, followed by CP and SWF boxes, respectively, although all boxes provided adequate performance, particularly when using ice.

**Overall Conclusions**

- Overall the EPS box provided the best thermal protection, followed by the CP and then the SWF box.
- A temperature gradient was observed between fillets at the top, middle and bottom of each box for both cooling mediums. Fillets at the top of each box remained the coolest. However, by the end of each trial, temperatures had generally equalised.
- Using ice as a coolant was far more effective than the single gel-ice pack at maintaining low average fillet temperature.
- The practice of lining the boxes was not suitable for ice chilling, as melt water collected in the bag and was observed to be in contact with fillets at the bottom of the fish boxes used. There are hygiene requirements which stipulate that melt water should be kept away from fish products. If a liner is to be used, an absorbent pad with sufficient capacity to absorb all the melt water must be used.

- In general when using ice as a coolant, Seafish recommend that ice should be added on the top and bottom of the fish box, in order to rapidly cool fish fillets in all sections of the box.

- When using gel-ice as a coolant, particularly when exposed to high ambient temperatures, more than one pack would be required to effectively cool the fillets. The appropriate number of gel-ice packs would need further investigation.

- Where fish is distributed in uncontrolled chilled distribution chain, the use of boxes with greater insulative properties such as EPS would be advisable, as product temperature can rise quite quickly at elevated ambient temperatures.

- In the simulated complete chilled distribution chain, all boxes performed satisfactorily in holding low fish temperature close to 0°C. In this situation, it may also be beneficial to have less insulation in some circumstances to allow the chill temperatures to influence product temperatures.

- As a general observation, using 6Kg fish and 2Kg ice (typical industry practice), all boxes appeared to be overfilled. This may lead to the crushing/damage of the fish when these boxes are stacked.

# Appendix I

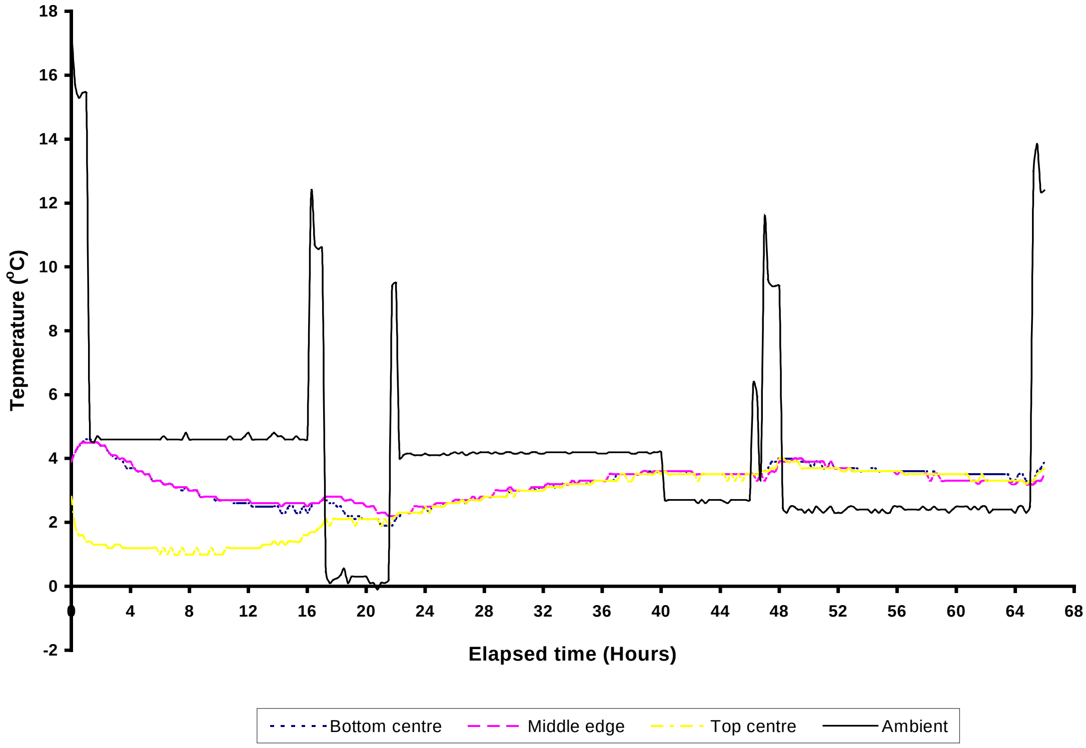


**Figure 1.1. Average fillet temperature in the EPS box held in a variable ambient temperature for 66 hours (gel-ice cooling of fillets)**

