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Improved reefer container for fresh fish

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Report summary

Titill / Title	**Improved reefer container for fresh fish /** Endurbættur kæligámur fyrir ferskfisk – LOKASKÝRSLA		
Höfundar / Authors	Sæmundur Elíasson, Björn Margeirsson, Sigurjón Arason		
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Ágrip á íslensku:	Meginmarkmið verkefnisins Endurbættur kæligámur fyrir ferskfisk var að endurbæta kæligáma og verklag við flutninga á ferskum sjávarafurðum með endurhönnun og prófunum. Markmiðið er að hönnunarúrbætur skili kæligámum sem ná jafnara hitastigi gegnum flutningaferlið. Leitast skyldi við að ná viðunandi endurbótum á kæligámum sem í dag er notast við með einföldum og kostnaðarlitlum aðgerðum. Afleiðingar bættrar hitastýringar í vinnslu- og flutningaferlum eru aukin gæði, stöðugleiki og öryggi, sem auka um leið verðmæti vörunnar. Samstarfsaðilar í verkefninu voru Matís, Háskóli Íslands, Eimskip Ísland og Samherji. Í þessari skýrslu er helstu niðurstöðum og afurðum verkefnisins lýst. Niðurstöður verkefnisins leiddu í ljós að þörf er á endurbótum í sjóflutningskeðjum og sýnt var fram á að hægt er að ná fram úrbótum með einföldum og kostnaðarlitlum aðgerðum. Hitastýringu við sjóflutninga má bæta með því að velja markhitastig og kæligáma sem hæfa best til flutninga ferskra fiskafurða. Kortlagning á hitadreifingu kæligáma sýndi fram á breytileika bæði í flutningsferlinu og með tilliti til staðsetningar innan gámsins en hönnunarúrbætur sem miðuðu að því að þvinga loftflæði innan gámsins skiluðu jafnari hitadreifingu. Einnig var sýnt fram á mikilvægi verklags við hleðslu kæligáma og meðhöndlun þeirra frá framleiðanda til kaupanda.		
Lykilorð á íslensku:	*Fiskur, hitastig, flutningar, hitastýring, kæligámar*		

Report summary

Summary in English:	The purpose of the project Improved reefer container for fresh fish is to use simple redesign and experimental testing to improve temperature control in reefer containers and work procedures of fresh fish products during transport. The design improvements are aimed at producing a reefer with more stable temperature through sea freight and transport. The aim is to get satisfactory improvements with simple and cost effective procedures. Improved temperature control in fish chill chains leads to increased product quality, stability and safety and thereby increased product value. The project was done in collaboration with Matís, University of Iceland, Eimskip Ísland and Samherji. This report describes the main results and products of the project. The results of the project showed that there is room for improvement in sea transport cold chains and with design improvements experiments it was demonstrated that they can be improved with simple and cost effective procedures. The results showed that the temperature control during sea freight may also be improved by selecting the reefer types most suitable for fresh fish transport and selecting different set point temperatures during summer and winter. The mappings of temperature distribution inside the reefers showed spatiotemporal variability and design improvements achieved a more uniform distribution by means of forced air circulation. Field tests demonstrated the importance of correct operating procedures during loading of reefers and their handling from processor to end location.
English keywords:	*Fish, temperature, transport, temperature control, reefer, refrigerated container*

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1 INTRODUCTION

The purpose of this report is to review the most important results obtained in the R&D project "Improved reefer container for fresh fish".

Insufficient temperature control in cold chains has negative effects on fresh fish quality and storage life. Until recent years, fresh fish fillets and other high-value, short storage life products have generally been transported by air freight but large volume exporters now take advantage of better temperature control[1] and the lower cost option of refrigerated sea transport. The main aim of the project was to improve temperature control in reefer containers and work procedures of fresh fish products during transport by using simple redesign and experimental testing. The design improvements are aimed at producing a reefer with more stable temperature through sea freight and transport. The aim is to get satisfactory improvements with simple and cost effective procedures.

Refrigerated containers used to transport frozen products are also used for chilled products at temperatures around 0 °C. Frozen products are less responsive to temperature fluctuations and refrigeration units often allow considerably more fluctuations than is optimal for chilled products. Older researches have confirmed the importance of stable temperature when storing seafood products[2,3]. Transportation of frozen products allows for 2–3 °C temperature fluctuations but for refrigerated fish fillets around 0 °C the fluctuations should be much less[4]. The project aim is to improve the reefer, which has largely remained unmodified over the last decade, in order to make it more suitable for transport and storage of chilled products.

Many studies have been done on refrigerated container shipments of chilled products. The majority of the published work, however, reefers to 20 ft. containers and transport of fruits. The work that was done on 40 ft. reefers[5,6] focused on temperature variation in palletised stows of

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[1] Margeirsson, B. 2012. Modelling of temperature changes during transport of fresh fish products. Doctoral thesis. Faculty of industrial engineering, mechanical engineering and computer science, University of Iceland.

[2] Axelsdóttir, K. 2002. Greining á flutningaferlum lausfrystra sjávarafurða. M.Sc. thesis. University of Iceland.

[3] Björnsson, H.Ó. 2005. Geymslu- og flutningastýring lausfrystra sjávarafurða. M.Sc. thesis. University of Iceland.

[4] Lauzon, H.L., Margeirsson, B., Sveinsdóttir, K., Guðjónsdóttir, M., Karlsdóttir, M.G., Martinsdóttir, E. 2010. Overview on fish quality research. Impact of fish handling, processing, storage and logistics on fish quality deterioration. Matís report 39-10.

[5] Billing, D. P., Hayes, A.J., McDonald, B. 1995. Temperature and airflow characteristics in reefer vessels carrying New Zealand produce. Prod. 19th International Congress of Refrigeration. Vol II: 485-492.

fruit showed that there was a significant variability both spatially across the width of the container as well as in time[7]. Temperature control is a critical parameter to retard quality deterioration of perishable foodstuffs, such as fresh fish, in the whole chill chain from catch, through processing and distribution to consumers. The importance of pre-cooling the product to the intended storage temperature before packaging has been shown and the thermal protection from external environment by insulated boxes has been tested and optimized[1,8].

In the current study, experiments were conducted in order to gain additional knowledge on reefer transport routes from Icelandic producers, temperature distribution during transport and the effects of design improvements. Result from transport experiments, mapping temperature distribution in reefers, are used to determine possible low-cost design improvements. The main results comprise assessment of temperature control during land and sea transport and redesign of the loading process into the reefer.

[6] Tanner, D. J., Amos, N. D. 2003.Temperature variability during shipment of fresh produce. Acta Horticulturae, 599 p.193-203.

[7] Punt, H., Huysamer, M. 2005. Temperature variance in a 12 m integral reefer container carrying plums under a dual temperature shipping regime. Acta horticulturae, 687, p. 289-296.

[8] Valtýsdóttir, K. L. 2011. The effects of different precooling techniques and improved packaging design on fresh fish temperature control. M.Sc. thesis. University of Iceland.

2 MATERIALS AND METHODS

In this section measurement devices and the measured reefers will be discussed. The field test experiments were carried out with fresh fish while other experiments conducted in static conditions used bacalao (salted cod). The reasons for using bacalao instead of fresh fish were that the temperature measurements were done over a period of time which exceeds the storage life of fresh fish.

2.1 Measurement devices

The specification of the different measurement devices used is presented in Table 1. Ibutton temperature loggers (DS1922L, see Figure 1) from Maxim Integrated Products (Sunnyvale, CA, USA) were used to monitor the air temperature inside the reefers and fish temperature within the insulated boxes (Figure 4). Its diameter is 17.35 mm and the thickness is 5.89 mm. Tidbit v2 temperature loggers (Figure 2) from Onset Computer Corporation (Bourne, MA, USA) were used to monitor the ambient temperature outside the reefers. All temperature loggers were factory calibrated and re-calibrated in a thick mixture of fresh crushed ice and water to ensure uniformity of the collected data. Relative humidity was monitored with HoBo U12 temperature and relative humidity loggers (Figure 3) from Onset Computer Corporation (Bourne, MA, USA).

Table 1. Specification of measurement devices

Device	Resolution	Range	Accuracy
Ibutton	0.0625 °C	–40 to 85 °C	±0.5 °C between –15 and 65 °C
Tidbit v2	0.02 °C	–20 to 70 °C	±0.2 °C between 0 and 50 °C
HoBo U12	0.03%	5 to 95%	±2.5%

Figure 1. Ibutton DS1922L temperature datalogger.

Figure 2. Tidbit v2 temperature datalogger.

Figure 3. HoBo U12 temperature and relative humidity datalogger.

