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Thermal Performance of Corrugated Plastic Boxes and Expanded Polystyrene Boxes

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Virðiskeðjan

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Report Summary

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Titill / Title	**Thermal Performance of Corrugated Plastic Boxes and Expanded Polystyrene Boxes**		
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Ágrip á íslensku:	Tilraunir voru gerðar á einangrunargildi tvenns konar pakkninga fyrir fersk fiskflök: 1) Bylgjuplastkassa (CP) og 2) Frauðplastkassa (EPS). Breytilegu hitastigi umhverfis pakkningarnar var stýrt í tilraunakæliklefum og fylgst með hitaþróun utan og innan pakkninga með hitasíritum. Bæði stakir kassar og heil bretti af kössum voru rannsökuð sem og kæligeta ísmotta, sem stundum eru settar efst í kassa fyrir flutning frá framleiðanda til kaupanda. Kælimotturnar (ísmotturnar) reyndust afar áhrifaríkar til að verja fiskflökin fyrir hitaálagi. Jafnframt sýndu niðurstöður fram á yfirburði varmaeinangrunar frauðplastkassa umfram bylgjuplastkassa óháð notkun kælimotta. Mismunur einangrunargildis er reyndar enn sýnilegri þegar kælimottur eru notaðar. Tilraunir með fullstaflað bretti af fiskikössum (u.þ.b. 300 kg á bretti) sýndu að meðalhitahækkun flaka getur verið tvöföld fyrir bylgjuplastkassa m.v. frauðplastkassa, að því gefnu að loftið umhverfis sé 10 °C heitt og á töluverðri hreyfingu. Að lokum var sýnt fram á að nokkurra klst. sveiflur í lofthita umhverfis heil fiskibretti geta valdið mjög ójafnri hitadreifingu innan stæðunnar á brettinu.		
Lykilorð á íslensku:	*fersk fiskflök, hitaálag, varmaeinangrun, frauðplastkassar, bylgjuplastkassar*		
Summary in English:	Experiments were carried out to compare the thermal performance of two different types of packaging for fresh fish fillets: 1) Corrugated plastic (CP) and 2) Expanded Polystyrene (EPS) boxes. The boxes containing fresh fillets were affected with dynamic thermal loads in air climate chambers. Meanwhile, the fillet temperature was monitored with temperature loggers. Both free standing boxes and whole pallets were affected with dynamic thermal loads in the study and the chilling effect of frozen cooling mats was studied by using them in some of the boxes. The frozen cooling mats proved very efficient for protecting fresh fish fillets against temperature abuse. Furthermore, the results show that the insulating performance of EPS is significantly better than of CP, independent of the usage of cooling mats. The difference in insulating performance between the two packaging types is actually exaggerated when cooling mats are used. The experiments with whole pallets revealed that the mean fillet temperature rise for a whole 300 kg fish pallet can be twofold using CP compared to using EPS, given that the movement of surrounding air is considerable and its temperature is 10 °C. Finally, it was shown that in dynamic temperature conditions, the temperature distribution in a whole pallet of fish fillets can be far from homogeneous.		
English keywords:	*fresh fish fillets, temperature abuse,thermal insulation, Expanded Polystyrene (EPS), Corrugated Plastic (CP)*		

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Contents

1 Introduction

The quality of fresh fish products can be seriously affected by the choice of packaging used for storage and transportation from the producer to the consumer. Regarding this, temperature control is probably the most important issue to consider because of the large impact that temperature and time has on both microbial and chemical properties of perishable products such as fresh fish fillets. Other factors, which can influence the quality of the products, include:

- cost (including cost related to material disposal, i.e. if the material can be recycled)
- strength
- space for cooling mats or ice with the products in order to maintain low product temperature
- weight
- space required for storage

The aim of this report is to describe experiments which were conducted at Matis in Iceland in July and August 2008. The objective of the experiments was twofold: 1) to compare thermal properties of the two different packaging types, 2) to calibrate and validate a heat transfer model for fresh fillets packed in boxes in dynamic temperature conditions.

Two types of packaging were used in the experiments. The first, a common type of EPS (expanded polystyrene), is commonly used for transporting fresh fish from Iceland to UK and other countries in Europe. The second, CP, i.e. corrugated plastic packaging (brand name: Coolseal), has been receiving increased attention because of environmental and economic reasons.

Results from temperature mapping of real cold chains[1] were taken into consideration when designing the dynamic temperature conditions used in the present study. Similar trials carried out by Seafish[2] have shown that the thermal insulation of EPS is significantly better than for CP.

[1] Margeirsson, B. et al. 2008. Chill on. *D1.10: Flow chart of selected fish supply chains including mapping of temperature and other relevant environmental parameters*

[2] http://www.seafish.org/pdf.pl?file=seafish/Documents/Fish%20box%20trials.pdf

2 Materials and methods

2.1 Temperature loggers

2.1.1 Ibutton temperature logger, type DS1922L

This logger (Figure 1) has an accuracy of ±0.5, a resolution of 0.0625 °C and an operating range of -40 to 85 °C. Its diameter is 17.35 mm and the thickness is 5.89 mm. Further information can be found on http://www.maxim-ic.com/quick_view2.cfm/qv_pk/4088. Loggers of this type were used for measuring the product temperature inside fish boxes with 5 minute intervals.

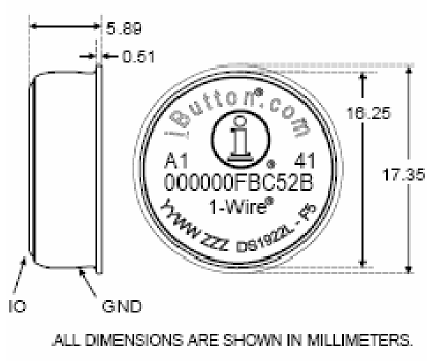


Figure 1. Ibutton temperature logger, type DS1922L used for measuring product temperature.

2.1.2 TidbiT v2 temperature loggers

This logger's (Figure 2) accuracy is ±0.2 °C, resolution is 0.02 °C and operating range is -20 to 70 °C. The dimensions of the logger are 3.0 x 4.1 x 1.7 cm. Further information can be found on http://www.onsetcomp.com/products/data-loggers/utbi-001. Loggers of this type were used for measuring ambient air temperature surrounding the fish boxes with 30 seconds intervals.

Figure 2. TidbiT v2 temperature logger used for measuring ambient air temperature.

2.1.2.1 HoBo U12 relative humidity (RH) and temperature logger

The accuracy of the RH measurements of this logger (Figure 3) is ±2.5 %, the resolution is 0.03 % and the operating range is 5 – 95 %. The accuracy of the temperature measurements is ±0.4 °C, the resolution is 0.03 °C and the operating range is -20 to 70 °C. Further information is found o n http://www.onsetcomp.com/search/compare?nid[]=2233&nid[]=2248&nid[]=2249&nid[]=2250&nid[]=2251&submit_button=Compare+Checked+Results.

Figure 3. HoBo relative humidity and temperature logger.

Loggers of this type were used for measuring the temperature and relative humidity of the air surrounding the packaging with 1 minute intervals.

2.2 Product

Whole and chilled haddock fillets were used in the trials, see Figure 4. Each box contained on average 3.22 kg of haddock fillets (maximum value 3.40 kg and minimum value 3.10 kg). Whole haddock fillets were used instead of cod loins because of a price difference between the two and also because of very similar thermal properties of cod and haddock. Rao and Rizvi (1995) state that the mean specific heat of cod at 4 – 32 °C is 3.69 kJ/(kg·K) compared to 3.73 kJ/(kg ·K) at the same temperature range for haddock[3]. Also, the enthalpies of these species below 0 °C (relative to -40 °C) are very similar according to the same reference, see Table 1.
The density of white fish varies from 990 kg/m^3 at -12 °C to 1060 kg/m^3 at +15 °C.[4,5]

Table 1. Enthalpy [kJ/kg] of frozen cod and haddock at various temperatures.[3]

	Temperature (°C)						
	-40	-10	-6	-4	-2	-1	0
Cod	0	74	96	118	177	298	323
Haddock	0	73	95	116	177	307	337

Temperature dependency of the thermal conductivity of white fish is shown in Table 2.

Table 2. Conductivity of cod and haddock (white fish) at various temperatures.[5]

Temperature (°C)	-10	-6	-2	-1	0	10
Conductivity [W/(m·K)]	1.479	1.400	1.322	1.302	0.430	0.430

Figure 4. Whole haddock fillets in a Coolseal box. Also shown is an ibutton temperature logger used for mapping product temperature.