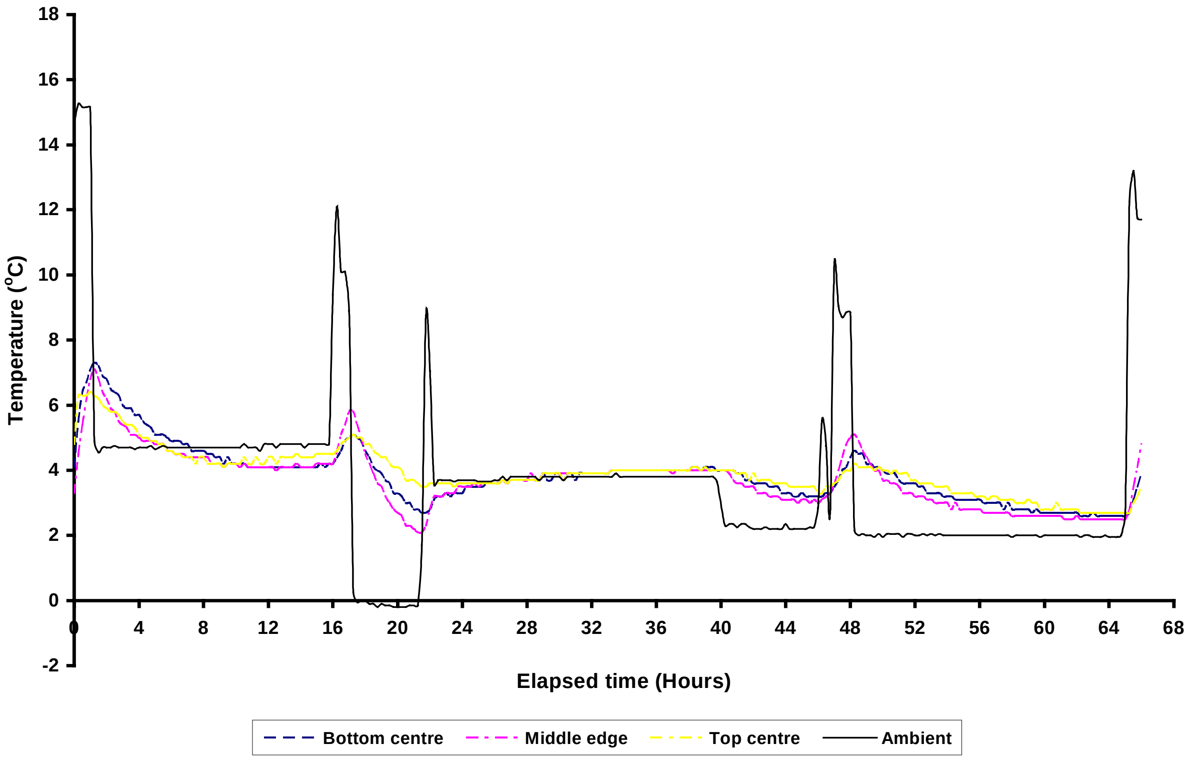


**Figure 1.2. Average fillet temperature in the SWF box held in a variable ambient temperature for 66 hours (gel-ice cooling of fillets)**