Figure 4. Whole haddock fillets in an EPS box. Also shown are temperature loggers used for monitoring temperature on top of fillets.

2.2 Measured reefers

The measured reefers were all 40 ft. high cube RF45 type boxes with integral refrigeration units and a T-bar floor. The reefers were chosen in collaboration with experts at the shipping company, emphasizing reefer types that are most commonly used for export of chilled fresh fish. The container boxes are similar in size and build with regard to material and insulation specifications. Table 2 shows the main sizes and characteristics of the RF45 container boxes. The dimensions listed are the inside measures of a container box.

Table 2: Characteristics of a RF45 container

Lenght	Width	Height	Own weight	Capacity	Volume
11.6 m	2.3 m	2.5 m	4,950 kg	29,000 kg	67 m^3

The reefers are equipped with refrigeration units from different manufactures (Thermo King, Carrier and Star Cool) specified in detail in the experimental reports[9,10]. The units have similar operating ranges and capacities, with cooling capacity ranging from 11.7 kW to 12.3 kW when maintaining temperature around 2 °C inside the reefer with 38 °C ambient temperature[11].

[9] Elíasson, S. 2012. Temperature control during containerised sea transport of fresh fish. M.Sc. thesis. University of Iceland.

[10] Elíasson, S., Margeirsson, B., Sigurjón, A. 2012. Project Report – Work Package 3. Experiments results. Matís.

[11] Thermo King, M. 2007. Available at http://www.containere-maritime.ro/Magnum_Brochure.pdf. Ingersoll Rand Climate Control Technologies. Diegem, Belgium.

Heating capacities of the units range from 5.25 kW to 5.6 kW[12]. In experiments 1 and 2 the refrigeration unit temperature was set at –2 °C, ventilation closed and the RU operation set to chilled mode, in which the evaporator fans run at high speed (up to 3,450 rpm). In experiments 3–6 the set point temperature was 0 °C. Table 3 shows the setup and set point temperature for each experiment. Reefer set point temperatures are generally decided by the producer or the shipper.

Table 3: Experiment description

	Set point temp.	Cargo load	Experiment
Experiments MSc	0 °C	Cod/Bacalao	Master thesis experiments
Experiment 1	–2 °C	Cod loins	Real sea transport - Single pallet measurement
Experiment 2	–2 °C	Saithe fillets	Real sea transport - Reefer measurement
Experiment 3	0 °C	Cod loins	Real sea transport - Reefer measurement
Experiment 4	0 °C	Cod loins	Real sea transport - Reefer measurement
Experiment 5	0 °C	Bacalao	Controlled environment - Setup comparison
Experiment 6	0 °C	Bacalao	Controlled environment - Setup comparison

The choice of pallet stowage pattern in the reefers commonly depends on the pallet sizes. The stowage patterns are chosen mostly with the aim of maximizing the number of pallets in the reefer and to balance the internal load. The most common pallet type for fresh fish transport is the Euro pallet (800x1200 mm), which is used in most experiments in this study. The most common stowage pattern used for the Euro pallet is shown in Figure 5. The Euro pallet stowage pattern refers to the layout of pallets and is not restricted to the Euro pallet as the stowage pattern is also used for other pallet sizes.

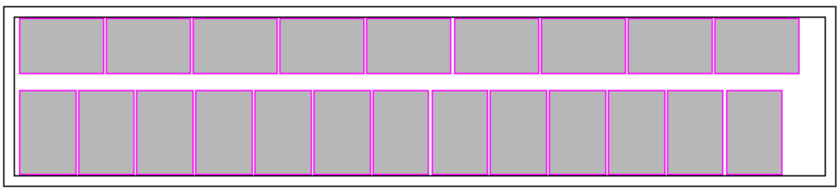

Figure 5: Europallet stowage pattern with Euro pallets in a 40 ft. reefer

Figure 6: Air bags between pallet loads

With the Euro pallet stowage pattern there is a longitudinal gap formed between the pallets. Due to the asymmetry of the stowage the gap is more to one side of the reefer centreline. With

[12] Carrier,Transicold. 2010. Operation and service manual-Container refrigeration unit 69NT40. Carrier corporation. New York, USA.

pallets pressed against the reefer walls this gap can be around 28 cm using Euro pallets. For Euro pallets, air filled bags are blown up between pallets to ensure stability and minimize pallet movement within the reefer during transport. Figure 6 shows containerised EPS boxes on Euro pallets with an air bag in position between the pallets. For all experiments a three dimensional grid was defined for the measurement points. Figure 7a shows 9 measurement points in a vertical cross section of a reefer. Left and right sides are viewed from the reefer door-end. In all experiments temperature loggers were placed in three horizontal levels; bottom, middle and top level, as presented in Figure 7b. The MSc experiments had measurement grids of 40–70 locations within the reefer. For experiments 2, 3, 5 and 6 a measurement grid comprising 3 vertical sections from the reefer RU-end to the door-end was used, as shown in Figure 7c. For experiment 4 the same measurement grid was used but another section added between the middle and door-end sections, as shown in Figure 7d.

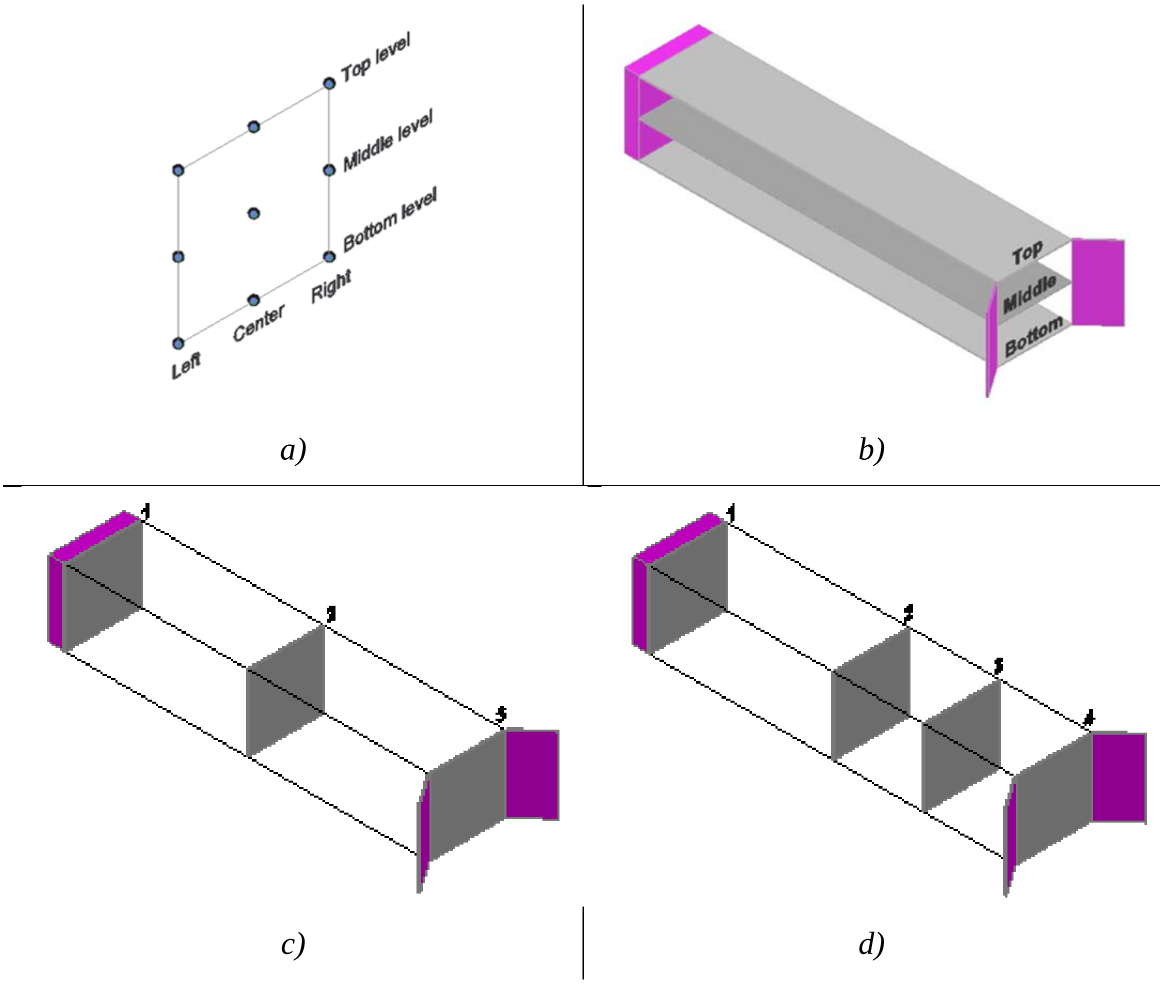

Figure 7: a) Logger placements in a vertical cross section, b) Definition of bottom, middle and top levels, c) Definition of vertical cross sections for experiments 2, 3, 5 & 6, d) Definition of vertical cross sections for experiment 4.