[3] Rao, M.A. and Rizvi. S.S. 1995. *Engineering Properties of Foods*. 2nd edn. Marcel Dekker, Inc. New York.
[4] Sanders, H.R. A computer programme for the numerical calculation of heating and cooling processes in blocks of fish. In: *Jubilee Conference of the Torry Research Station.* 23-27 July 1979. Aberdeen, Scotland, p. 263 – 272.
[5] Alhama, F., Gonzáles Fernández, C. F., Zueco, J. 2004 Inverse determination of specific heat of foods. *Journal of Food Engineering* 64, 347-353.

2.3 Packaging

2.3.1 Expanded Polystyrene (EPS)

The outer dimensions of the EPS boxes are 400 x 262 x 137 mm and the inner dimensions are 355 x 220 x 90 mm. Physical properties of the EPS boxes are as follows:

Heat capacity [6]	(1.28 ± 0.05) kJ/(kg · K)
Heat conductivity [7,8]	0.033 W/(m · K)
Density [9]	25 kg/m^3
Mass[9]	197g (box 127g, lid 70g)

Figure 5. Insertion of an ibutton temperature logger in an EPS box.

2.3.2 Corrugated plastic (CP=Coolseal)

The outer dimensions of the CP boxes (Figure 6) are 395 x 247 x 85 mm and the inner dimensions are 370 x 230 x 80 mm.

Figure 6. Corrugated plastic box (CP, brand: Coolseal). Left: whole box. Right: cut through the box walls.

Physical properties of the CP boxes are as follows:

Density	150 kg/m^3 (calculated)
Mass	178 g

[6] Al-Ajlan, S.A. 2006. Measurements of thermal properties of insulation materials by using transient plane source technique. *Applied Thermal Engineering* 26, 2184-2191.
[7] Holman, J.P. 2002. Heat transfer. McGraw-Hill. New York.
[8] http://www.engineeringtoolbox.com/thermal-conductivity-d_429.html
[9] Baldursson, J.S. product manager at Reykjalundur plastiðnaður. Personal communication. 26 August 2008.

2.3.3 Cooling mats

In some trials one cooling mat was put on top of the fillets as is practiced in the chilled supply chain from Iceland to UK assessed by Margeirsson et al. (2008). The mats were filled with frozen water of average total weight of 230g. The temperature of the cooling mats was -18 °C when the mats were put in the boxes. Timing of insertion of the mats is shown in Figure 17 and Figure 23.

2.3.4 Pallets

The fish boxes were arranged on top of pallets like shown in Figure 7, except that the height of the pallets was 12 cm instead of 16.6 cm as shown in the figure. The pallets were only used for the whole pallets in Chamber 1-1 but not for the free standing boxes in Chamber 1-2 (see 2.4).

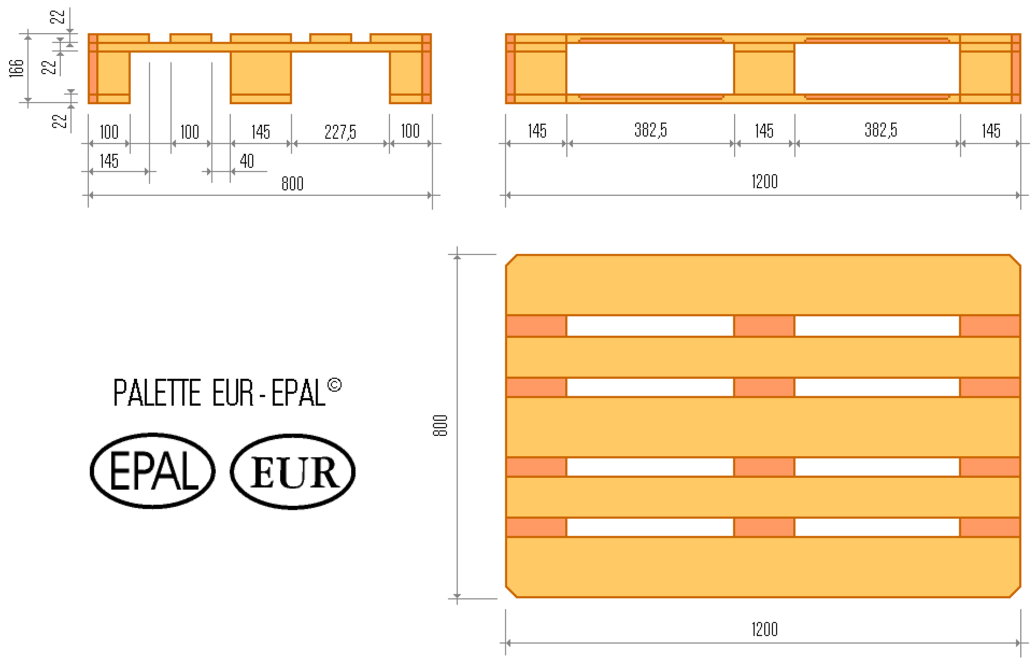


Figure 7. Dimensions of a Europallet.

2.4 Air climate chambers

The experiments were done in two parts: (1) whole pallets in Chamber 1-1 (see 2.4.2) and (2) free standing boxes in Chamber 1-2 (see 2.4.3).

2.4.1 Cooling system

In this study two air climate chambers of the same type were utilised (Chamber 1-1 and Chamber 1-2). Inside each chamber is a cooling unit which consists of a ceiling mounted air cooling evaporator and a fan in front of the evaporator (see technical data in appendix A). In the first part of the experiment the cooling fan in the cooling unit was turned off but in the latter part (after 7.77 days, see Figure 17) the fan was set to maximum speed, i.e. 50 Hz. This was done in both chambers in order to study the effect of the fan on the heat transfer through the packaging, i.e. compare free and forced convection. Using this information, heat transfer models built for the packed fillets can be calibrated to compensate for both cooling methods (air blast cooling vs. spiral cooling with fan off) starting from the same temperature.

2.4.2 Whole pallets in Chamber 1-1

This experiment was conducted from 23 July to 3 August 2008. Two pallets, each with 96 fish boxes (12 rows, 8 boxes in each row), were put in the climate testing chamber 1-1 (see Figure 8). One of the two pallets contained conventional EPS (Expanded Polystyrene) boxes and the other contained corrugated plastic (CP) boxes. The CP pallet was located below the cooling unit and the EPS pallet in front of the CP pallet as shown in Figure 9.

Figure 8. Left: Whole pallet with EPS boxes. Right: Pallet with Coolseal boxes not showing the two uppermost rows. The pallet in front of the Coolseal pallet was loaded with EPS boxes.

2.4.2.1 Ambient temperature

The configuration of ambient temperature and humidity loggers is presented in Figure 9 - Figure 11 and the ambient temperature evolution throughout the experiment is presented in Chapter 3.