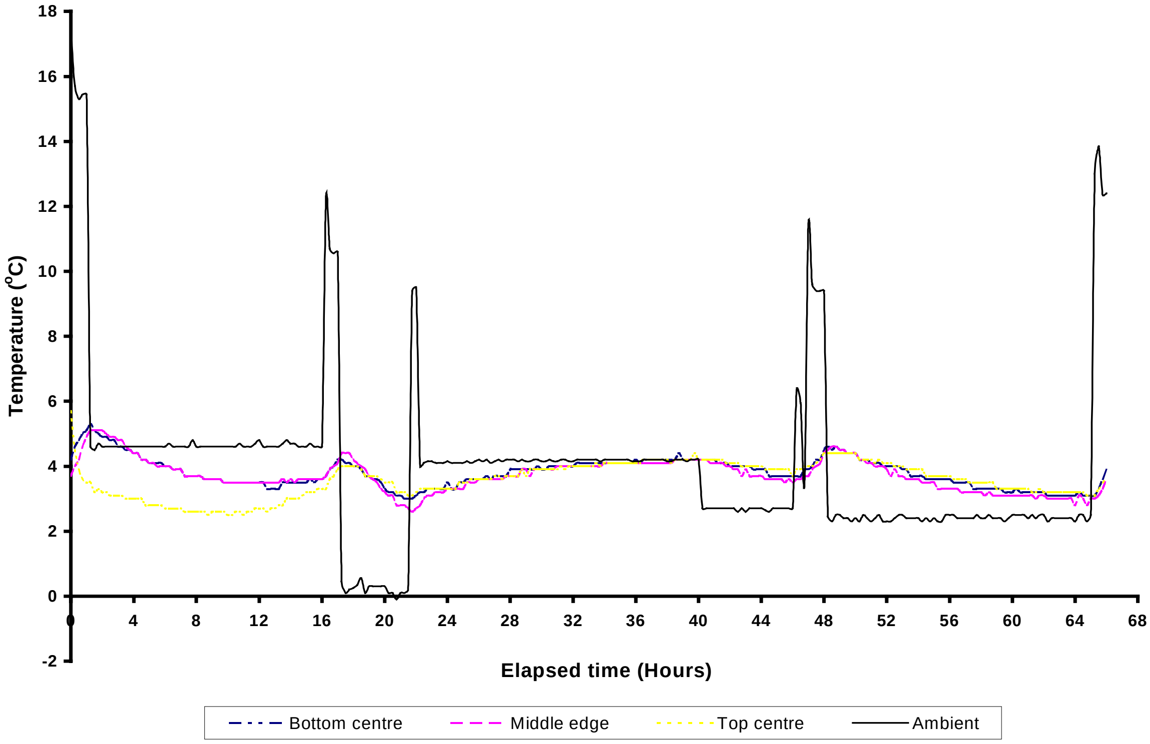


**Figure 1.3. Average fillet temperature in the CP box held in a variable ambient temperature for 66 hours (gel-ice cooling of fillets)**

# Appendix II

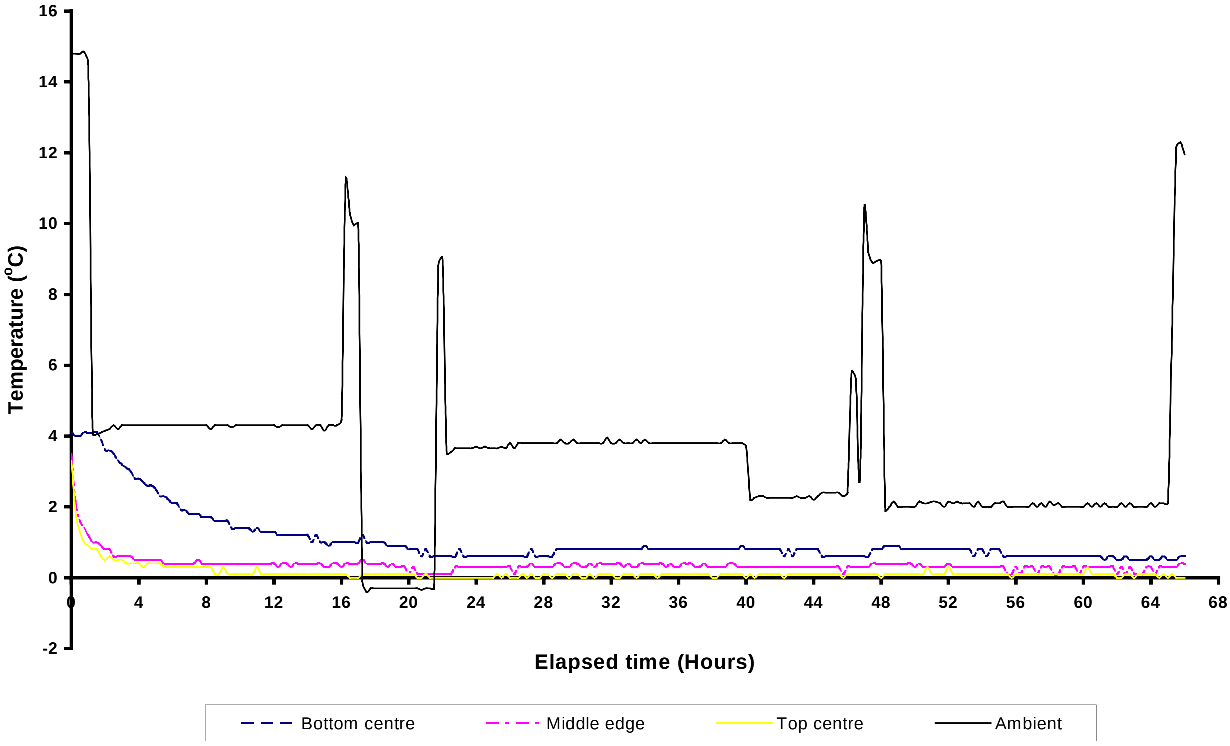


**Figure 2.1. Average fillet temperature in the EPS box held in a variable ambient temperature for 66 hours (top icing of fillets)**