3 RESULTS AND DISCUSSION

In this section the main results of the experiments listed in Table 3 are reviewed and discussed.

3.1 Effects of ambient temperature on reefer performance

Temperature mappings were done during summer (July) and winter (March)[9]. Figure 8 shows temperature evolution for two different loading patterns carried out in an outside, stationary environment at a container terminal in Reykjavík. The average temperature inside the reefer was found to be 1 to 2 °C above the set temperature of 0 °C. The effects of the ambient temperature fluctuations inside the reefer are relatively small close to the RU-end and down by the container floor. However they are more noticeable farther from the RU-end and by the door-end ceiling the daily ambient temperature changes result in temperature fluctuations of 1 to 1.5 °C inside the reefer.

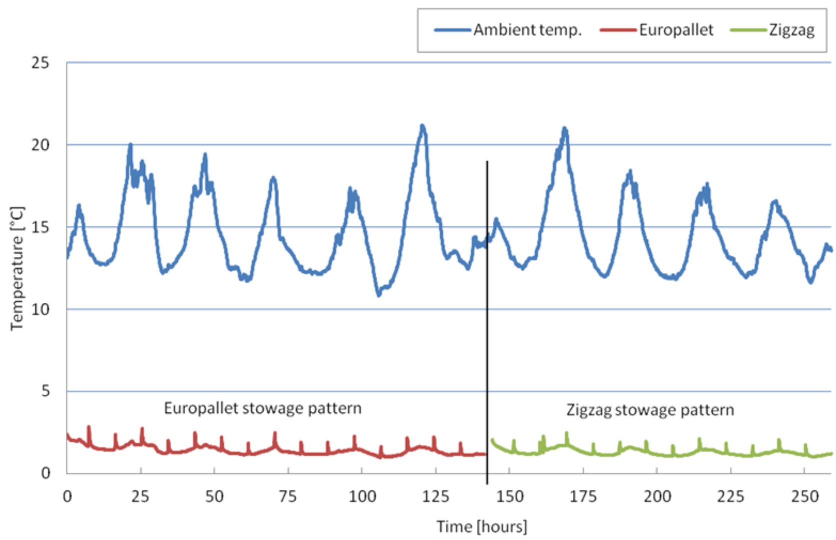

Figure 8: Ambient and reefer average air temperatures during summer

Figure 9 shows a similar temperature mapping of a single reefer during winter time with the same set point temperature. The average temperature was found to be fairly stable around an average value of 0.2 °C, fluctuating less with the ambient temperature than during summer.

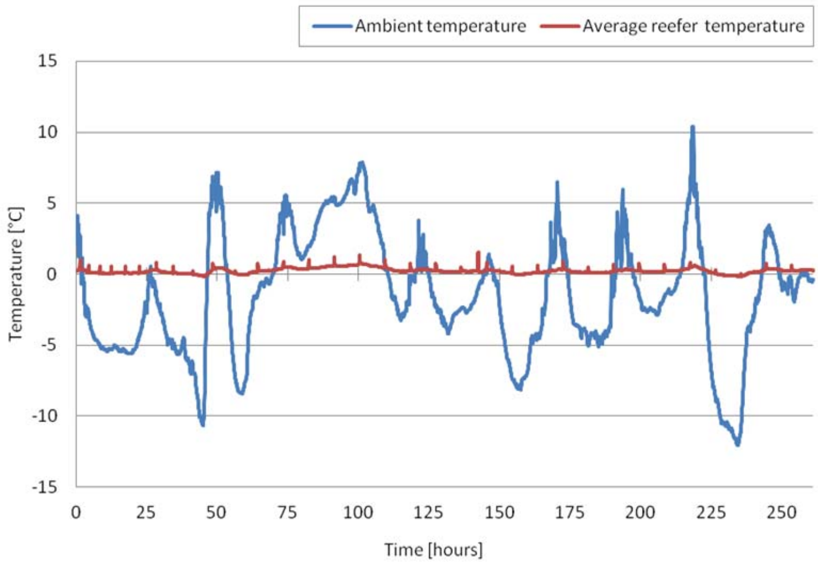

Figure 9: Ambient and reefer average air temperatures during winter

Figure 10 and Figure 11 show the relative frequency distribution for all temperature measurement observations collected inside the reefers during the experiments. Values between 1 and 2 °C occur most frequently during the summer experiment and during winter the most frequent values are between 0 and 0.5 °C.

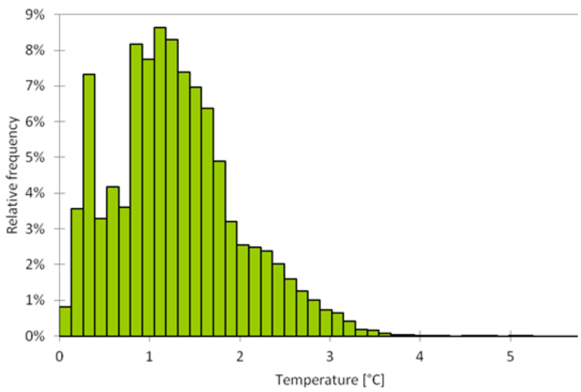

Figure 10: Temperature during summer

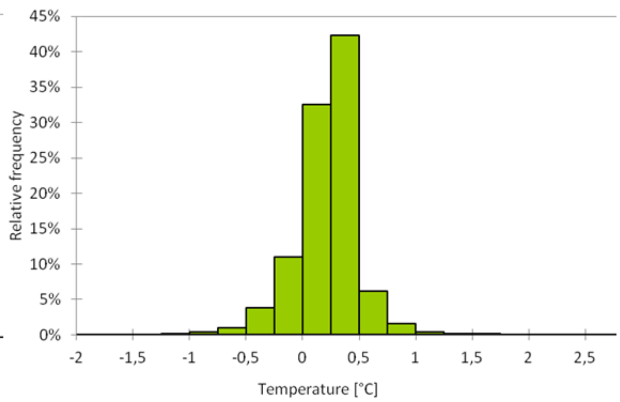

Figure 11: Temperature during winter

Table 4 shows the average air temperature for each vertical cross section from the RU-end (section 1) to the door-end (section 7). Both stowage patterns in this experiment were done with industrial pallets (1000x1200 mm). Neither stowage pattern measures the highest average temperatures at the door-end section during summer. The average temperature distribution is more homogenous throughout the reefer vertical cross sections with the Euro pallet pattern whereas with the Zigzag pattern temperatures are lower at the RU-end and higher at the door-end. The difference between the highest and the lowest temperatures is greater in the Zigzag pattern compared to the Euro pallet. The average temperature during winter measures lowest by the reefer door-end section due to ambient conditions.

Table 4: Average temperature over vertical cross sections [°C]

	Section 1	Section 2	Section 3	Section 4	Section 5	Section 6	Section 7
Summer (Europallet)	0.7	1.1	1.2	1.1	1.4	1.4	1.3
Summer (Zigzag)	0.6	0.9	0.9	1.0	1.6	1.8	1.7
Winter	0.3	0.3	0.2	0.2	0.2	0.2	0.1

3.2 Temperature control during land and sea transport

Temperature measurements from various locations in Iceland to buyers in France showed that while the sea transport is generally well temperature controlled, the transport chain is often broken during land transport and when loading and unloading reefers to the ship. Figure 12 shows the ambient temperature around a pallet from packaging to reefer loading, where the pallet is stored in a freezer storage after processing and then moved to a loading area before being containerized. While in the freezer storage the temperature in the pallet top corner box lowered but a temperature change was not noticeable in the middle and bottom corner boxes.