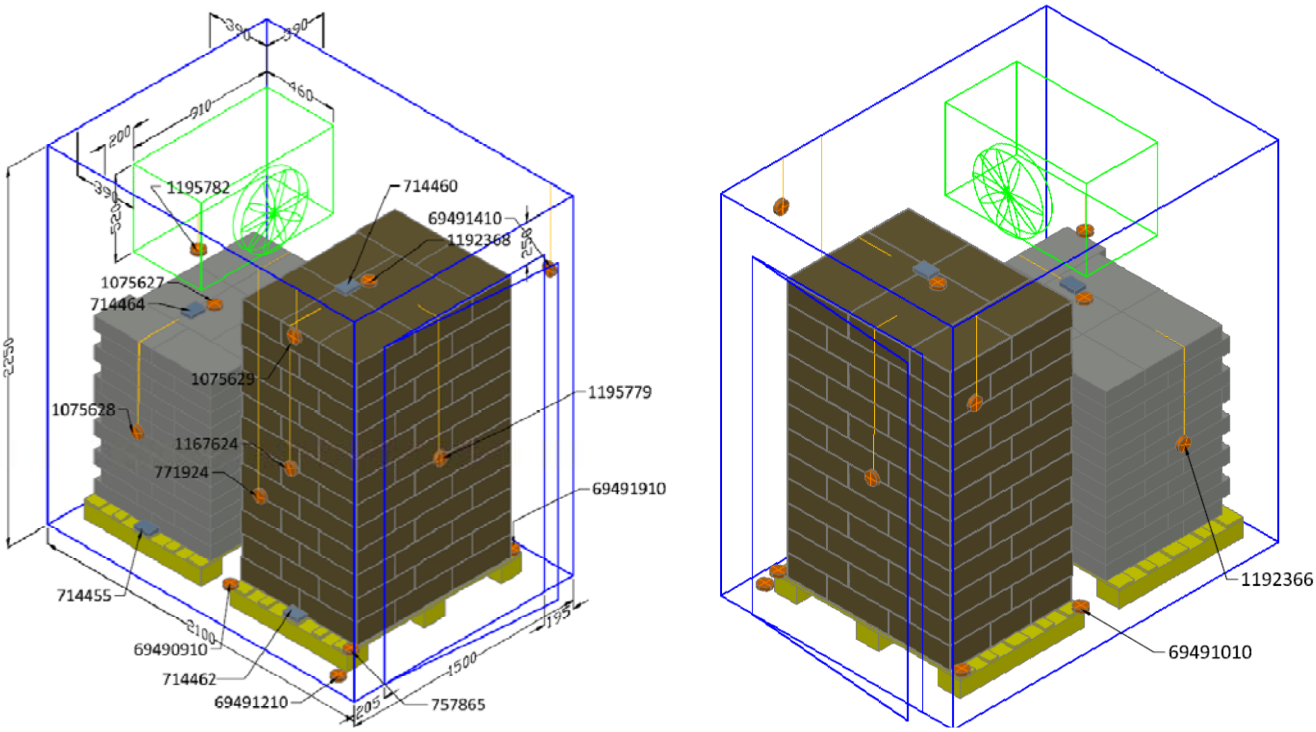


Figure 9. Three dimensional view of the configuration of ambient temperature and humidity loggers in Chamber 1-1 from 23 July to 3 August 2008. The humidity loggers are represented by gray boxes and the temperature loggers by orange buttons.

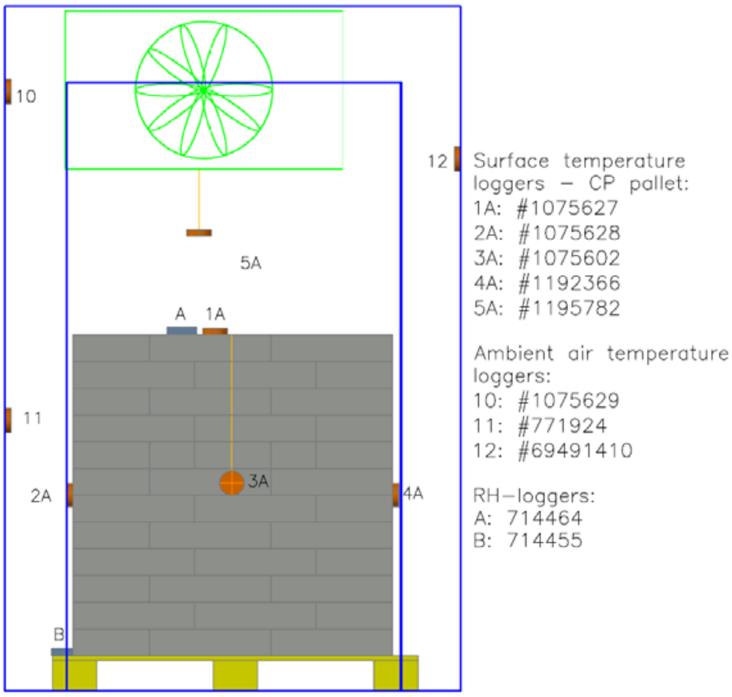


Figure 10. Two dimensional view of the configuration of temperature and humidity loggers surrounding the CP pallet in Chamber 1-1 from 23 July to 3 August 2008.

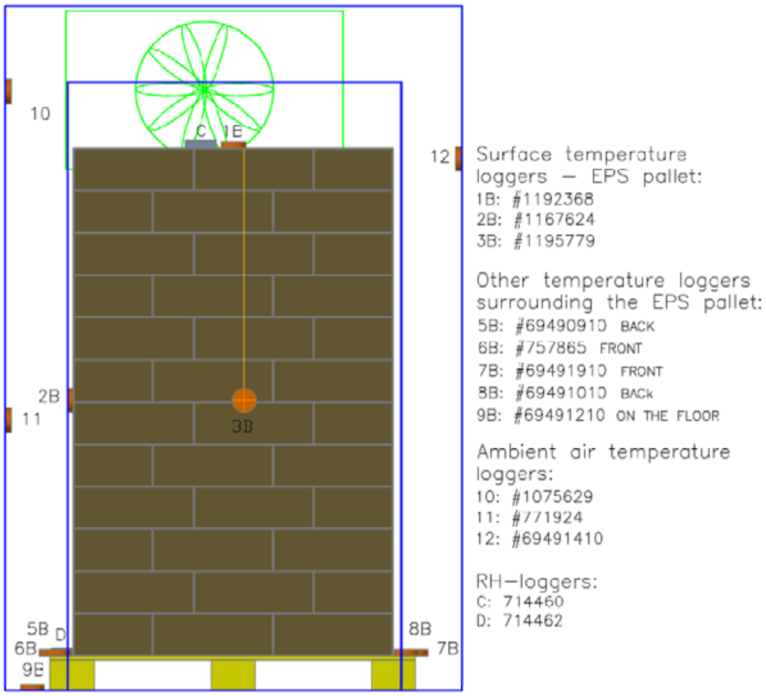


Figure 11. Two dimensional view of the configuration of temperature and humidity loggers surrounding the EPS pallet in Chamber 1-1 from 23 July to 3 August 2008.

2.4.2.2 Product temperature

In order to obtain a good overview of the temperature distribution inside the two pallets 48 temperature loggers were used per pallet. Two loggers were put in each of the 24 boxes mapped on each pallet as is presented in Figure 13. One of two loggers was placed at the bottom of the box and the other was placed in the middle of the box (see Figure 12).

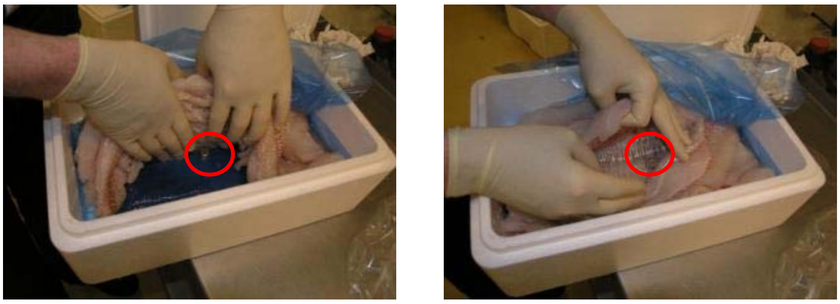


Figure 12. Left: Temperature logger placed at the bottom of an EPS box. Right: Temperature logger placed in the middle of an EPS box.

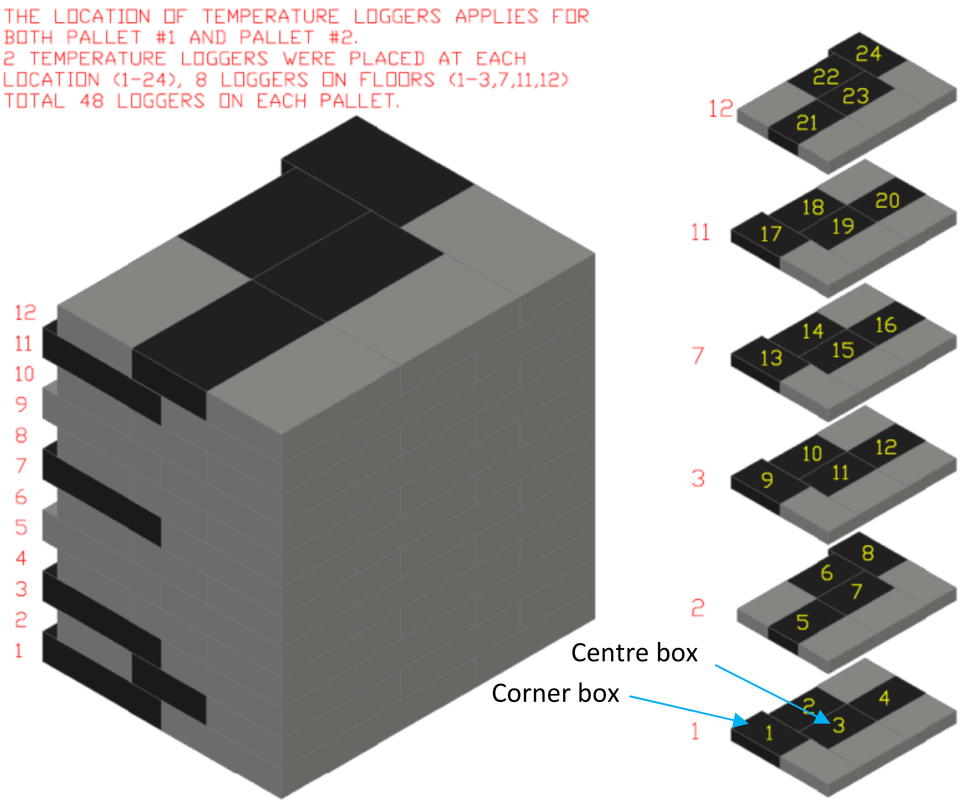


Figure 13. Configuration of boxes containing product temperature loggers on both pallets from day 0 to day 11.