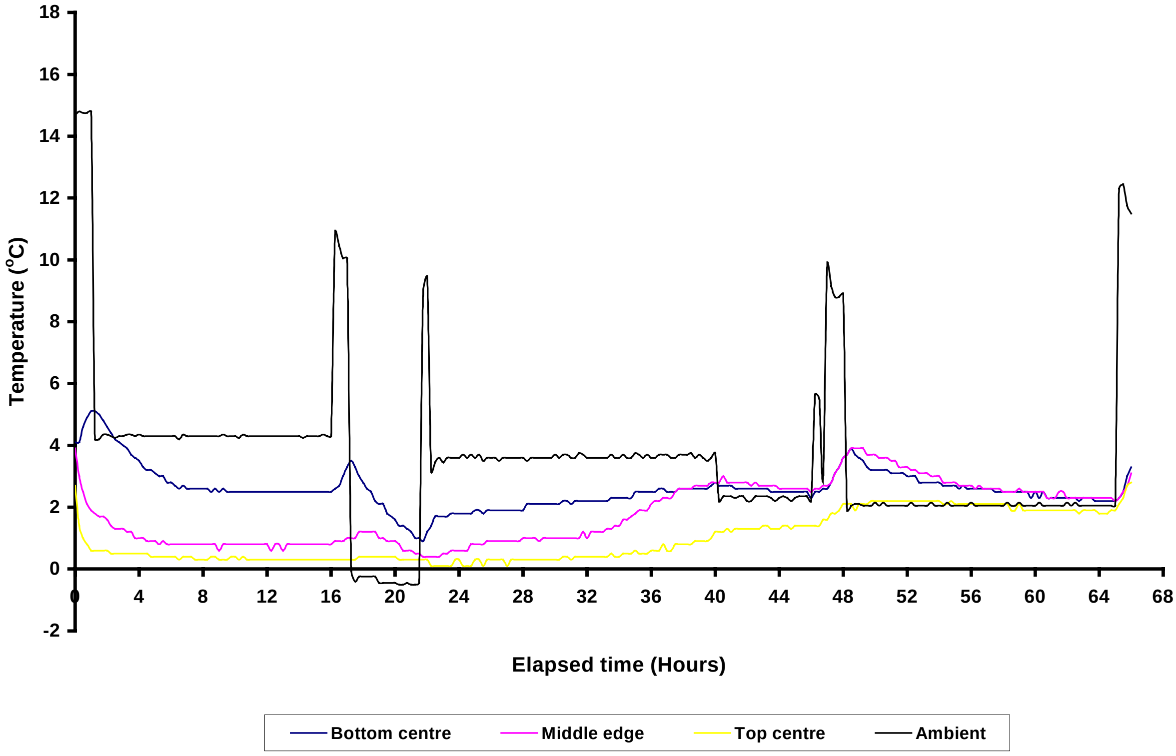


**Figure 2.2. Average fillet temperature in the SWF box held in a variable ambient temperature for 66 hours (top icing of fillets)**

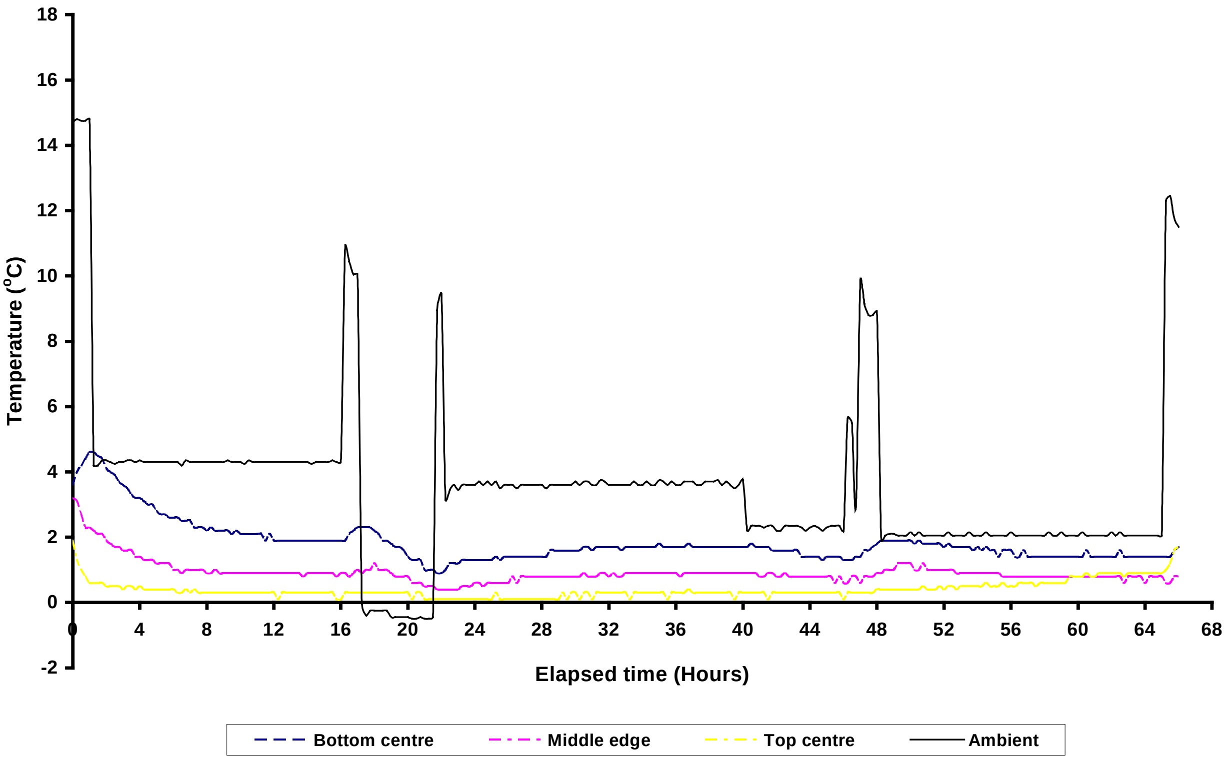


**Figure 2.3. Average fillet temperature in the CP box held in a variable ambient temperature for 66 hours (top icing of fillets)**