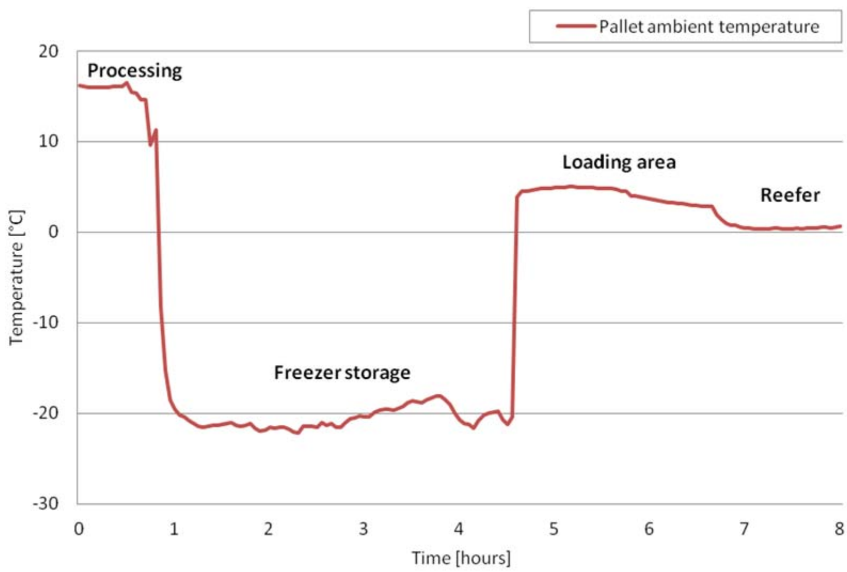

Figure 12: Ambient temperature from production to container loading

Figure 13 shows the average temperature of all loggers inside EPS (*expanded polystyrene*) boxes and outside a measured pallet in Experiment 1, from a processor in North-Iceland to a final destination in France. The sea freight is from Iceland to Denmark. The pallet is stored at the processor in an unchilled storage at around 6 °C for 20 hours before transport. The average temperature of the fish is around 0.5 °C after production and rises to around 1 °C during the unchilled storage time. The average temperature inside the reefer during land transport is 0 °C and around –1 °C during shipping. The reefer refrigeration unit is set to –2 °C during shipping. The average temperature of the fish drops just below 0 °C during transport as the transport temperature is well below the production temperature. After shipping the ambient temperature around the pallet is higher during land transport and the fish temperature rises again just above 0 °C before delivery to the final destination.

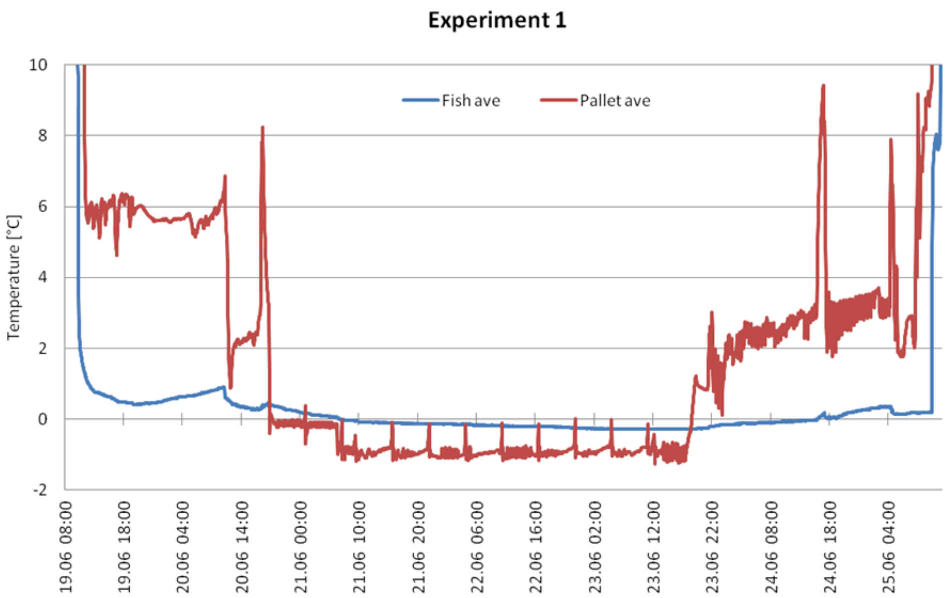

Figure 13: Reefer and fish average temperatures

Figure 14 shows results from a field test done in the MSc project, where the average temperature is measured in the ambient outside the reefer, in the air inside the reefer and in the EPS boxes containing fish loins. The temperature in the reefer rises slightly when it is disconnected from a power supply before loading onto the ship. The average air temperature inside the reefer throughout most of the shipping is around 0.6 °C, before it is unplugged again when preparing for arrival at the shipping port in the Netherlands. There it remains unplugged for approximately 8 hours causing the average air temperature inside the reefer to rise above 6 °C.

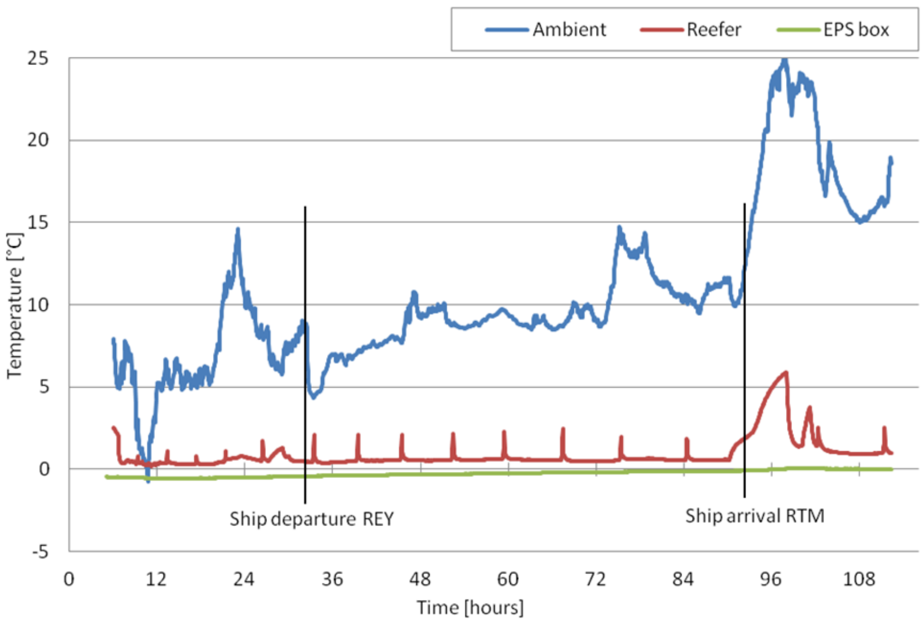

Figure 14: Temperature profiles from the processor (Iceland) to the final destination (France)

In another field test from Experiment 3, shown in Figure 15, the average temperature inside the reefer also rises when it is disconnected from a power supply before loading onto the ship. The cod loins were superchilled to around –1 to –0.5 °C before packaging. The average air temperature inside the reefer throughout most of the shipping is 0.6 °C, before it is unplugged again when preparing for arrival at the port in the Netherlands. There it remains unplugged causing the average air temperature inside the reefer to rise above 5 °C, and the reefer does not recover as the average temperatures during continuation land transport are high and fluctuating.

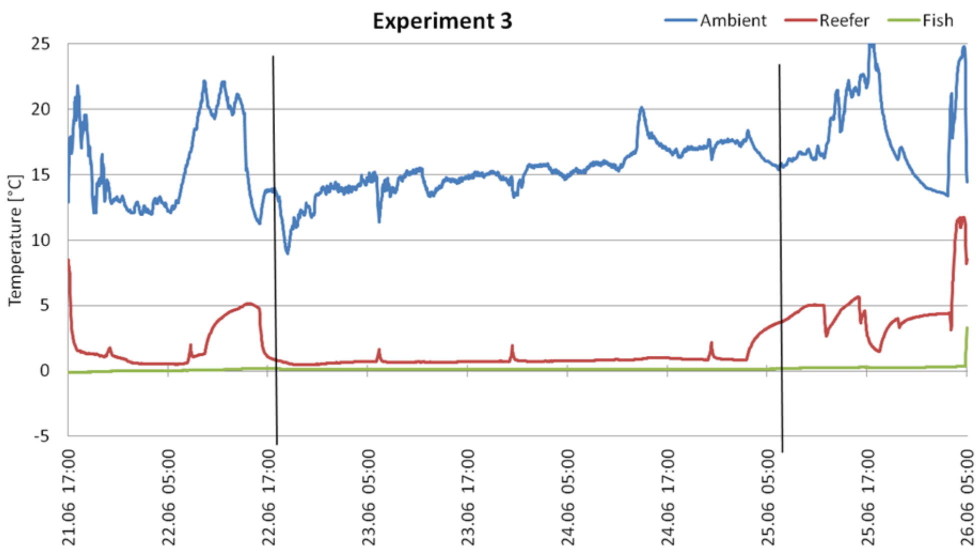

Figure 15: Temperature profiles from the processor (Iceland) to the final destination (France) in Experiment 3

Experiment 4 was done at the same time as Experiment 3, using a reefer from another processor from another location in Northern Iceland where the cod loins were chilled to 0.5 to 1 °C before packaging. The temperature results for Experiment 4 are shown in Figure 16, using the same sea freight and the same final destination as the reefer from Experiment 3. The average temperature inside the reefer rises above 5 °C when it is disconnected from a power supply before loading onto the ship. The average air temperature inside the reefer throughout most of the shipping is 0.8 °C, before it is unplugged again when preparing for arrival at the port in the Netherlands. There it remains unplugged causing the average air temperature inside the reefer to rise above 6 °C, and the reefer does not recover during the continued transport.