2.4.3 Free standing pallets in Chamber 1-2

This experiment was conducted from 23 July to 3 August 2008. Four free standing EPS boxes were stored on the floor of an air climate chamber called Chamber 1-2 (see Figure 14 - Figure 15).

Figure 14. Four EPS boxes and four CP boxes placed on the floor of Chamber 1-2.

2.4.3.1 Ambient air and surface temperatures

The surface and ambient air temperatures were measured both on top of some boxes, on the floor and in the air 1 m above the boxes in order to grasp spatial temperature differences. The ambient air temperature evolution throughout the experiments is presented in Chapter 3.

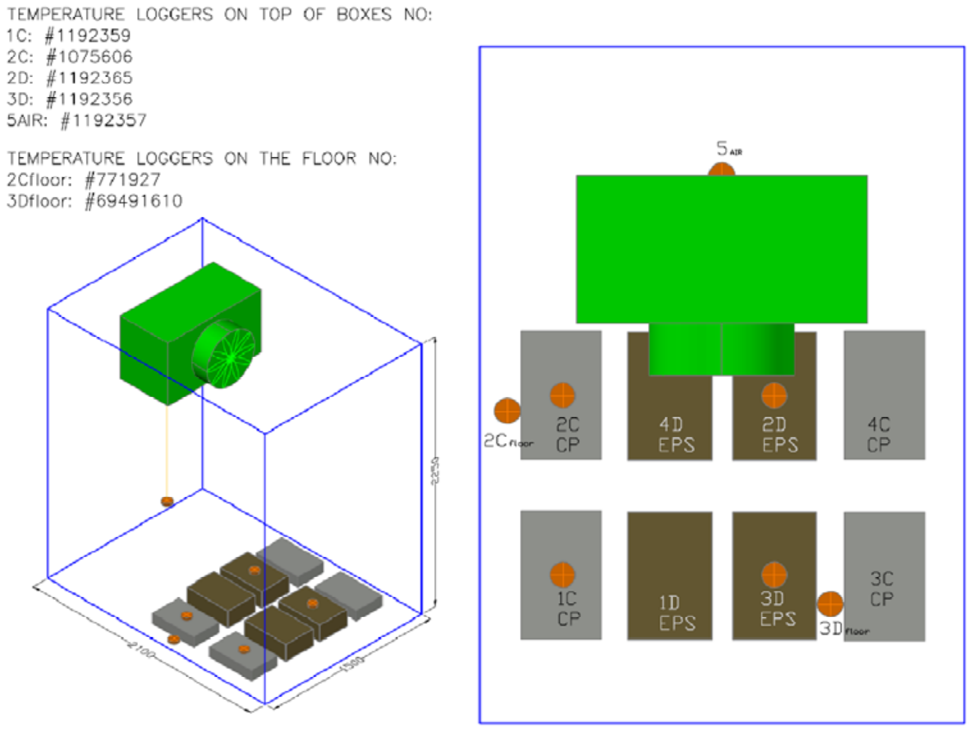
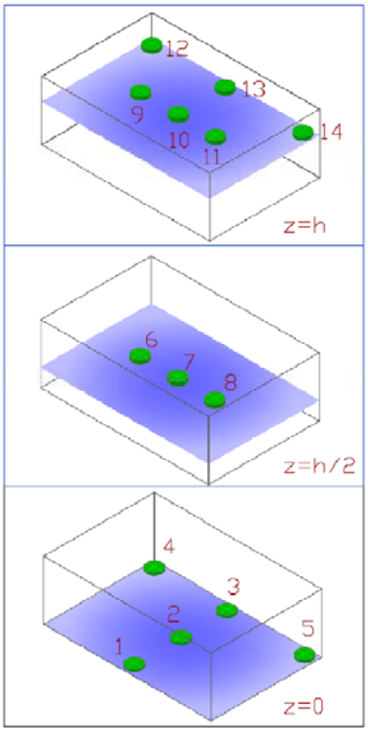


Figure 15. Configuration of ambient temperature loggers inside Chamber 1-2. The brown boxes represent the EPS boxes (1D – 4D) and they gray ones (1C – 4C) represent the CP boxes.

2.4.3.2 Product temperature

In the beginning of the experiment none of the boxes had cooling mats but they were added to two of the EPS boxes and two of the CP boxes as shown in Figure 17. One CP box (marked “2C”) without a cooling mat and one EPS box (marked “3D”) without a cooling mat had 14 temperature loggers each, distributed in the boxes in locations no. 1 – 14 as shown in Figure 16. The other six boxes (two without a cooling mat and four containing cooling mats) had four loggers in locations no. 1 – 4 in Figure 16. It should be noted that the thickness of the pile of haddock inside the boxes was not even all over the box: the thickness was ca. 6 – 10 cm in the middle but only 3 – 5 cm close to the edges.



TEMPERATURE LOGGERS WERE PLACED AT 14 DIFFERENT LOCATIONS INSIDE BOXES 1C-4C & 1D-4D. THE LOCATION APPLIES TO BOTH TYPES OF BOXES AND h REFERS TO THE HEIGHT OF EITHER TYPE #1 (COOLSEAL) OR #2 (EPS). THE TEMPERATURE LOGGERS WERE PLACED AS FOLLOWS IN BOXES NO:

1C: 1-352 2-337 3-333 7-182

2C: 1-17 2-29 3-22 4-323 5-325 6-310 7-357 8-318 9-341 10-307 11-330 12-319 13-322 14-321

3C: 1-14 2-324 3-166 7-350

4C: 1-11 2-19 3-326 7-74

1D: 1-185 2-25 3-385 7-128

2D: 1-125 2-143 3-151 7-360

3D: 1-196 2-305 3-51 4-335 5-317 6-336 7-4 8-331 9-340 10-327 11-314 12-306 13-334 14-312

4D: 1-316 2-155 3-302 7-199

Figure 16. Location of product temperature loggers inside free standing boxes in Chamber 1-2.

3 Results

3.1 *Freestanding boxes*

3.1.1 Ambient air and surface temperatures

The ambient air and surface temperatures during the experiments, which lasted for 11 days, are shown in Figure 17.