# Appendix III

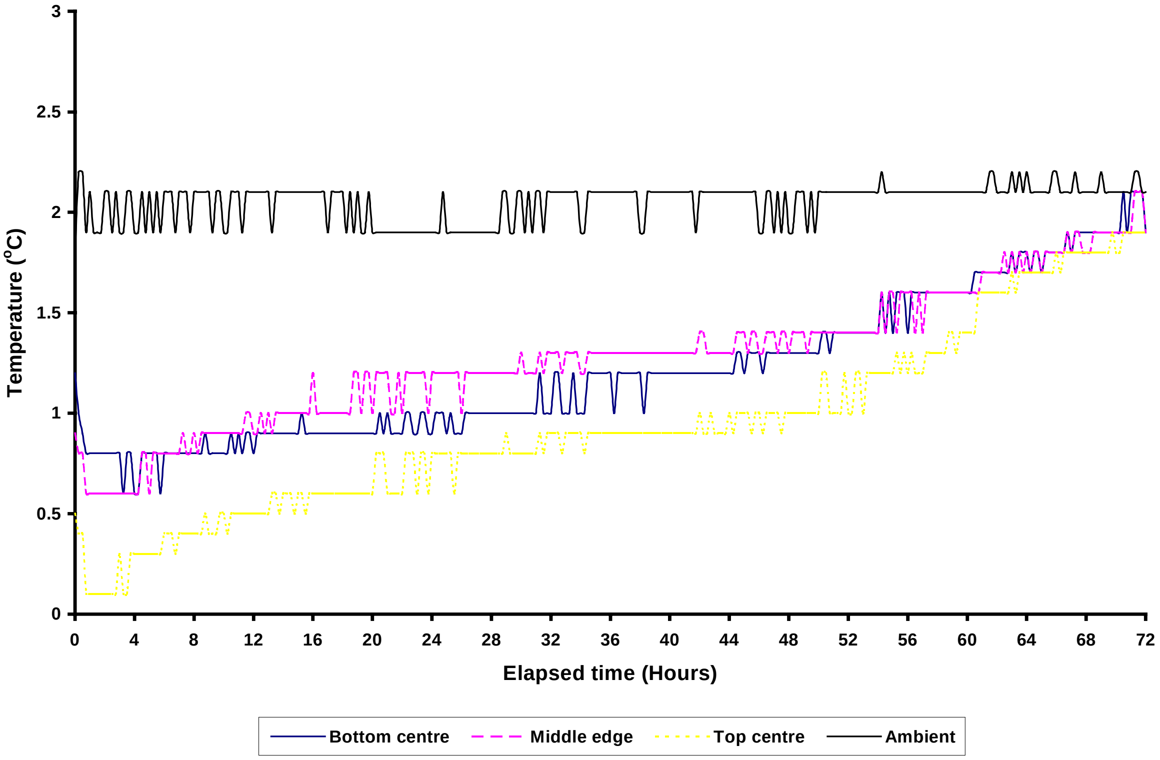


**Figure 3.1. Average fillet temperature in the EPS box held in a constant ambient temperature of 2°C for 72hours (gel-ice cooling of fillets).**