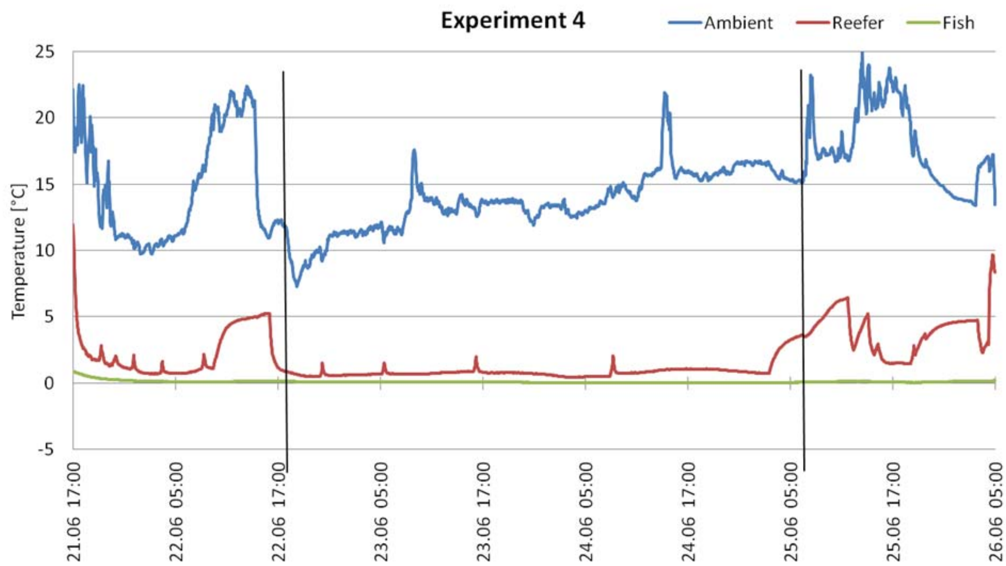

Figure 16: Temperature profiles from the processor (Iceland) to the final destination (France) in Experiment 4

Figure 17 shows the average temperature of loggers inside EPS boxes in contact with fish loins, from the reefer loading in Iceland to delivery in France, in a temperature mapping study from one of the field trips. The average temperature of pallet 4, located by the reefer doors, rises more rapidly than in the other pallets located closer to the refrigeration unit. A temperature rise inside all EPS corner boxes is noticeable when the reefer is unplugged during arrival in the Netherlands. Top corner boxes on pallets were subject to the greatest temperature rise through the journey. Boxes in bottom corners of pallets suffer less thermal load and boxes located in the middle of pallets are not affected, except on pallet 4, by the reefer door-end.

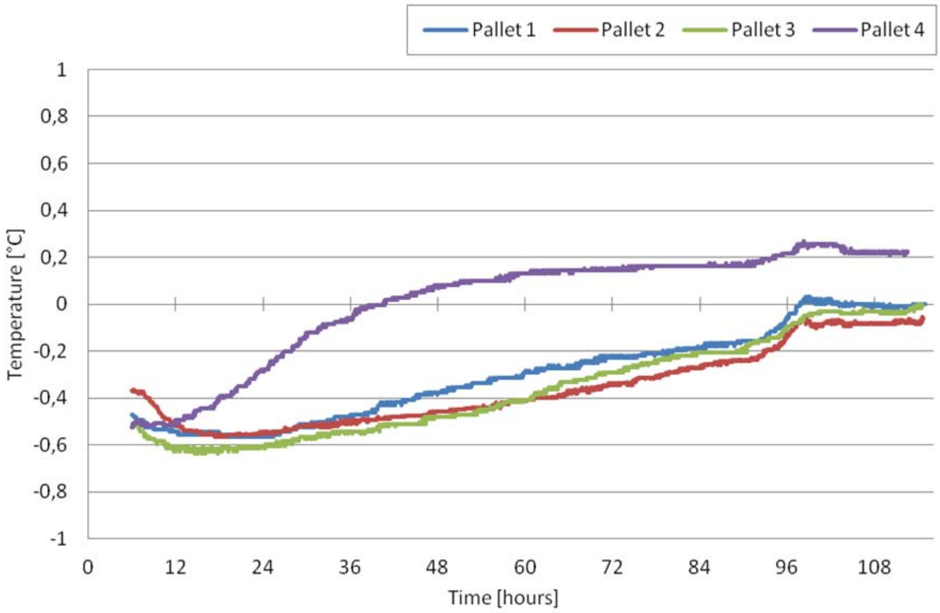

Figure 17: Average temperature of EPS boxes from reefer loading in Iceland to delivery in France

3.3 Temperature distribution in reefer containers

Temperature measurements at around 40–70 positions inside different types of refrigerated sea containers during the MSc experiments revealed that the mean air temperature inside fully loaded containers at ambient temperature of around 15 °C can be 1 to 2 °C above the set point temperature of 0 °C [9]. Furthermore, around 1 °C higher air temperature can be expected in the quadrant at the back of the container as compared to the quadrant closest to the refrigerating equipment at the front of the container. Taking into account that storage life of whitefish products is larger for products stored at –1 °C than at 0 °C,[13] these results imply that the set point temperature should be set to no higher than –1.5 to –1.0 °C during periods when the expected ambient temperature is higher than 10 to 15 °C. On the other hand, measurements during the winter time at ambient temperature around –5 to 5 °C, mean air temperature of around 0 to 0.5 °C can be expected under these more favourable conditions. This implies that in order not to risk excessive freezing of whitefish products due to air temperature fluctuations inside containers in the wintertime, the set point temperature should probably not be set at lower temperature than –1.0 °C.

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[13] Lauzon, H.L., Margeirsson, B., Sveinsdóttir, K., Guðjónsdóttir, M., Karlsdóttir, M.G., Martinsdóttir, E., 2010. *Overview on fish quality research - Impact of fish handling, processing, storage and logistics on fish quality deterioration*. Matís report 39-10. 2010. Overview on fish quality research - Impact of fish handling, processing, storage and logistics on fish quality deterioration. Matís report 39-10.

Figure 19 shows contour plots of the average air temperature during a winter experiment for the bottom, middle and top levels shown in Figure 18. The supply air from the RU cools down as it reaches the reefer door-end and at the top level door-end the average air temperature is close to 0 °C.

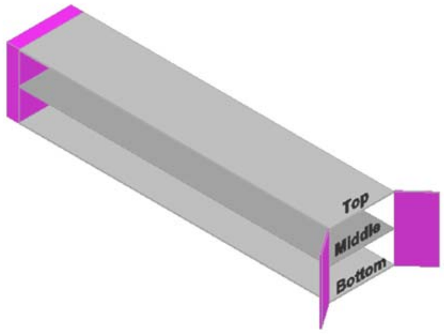


Figure 18: Definition of levels in the reefer

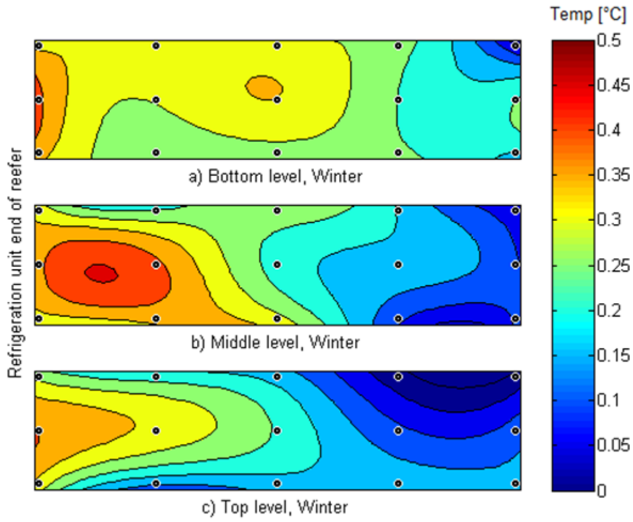


Figure 19: Temperature contours during winter at the three levels shown in Figure 18

This is reversed during summer when ambient temperature is higher than the refrigeration unit set point, as seen in Figure 20 below, where the temperature of the supply air from the RU rises as it reaches the reefer door-end. Figure 20 shows a difference in the temperature distribution between two different pallet stowage patterns. The average air temperature at the bottom level was similar for both stowage patterns. Average air temperature distribution is more homogenous through the middle level in the Euro pallet pattern, with higher temperature at the reefer´s right side. The temperature distribution at the top level is also more homogenous for the Euro pallet pattern compared to the Zigzag pattern. At the top level side in both setups, average temperatures above 2 °C are measured but in the Zigzag pattern average temperatures are higher by the door-end, reaching up to 3 °C by the door-end right side.