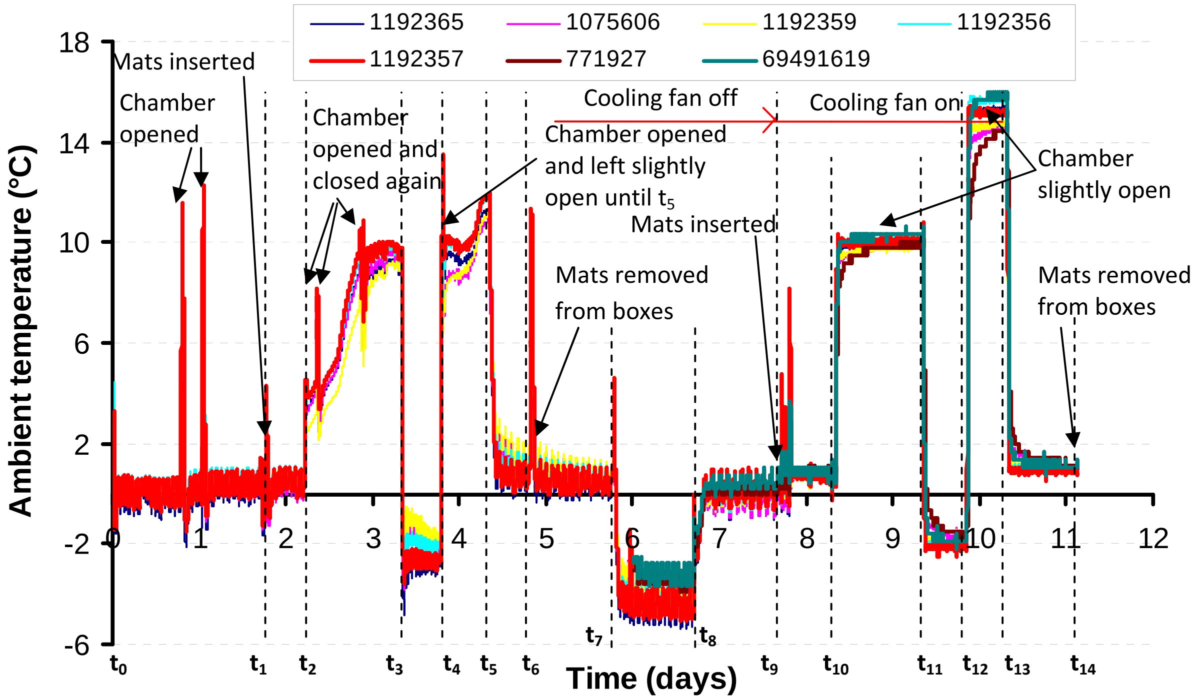


Figure 17. Ambient air and surface temperatures fluctuations inside Chamber 1-2, results from seven temperature loggers distributed throughout the chamber, see locations in Figure 15. Temperature logger no. 1192357 was hanging down from the refrigeration unit. The cooling fan was off until after 7.8 days.

The small fluctuations seen during constant temperature periods are related to the accuracy of the regulation system of the climate chamber. The regulation was on during all the experiment but the set point temperature was different as can be seen in Table 3, which presents relevant events and explains different time steps of the experiment. This temperature profile was chosen in order to simulate challenging temperature conditions, which fresh seafood products often face in cold chains. The cooling mats were inserted into the boxes approximately half a day before a temperature abuse started. This mimics the circumstances before and during a real temperature abuse on board an airplane.

Table 3. Relevant events and time steps in the experiment on free standing boxes in Chamber 1-2.

Time step	Time (hours)	Time (days)	Event	T_{set} = Set point temp. (°C)	Fan off/on
t_0	0	0	Boxes without cooling mats placed in chamber	1	off
t_1	42.5	1.77	Cooling mats inserted	1	off
t_2	53.5	2.23	T_{set} increased, chamber opened but closed again	10	off
t_3	80	3.33	T_{set} decreased	-2	off
t_4	91.5	3.81	T_{set} increased, chamber opened and left slightly open	15	off
t_5	101.5	4.23	T_{set} decreased and chamber closed	1	off
t_6	115	4.79	Cooling mats removed from boxes	1	off
t_7	142.5	5.94	T_{set} decreased in order to speed up the descend of product temperature to ca. 1 °C	-4	off
t_8	161	6.71	T_{set} increased	1	off
t_9	186.5	7.77	Cooling mats inserted, fan put on full throttle	1	on
t_{10}	200.5	8.35	T_{set} increased, chamber opened and left slightly open	10	on
t_{11}	224.75	9.36	T_{set} decreased and chamber closed	-2	on
t_{12}	236.75	9.86	T_{set} increased, chamber opened and left slightly open	15	on
t_{13}	248.75	10.36	T_{set} decreased and chamber closed	1	on
t_{14}	266.5	11.10	End of experiment	1	on

3.1.2 Product temperature inside boxes containing cooling mats

Temperature inside the four boxes containing cooling mats at time intervals specified in Table 3 is shown in Figure 18. Judging from these results, the fish fillets in the CP boxes are obviously worse protected against temperature abuse than the fillets in the EPS boxes when cooling mats are used.

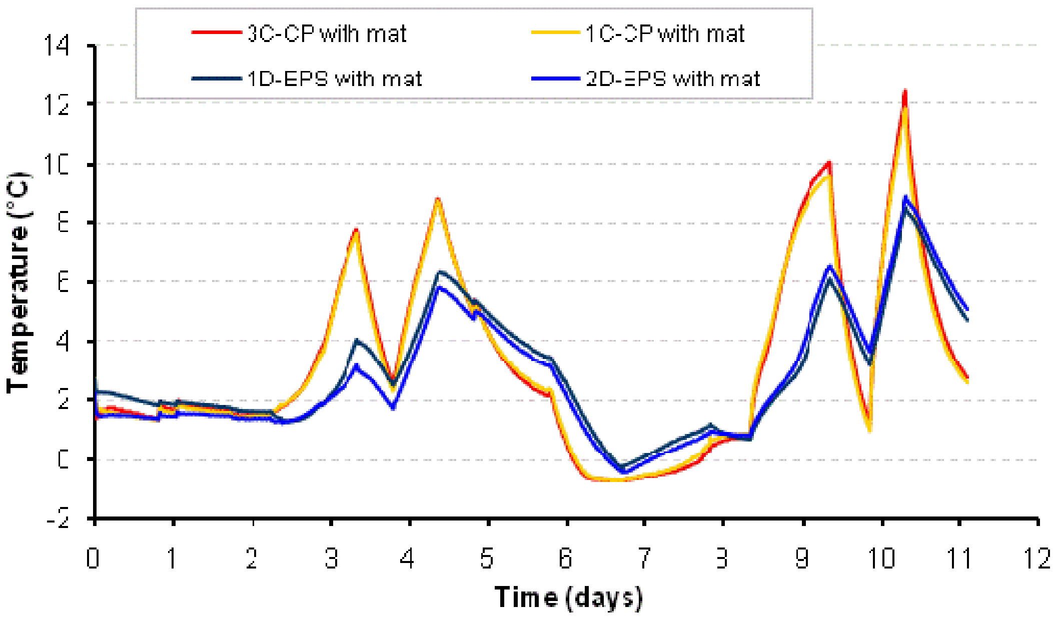


Figure 18. Product temperature inside free standing boxes in chamber 1-2. The boxes contain one cooling mat each and the temperature shown is a mean value calculated from four different locations inside each box.

3.1.3 Product temperature inside boxes without cooling mats

Temperature inside the four boxes without cooling mats is presented in Figure 19 – 20. The only difference between the two figures is that in Figure 20 is the mean temperature calculated from all of the fourteen loggers inside boxes 2C and 3D but in Figure 19 it is calculated from four loggers at locations no. 1,2,3 and 7 according to Figure 16. Comparison between Figure 18 and Figure 19 reveals that the difference between the two packaging material is actually not as much when cooling mats are not used. In other words, the temperature rise in the EPS boxes is almost as great as the temperature rise in the CP boxes in the case of a temperature abuse when frozen cooling mats are not used.

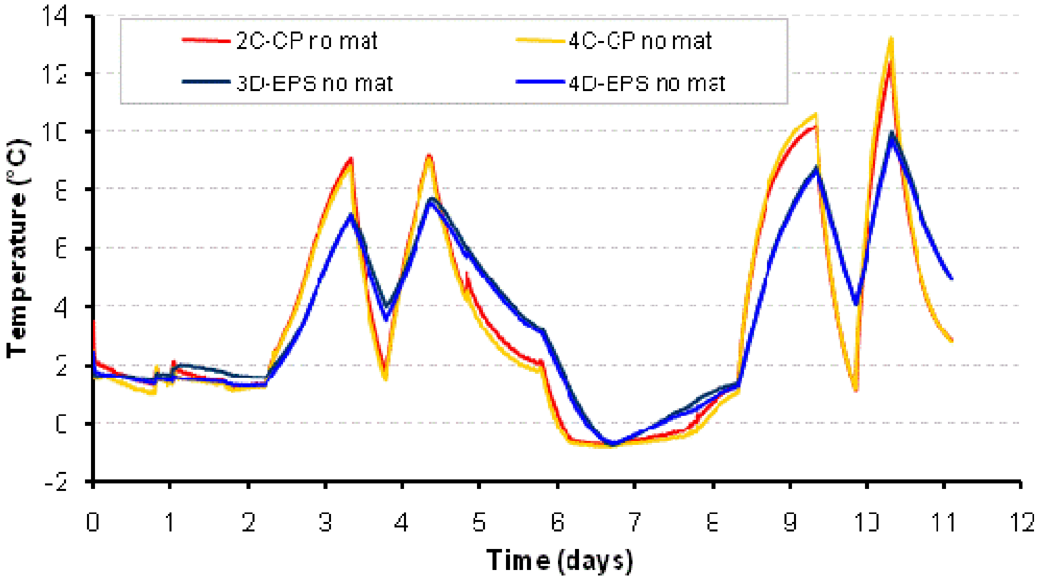


Figure 19. Product temperature inside free standing boxes in chamber 1-2. The boxes do not contain any cooling mat and the temperature shown is a mean value calculated from four different locations inside each box.