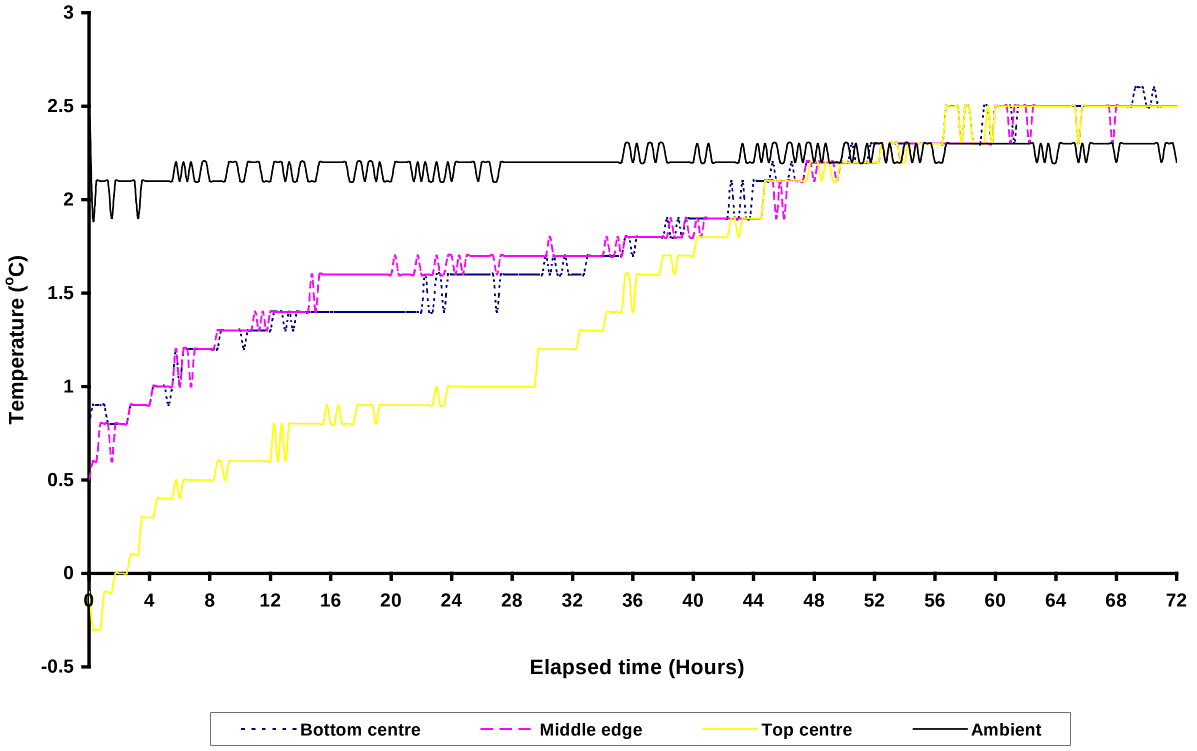


**Figure 3.2. Average fillet temperature in the SWF box held in a constant ambient temperature of 2°C for 72hours (gel-ice cooling of fillets).**

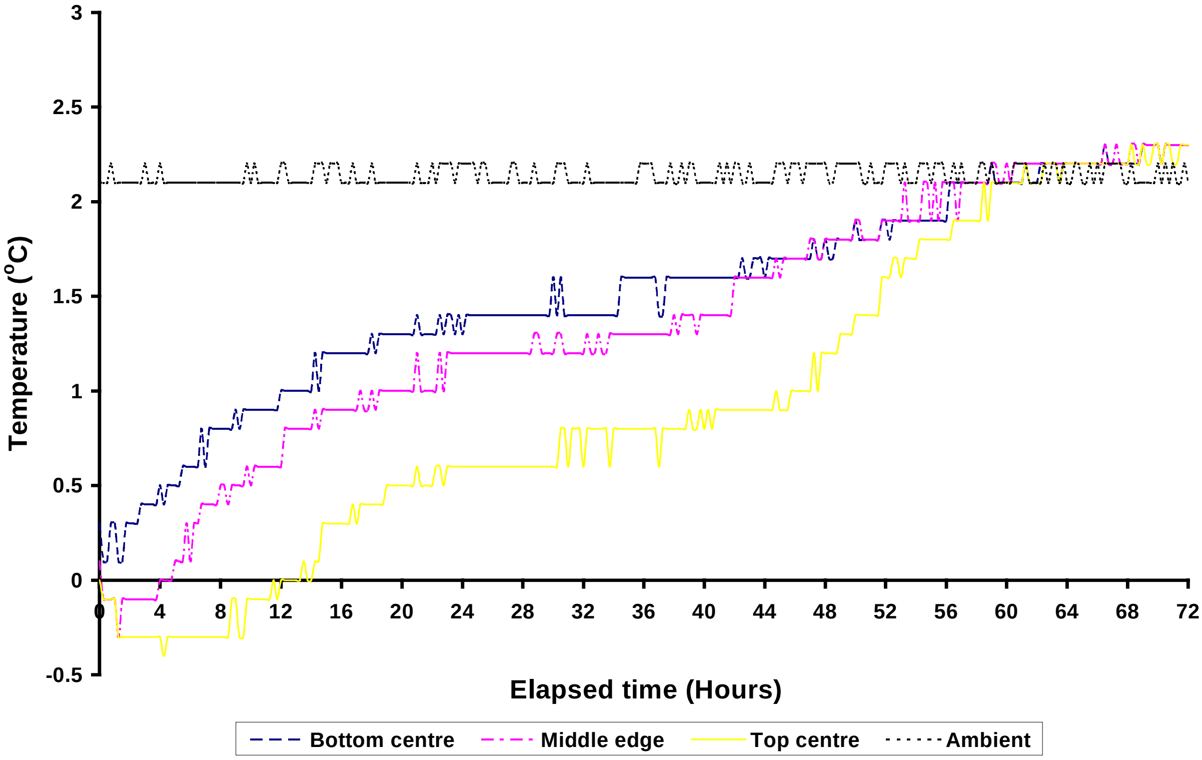


**Figure 3.3. Average fillet temperature in the CP box held in a constant ambient temperature of 2°C for 72hours (gel-ice cooling of fillets).**