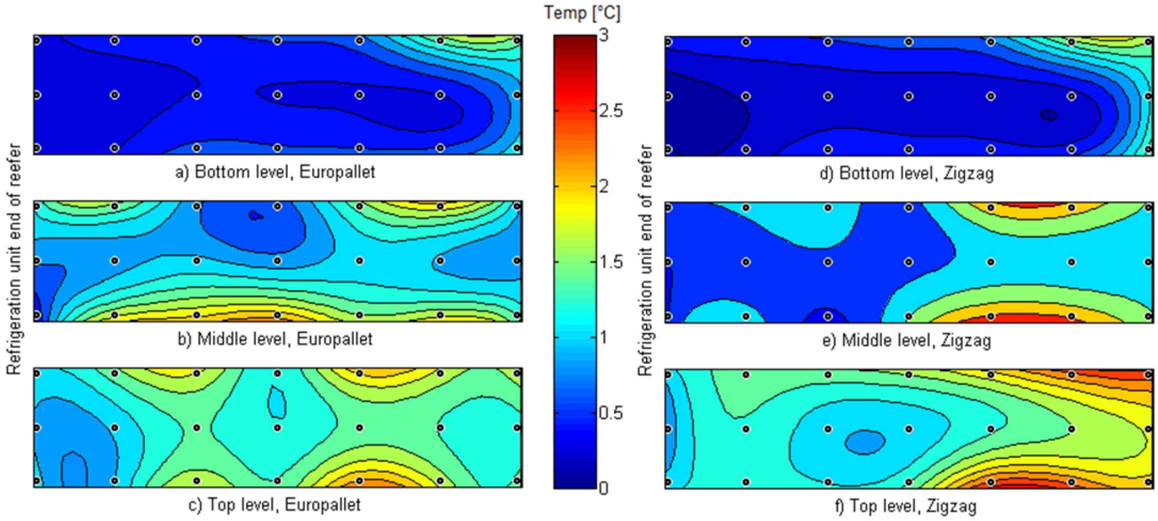


Figure 20: Temperature contours during summer at three levels with Euro pallet (left) and zigzag (right) loading patterns

Figure 22 shows the average temperature distribution of vertical cross section inside a reefer transport from South-Iceland to England during Experiment 2. The reefer refrigeration unit was set to –2 °C during sea transport and the measurement grid is shown in Figure 21. The temperature is lowest by the refrigeration unit and in the middle of the mid-section. Temperatures are higher at the reefer door-end. All sections show external heat flowing through the reefer walls and the roof, and the effects of heating are considerably higher by the reefer door-end area.

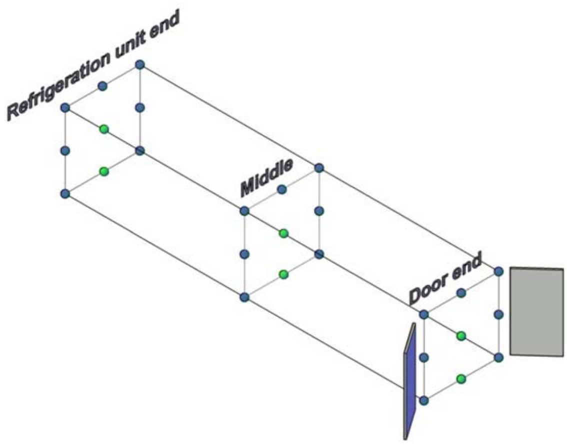


Figure 21: Measured sections, Experiment 2

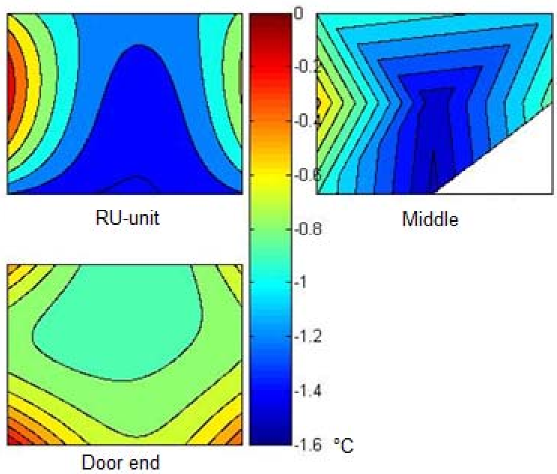


Figure 22: Mean temperature distribution, Experiment 2

Figure 23 and Figure 24 show the contour plot average temperature distributions in the vertical cross sections at the RU-unit, in the middle and at the door-end for Experiments 3 and 4, which were conducted at the same time for different reefers. All the plots have a common “cold spot” in the middle and by the reefer floor and "hot spots" where external heat flows through the reefer walls.

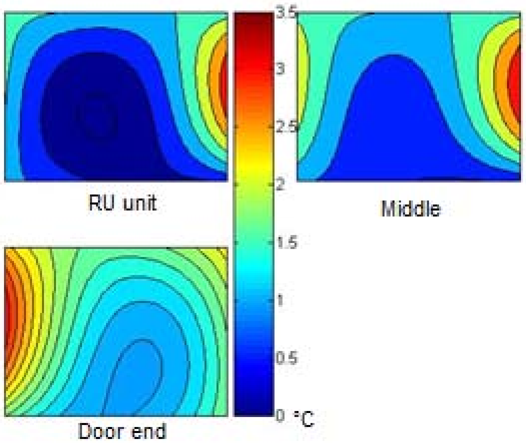


Figure 23: Mean temperature distribution, experiment 3

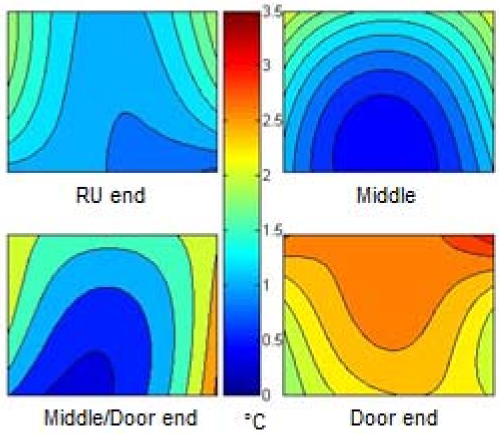


Figure 24: Mean temperature distribution, experiment 4

3.4 Design improvements

Experiments with conventional pallet setups have shown that the temperature is higher by the container walls compared to the middle. This is due to heat transfer from the outside through the walls and pallets being pushed tightly up against the walls, restricting air flow between the pallet loads and the container walls. When pushed up against the container walls, air bags are blown up between pallets to stabilize the cargo, as shown in Figure 6. The loading procedure improvement in experiment 5 tested pushing the pallets together in the middle and placing air bags to the sides, against the walls. This arrangement uses up more air bags compared to the conventional setup however.

Experiment 5 was carried out in July in an outside, stationary environment at a container terminal in Reykjavík. The stowage pattern in one reefer was kept conventional, as shown in Figure 25, while the stowage pattern in the other reefer was set so the pallets were pushed together in the reefer centreline making free space by the reefer walls, as in Figure 26. Both reefers were fully loaded with 23 industrial bacalao pallets and the refrigeration unit set to 0 °C.

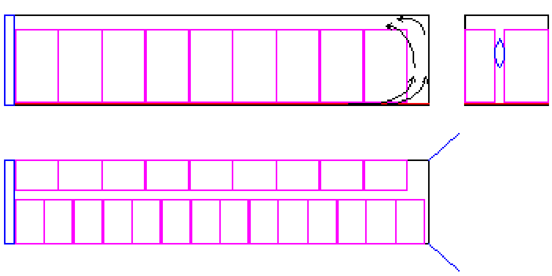


Figure 25: Conventional Euro pallet setup

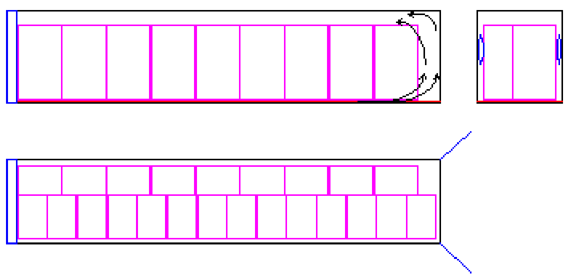


Figure 26: Improved Euro pallet setup

A measurement grid with 3 horizontal sections was used for each reefer, as shown in Figure 27, with 27 measurement points in total. The reefers were located side by side (with space between them), so the measurements are similar. The average temperature of both reefers is close to 1 °C but the reefers are set to 0 °C.