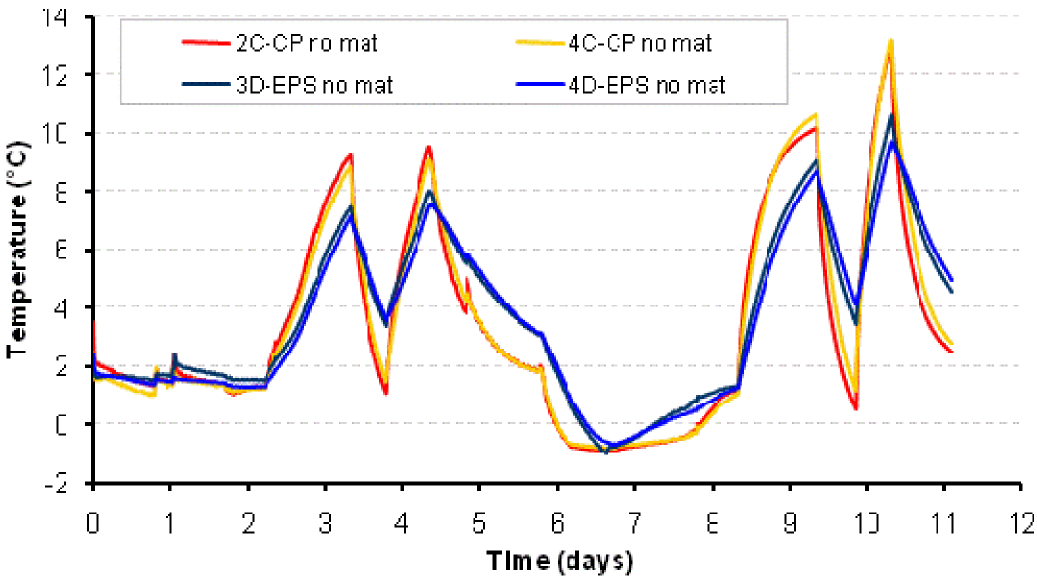


Figure 20. Product temperature inside free standing boxes in chamber 1-2. The boxes do not contain any cooling mat and the temperature shown is a mean value calculated from four different locations inside boxes 4C and 4D but from fourteen different locations inside boxes 2C and 3D. See locations of loggers in Figure 16.

In order to make the comparison easier for the reader, Figure 21 presents the results for all four packaging solutions along with the ambient air temperature measured 1 m above the boxes (with logger no. 1192357). The figure clearly shows that the best solution for protecting fresh fillets against temperature abuse is using cooling mats in EPS boxes and that the worst of the four solutions is using CP boxes without cooling mats. Furthermore, EPS boxes without cooling mats seem to maintain a slightly lower product temperature during temperature abuse than CP boxes with cooling mats.

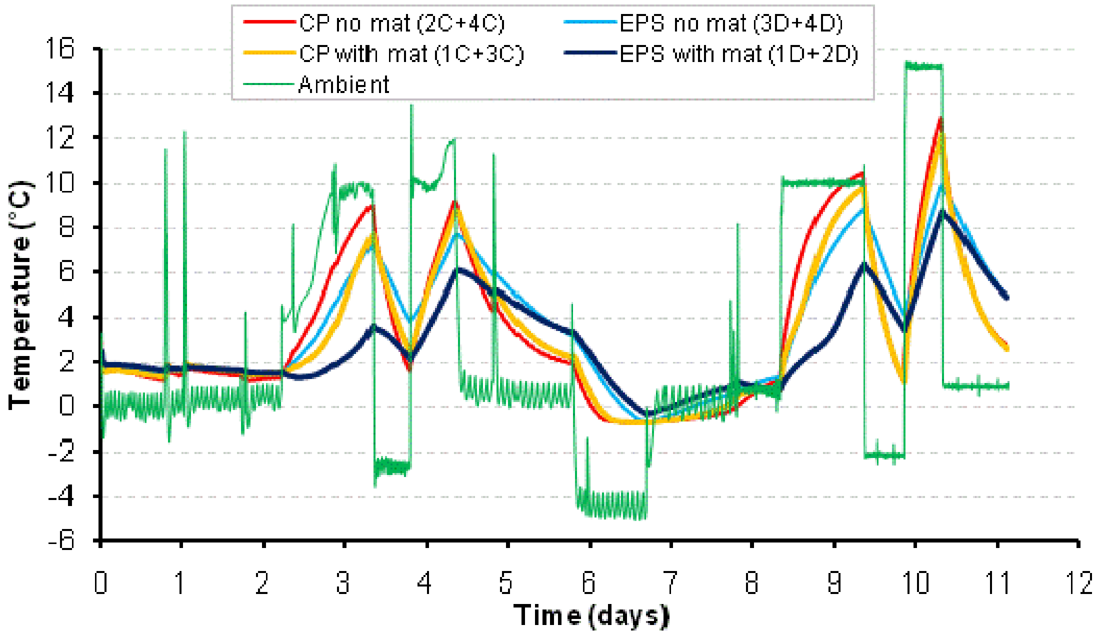


Figure 21. Product temperature inside four different types of packaging solutions shown with the ambient air temperature profile throughout the whole experiment. The product temperature shown is a mean value calculated from four different locations inside each box, mean calculated from two boxes for each solution.

This experiment thus reveals that the great insulating properties of the EPS boxes makes this type of packaging a lot more suitable in case of seriously uncontrolled chilled chains. Actually, an EPS box without a cooling mat seems to perform similarly as a CP box with a cooling mat.

However, since the CP boxes are less insulating, in some parts of chilled chains it may even be beneficial to use CP boxes. This is in case of lower surrounding temperature than product temperature, i.e. in cases where heat transfer from the products through the packaging and to the surroundings is preferred.

3.2 *Whole pallets*

3.2.1 Ambient air and surface temperatures

Results from all ambient temperature and humidity loggers are presented in Figure 22. Timing of relevant events (insertion of cooling mats, changes in set point temperature etc.) is identical to the procedure for the free standing boxes in chamber 1-2 described in Table 3 in 3.1.1.