# Appendix IV

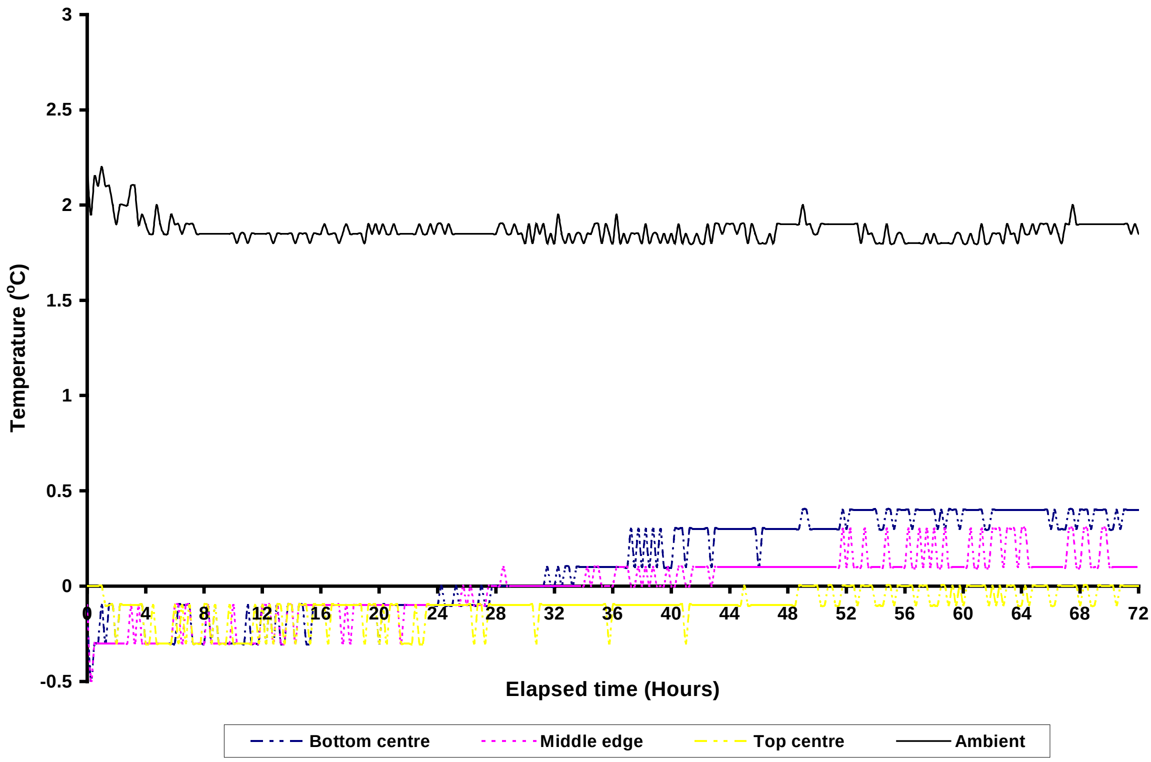


**Figure 4.1. Average fillet temperature in the EPS box held in a constant ambient temperature of 2°C for 72hours (top icing of fillets).**