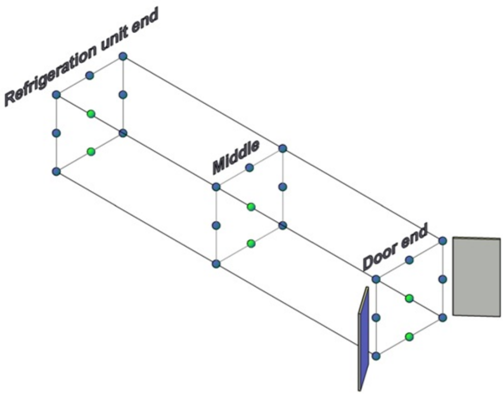


Figure 27: Experiment 5 measurement grid

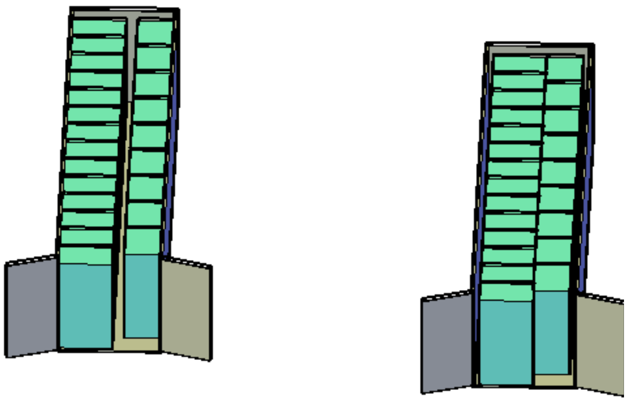


Figure 28: Experiment 5 pallet setup

The temperature measurements were found to be similar for both setups indicating that there is not a significant difference between the two setups. However the difference could be less noticeable due to the experimental set up, as in the conventional setup the chilled fish is being pushed up against loggers at the reefer walls.

The results from the MSc experiments imply that the cold air blown along the floor gratings is not delivered properly from the refrigeration unit to the other end of the container. Partly blocking floor gratings close to the refrigeration unit should distribute cold air better to the other end of the container, by the doors.

Experiment 6 was carried out in an outside, stationary environment at a container terminal in Reykjavik to test the effects of blocking the floor compared to the conventional setup.

Measurements on two reefers took place over a period from July to August. The stowage pattern in one reefer was kept conventional Euro pallet setup, as shown in Figure 29. The stowage pattern in the other reefer was the same but there the T-bar floor was partly blocked in the reefer RU-end half, as shown in Figure 30.

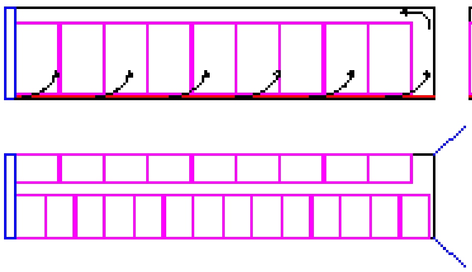


Figure 29: Conventional Euro pallet setup

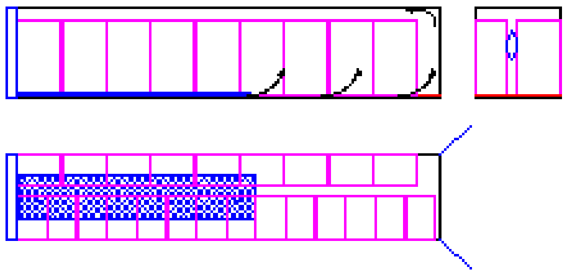
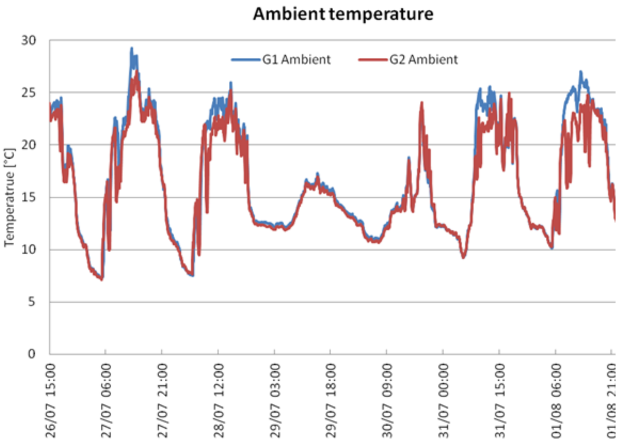


Figure 30: Partly blocked floor setup

Figure 31: T-bar floor blocking

Figure 32: Measured reefers in container terminal

Figure 33 shows the average ambient temperature for each reefer, G1 representing the floor blockage setup and G2 with the conventional setup. The reefers were located side by side (with sufficient space between them to exclude thermal interference between the two reefers), so the ambient measurements are similar. Figure 34 shows the average temperature inside each reefer, G1 records lower average temperature during the whole measurement period.



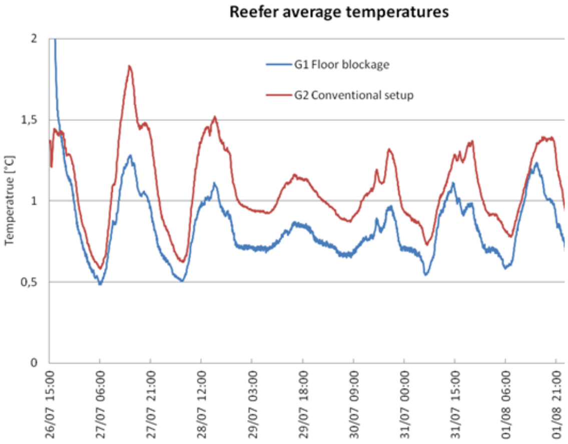
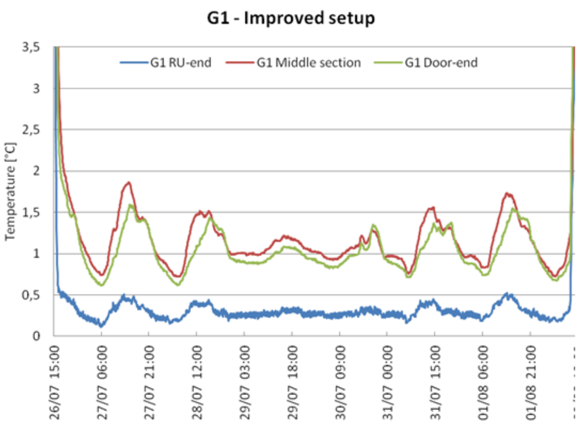


Figure 33: Average ambient temperature for reefers

Figure 34: Average temperature inside reefers

Figure 35 and Figure 36 show the average temperatures for sections 1, 2 and 3 for both reefers. The average temperature is similar for section 1 in both reefers but section 3 is much lower for reefer G1. Section 2 measures slightly higher for reefer G1 and the results show that the temperature distribution is more uniform throughout the reefer with setup G1.



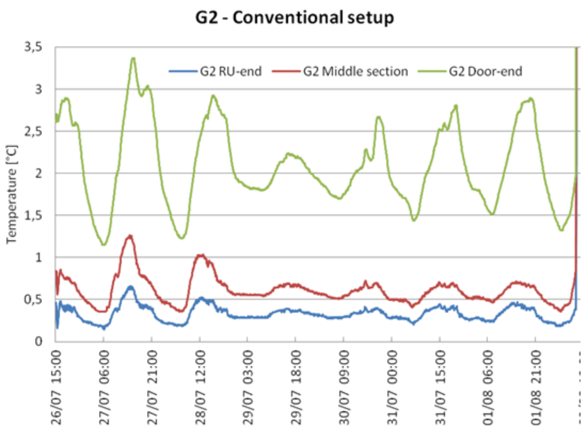


Figure 35: Average of vertical sections for G1

Figure 36: Average of vertical sections for G2

Figure 37 and Figure 38 show the average temperature of longitude vertical sides inside the reefers, from left to right. The middle of the reefers records the lowest temperature in both setups while higher temperatures are recorded by the reefer walls. The difference between the highest and lowest temperature is greater for setup G2. Figure 39 and Figure 40 show average temperature of bottom, middle and top level for both setups. The bottom, middle and top levels record lower temperatures for setup G1. Figure 41 and Figure 42 show measurement on relative humidity for both reefers. The relative humidity measures lower at the door-end for both setups.