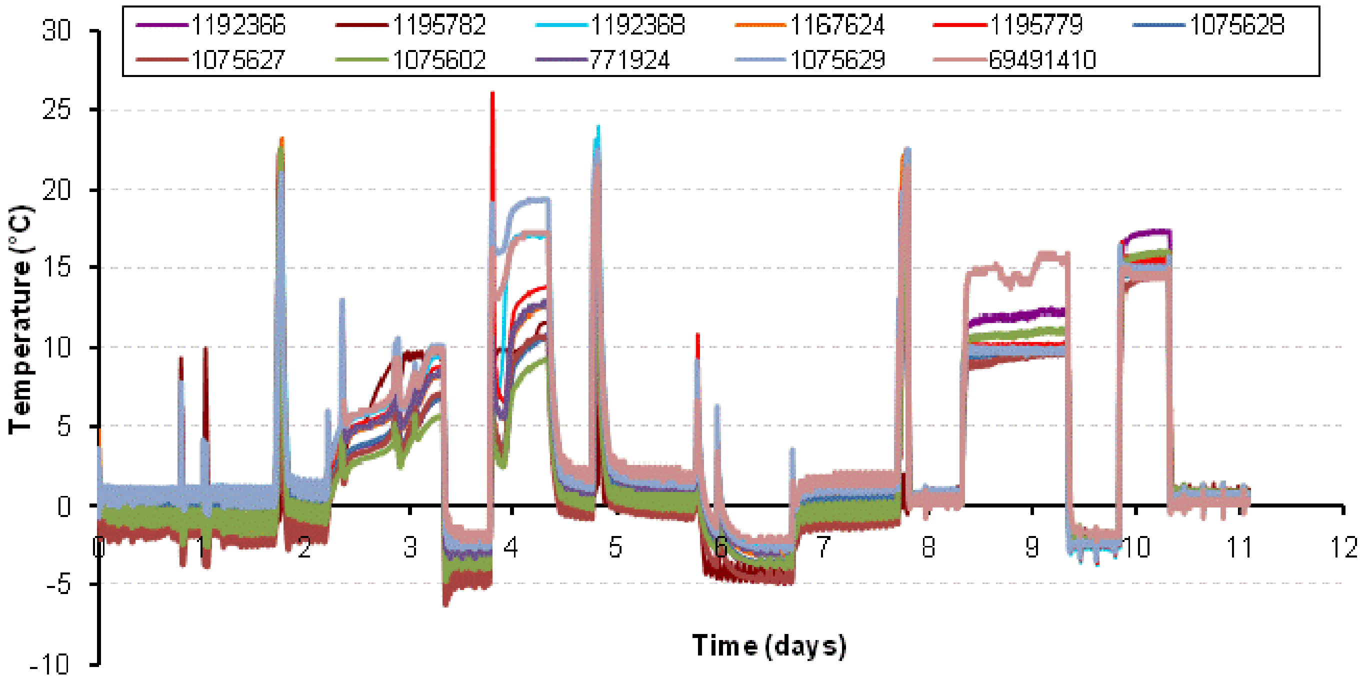


Figure 22. Temperature fluctuations inside Chamber 1-1, results from ten temperature loggers distributed throughout the chamber as shown in Figure 9 – 11. A description of relevant events is given in Table 3.

The relevant events are shown in Figure 23, which reveals that the air surrounding the CP pallet was a bit colder than the air surrounding the EPS pallet throughout most of the experiment. This can mainly be explained by two facts:

1) the CP pallet was situated farther within the chamber, i.e. farther away from the door,

2) the door was slightly open during three periods of temperature abuse. This fact should be kept in mind when the product temperature rise in the two different pallets is compared during the periods when the pallets are abused by high ambient temperature.

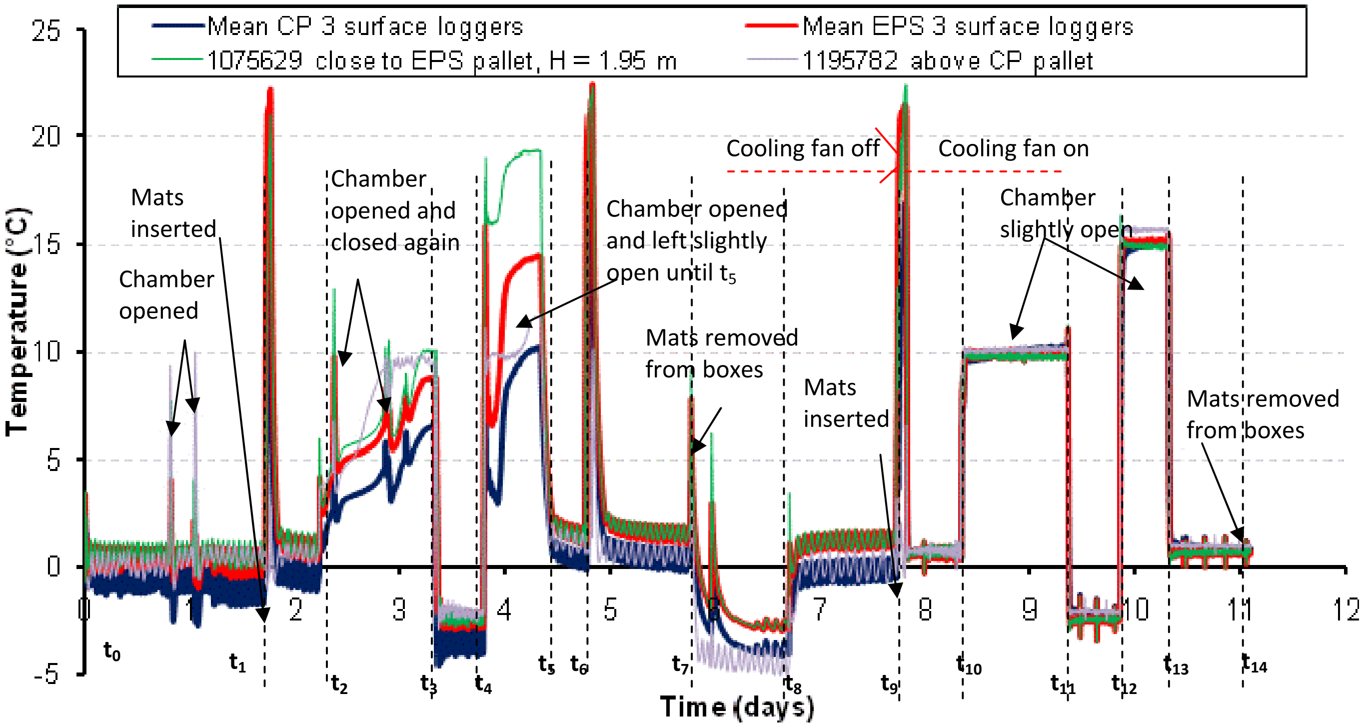


Figure 23. Temperature profiles for the surface of the two pallets (calculated from 3 surface loggers for each pallet) and two ambient air temperature profiles.

3.2.2 Product temperature

The evolution of the mean temperature inside all of the 24 boxes mapped on each pallet can be seen in Figure 24 along with the ambient air temperature calculated from three loggers.

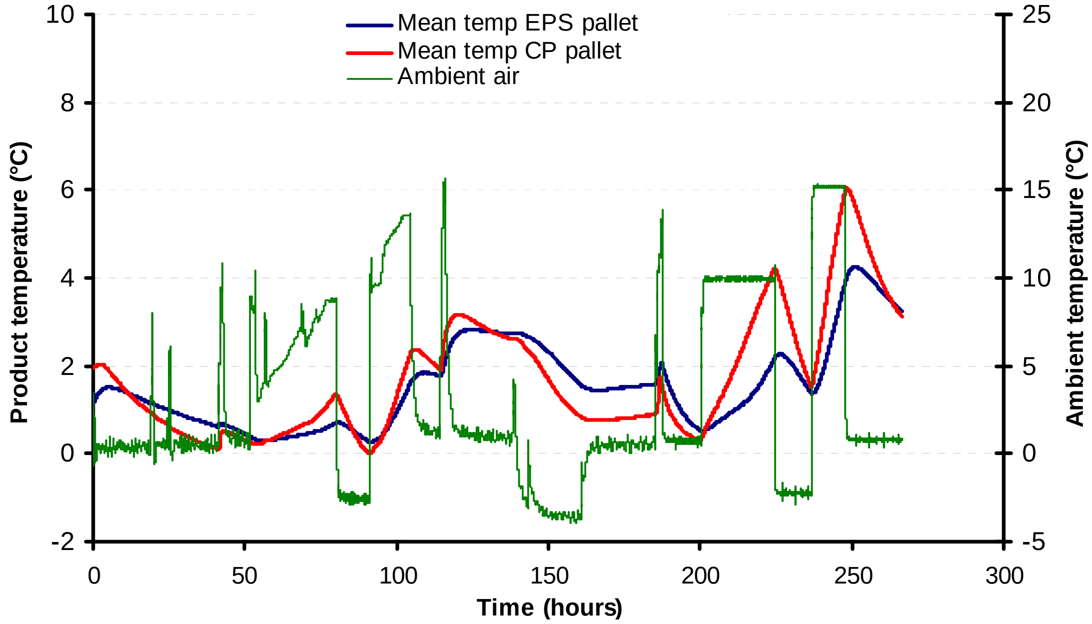


Figure 24. Mean temperature inside 24 boxes (2 loggers in each box) on each pallet. The ambient temperature is calculated from three surrounding temperature loggers (no. 1195782, 69490910 and 1075629).

No significant difference is seen between the two pallets during the first 186.5 hours when the air in the chamber is quite still although it is quite clear from the figure that if the first two high ambient temperature intervals would have been longer, more difference would have been yielded between the two pallets. Noticeably more temperature sensitivity is experienced for the CP pallet compared to the EPS pallet during the two temperature abuses from 53.5 to 80 hours and from 91.5 h to 101.5 h. The difference in temperature sensitivity is much clearer during the temperature abuse from 200 h to 225 h. During this period, the mean product temperature in the EPS boxes rises from 0.5 to 2.3 °C (1.8 °C rise) while the mean product temperature in the CP boxes jumps from 0.3 to 4.2 °C, i.e. a 3.9 °C rise. It should be noted that the fan is on during this period and the blast obviously underlines the clear difference of insulating performance between the two packaging materials.