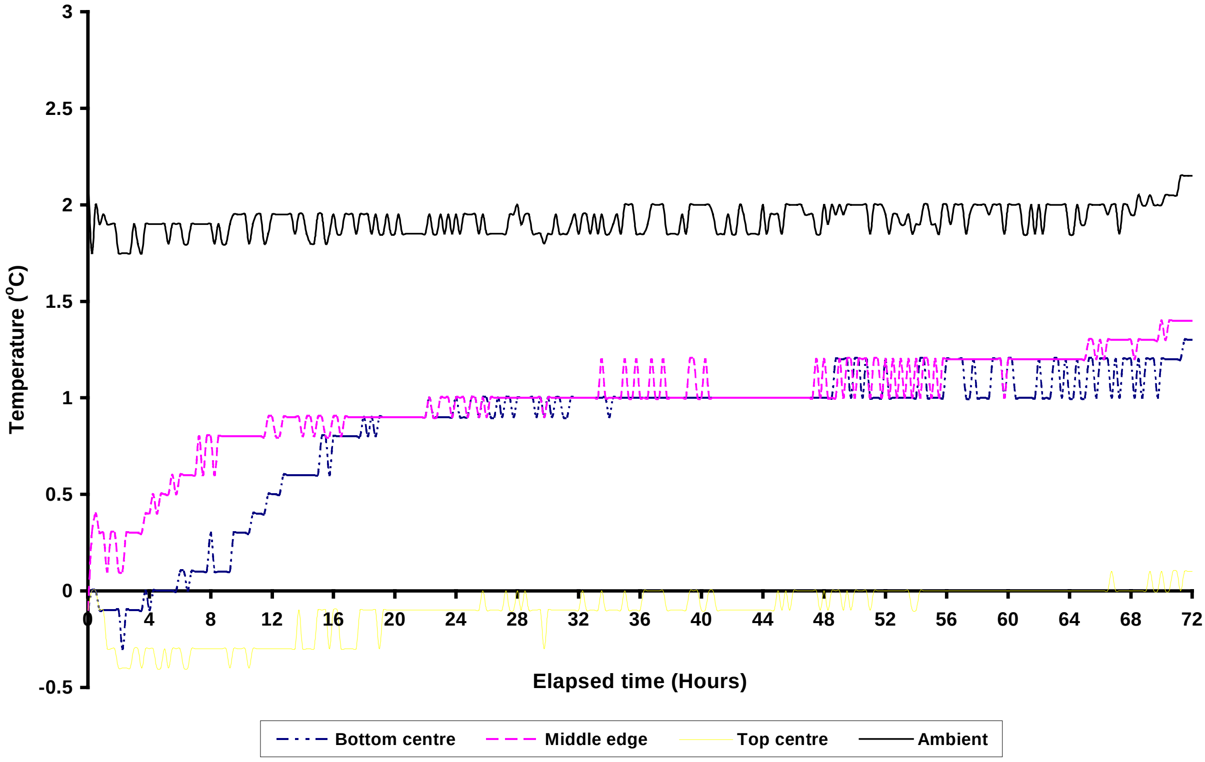


**Figure 4.2. Average fillet temperature in the SWF box held in a constant ambient temperature of 2°C for 72hours (top icing of fillets).**

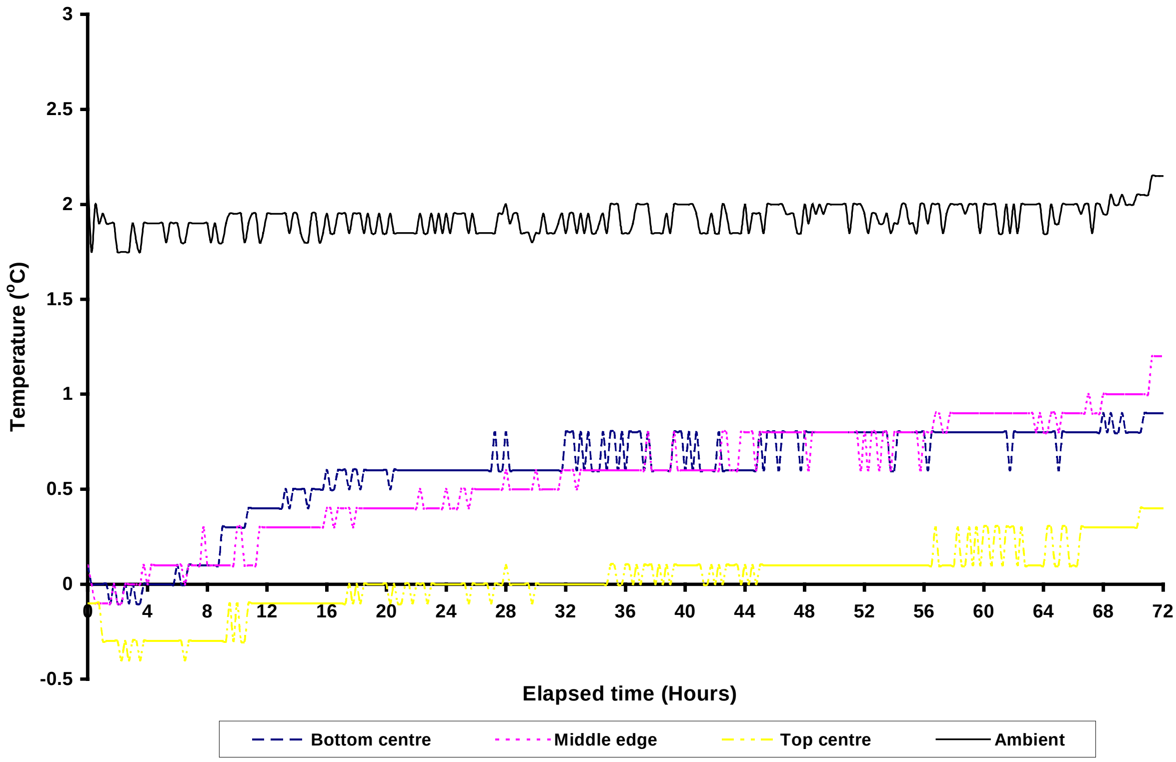


**Figure 4.3. Average fillet temperature in the CP box held in a constant ambient temperature of 2°C for 72hours (top icing of fillets).**