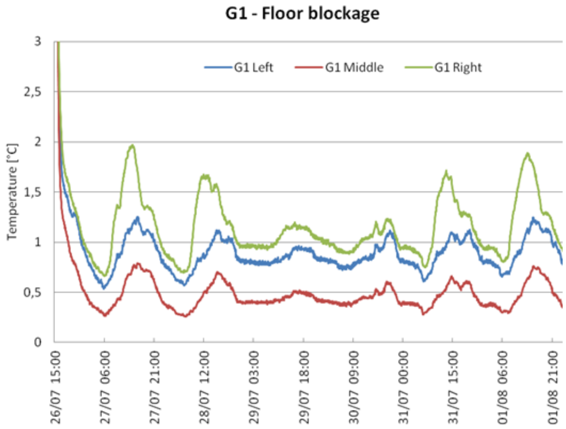


Figure 37: Average temperature of sides for G1

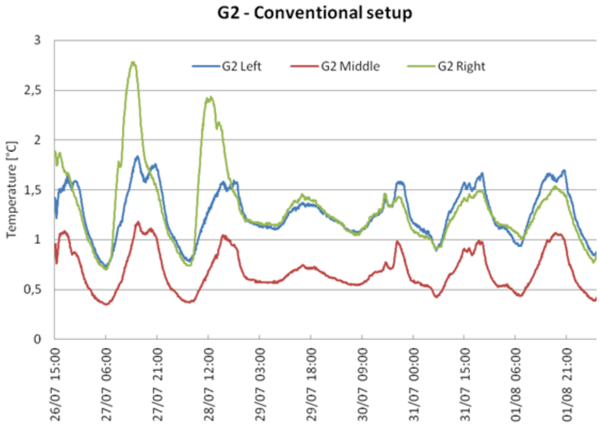


Figure 38: Average temperature of sides for G2

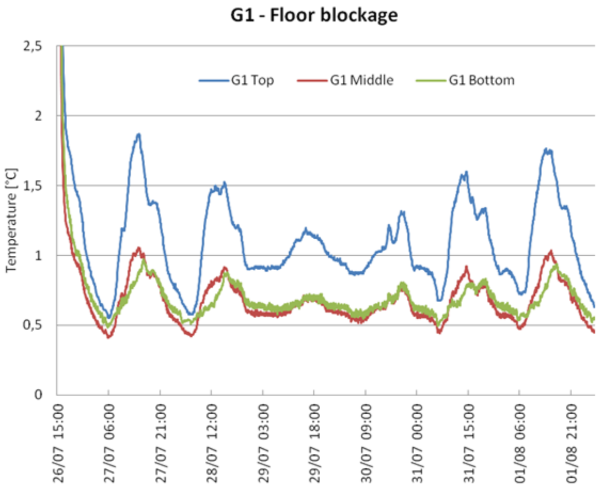


Figure 39: Average temperature of levels for G1

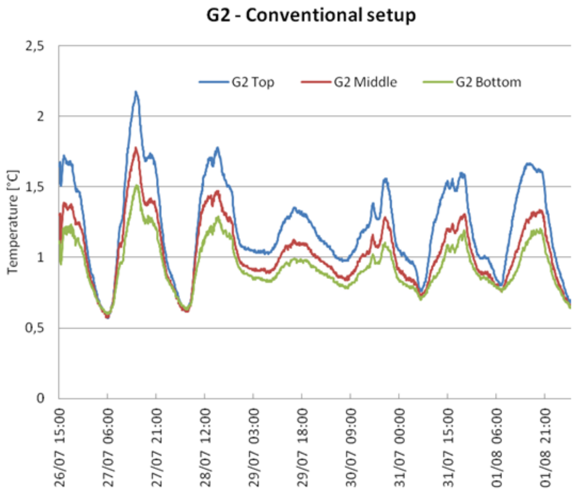


Figure 40: Average temperature of levels for G2

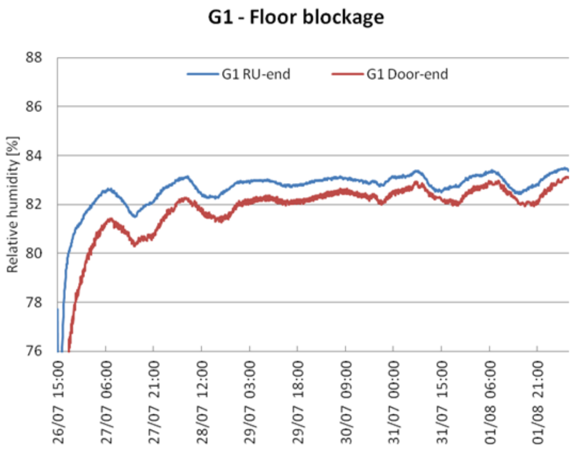


Figure 41: Relative humidity for G1

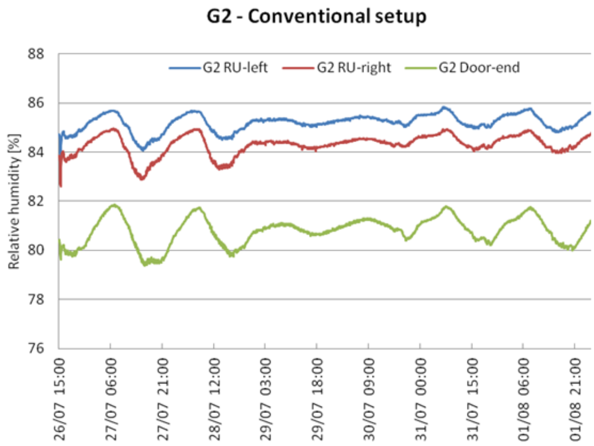


Figure 42: Relative humidity for G2

4 CONCLUSIONS

In conclusion the results of the project show that temperature control during containerised sea transport may be improved by simple design improvements, changes in operation procedures and conditional temperature settings of the reefer.

The transport results showed that the effect of precooling at the processor will help maintain the temperature through the transport chain. After production fresh fish should be stored at a temperature close to the desired transport temperature but not in a freezer or an unchilled storage as is commonly done. Loading cargo at temperatures above the desired transport temperature should be avoided and the loading should preferably take place in a temperature controlled environment or at least under a shelter during the summertime.

While temperature was found to be stable through the sea freight, the land transport and transport of the reefers from the dock to shipping is less controlled. Improvements at loading facilities when moving and loading containers are needed. Information from producers and truck drivers are often incomplete and that can be the cause for unnecessary pallet movement and excessive waiting time for pallets before they are containerised, resulting in a temperature rise in the product. The time reefers are unplugged during transport should be minimized. This is especially relevant prior to loading and unloading the reefer from container ships. When transporting fresh fish, reefer set point temperatures should be set between –1.5 and –1 °C during summer and –1 to 0 °C during winter because of influences of variable season ambient conditions. Reefers older than 2–3 years should be used for less sensitive cargo than fresh fish as newer reefers were found to perform better. As the doors of the reefer were found to constitute a weak point regarding leakage, they must be regularly monitored and repaired.

Temperatures and temperature fluctuations were generally found to be the greatest at the reefer´s door-end area and the design improvement results showed that by forcing air flow to that area temperature control can be improved. The cargo should also be spaced from the reefer walls to allow for air flow from the refrigeration unit to counteract heat gain from the ambience.

ACKNOWLEDGEMENTS

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PUBLICATIONS

The following has been published on the results of the current project:

Elíasson, S. 2012. Temperature control during containerised sea transport of fresh fish. MSc. Thesis, University of Iceland.

Elíasson, S., Margeirsson, B., Arason, S., Pálsson, H. Temperature control during containerised sea transport of fresh fish. Presentation given at the 4th Trans-Atlantic Fisheries Technology Conference, 30 Oct–2 Nov, 2012. Clearwater Beach, FL, United States.

Margeirsson, B., Pálsson, H., Arason, S., Lauzon, H.L., Jónsson, M.Þ., Gospavic, R., Popov, V. Quality deterioration and numerical modelling of temperature fluctuations of chilled cod fillets packaged in different boxes stored on pallets under dynamic temperature conditions. In: 2nd IIR International Conference on Sustainability and the Cold Chain, Paris, 2–4 April, 2013. Submitted 6 Dec, 2012.

Margeirsson, B. Aukin verðmæti sjávarfangs - bætt nýting aukaafurða og betri kælikeðja. Presentation given at an open meeting on Héðinn Protein Plant, 16 May, 2012. Snæfellsbær, Iceland.

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4) Lauzon, H.L., Margeirsson, B., Sveinsdóttir, K., Guðjónsdóttir, M., Karlsdóttir, M.G., Martinsdóttir, E. 2010. Overview on fish quality research. Impact of fish handling, processing, storage and logistics on fish quality deterioration. Matís report 39-10.
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