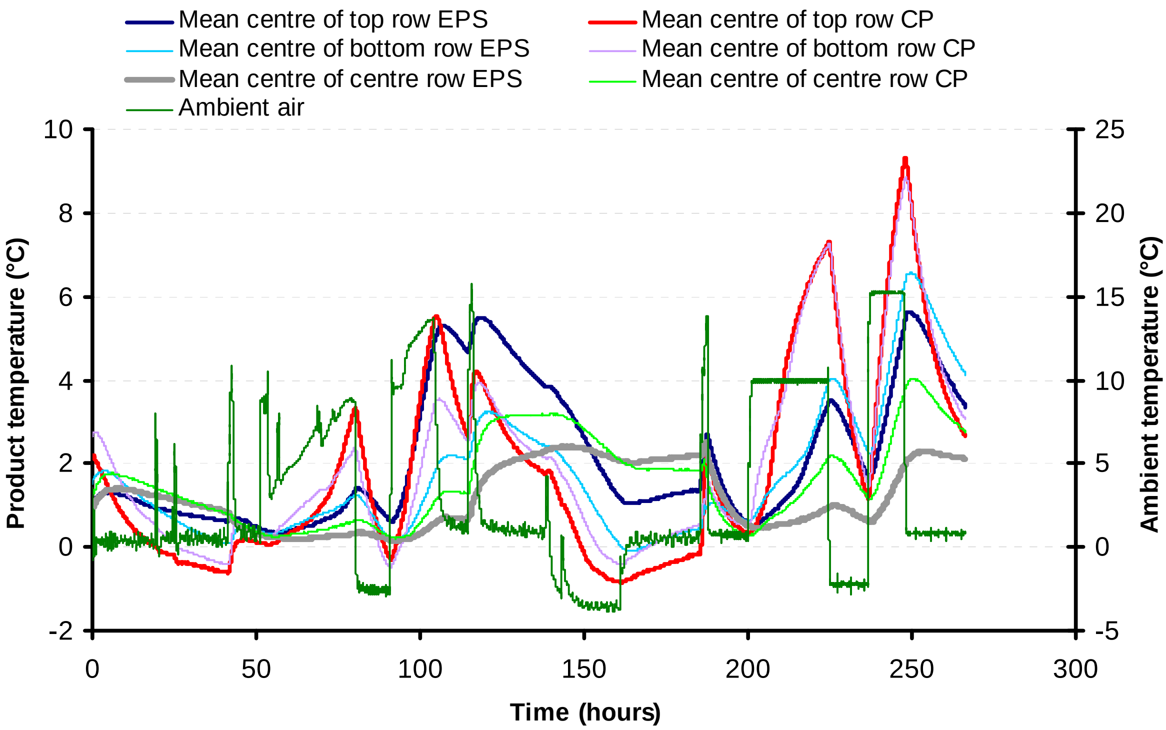


Figure 25. Mean temperature in the centre of boxes at three heights on the two pallets. The bottom rows are marked no. 1, the centre rows no. 7 and the top rows no. 12 in Figure 13. The ambient temperature is calculated from three surrounding temperature loggers (no. 1195782, 69490910 and 1075629).

Figure 25 reveals that the temperature distribution on both pallets is far from being homogenous, especially during periods of high ambient temperature. This is predictable since according to basic theories of heat transfer, the heat from the surrounding is transferred from the outside (upper and lower) layers of boxes into the centre of the stack on each pallet, i.e. from the hot surroundings to the cold stack of boxes. The outer layers (including the top and bottom layers) act as insulation for the inner boxes.

What is also evident from Figure 25 is that the EPS boxes are less sensitive to temperature abuse than the CP boxes in all rows. This confirms the results already presented in Figure 24. As already noted, the air blast during the last two temperature abuse periods, emphasises the significant difference in insulating performance between the two packaging types.

The maximum temperature measured in all of the 24 boxes on each pallet is shown in Figure 26. As before the high ambient temperature more easily affects the product temperature in the CP boxes. As an example, the maximum product temperature in the CP boxes increases in 25 h from 0.8 °C at time 200 h to 8.7 °C at time 225 h. At the same time the maximum product temperature in the EPS boxes rises from

1.3 °C to 5.1 °C. This occurred in 10 °C surrounding temperature and wind conditions that pallets can easily face e.g. at airports: 0.5 – 9 m/s air velocity depending on the location inside the chamber. The highest air velocity close to the packaging was measured above the top EPS row (ca. 2-6 m/s) but it was notably lower close to the CP pallet.

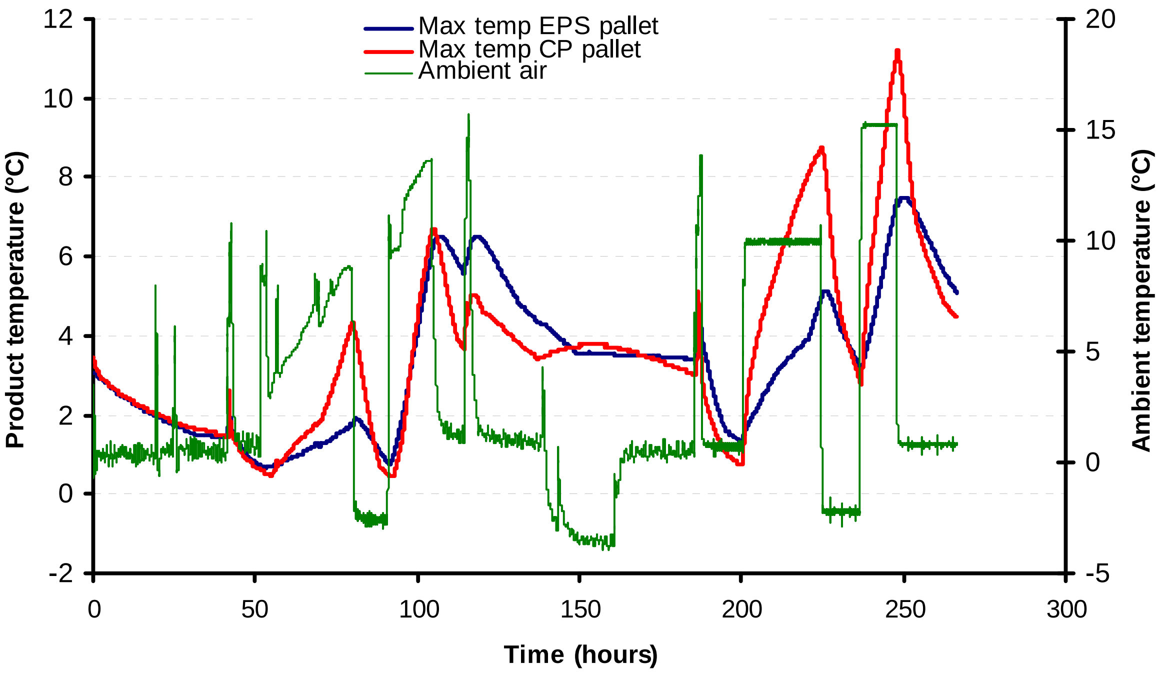


Figure 26. Maximum product temperature on the two pallets. The ambient temperature is calculated from three surrounding temperature loggers (no. 1195782, 69490910 and 1075629).

The lowest product temperature on the two pallets can be seen in Figure 27. Once again, the lower insulation value of the CP boxes can be used to explain the results: during chilling periods (surrounding temperature -4 to 1 °C), the fillets in the CP boxes facing the ambient air are chilled faster than the fillets in the similar EPS boxes and thus, the lowest temperature on the CP pallet decreases faster than on the EPS pallet. This shows that if the fillets are not packed at the recommended storage and transportation temperature (close to and even below 0 °C)[10], they are actually chilled faster in CP than in EPS when placed in a chilled-storage room before transportation. The same applies if any other part of the cold chain is broken: cooling too warm products simply happens faster if the insulation of the packaging is worse.

What has already been written about the temperature distribution in vertical cross-sections through the pallets also applies for horizontal cuts: during temperature abuse the temperature distribution is often far from being homogeneous. This is depicted in Figure 28 - Figure 29, which compare mean product temperature of corner boxes to the mean product temperature in the boxes in the centre of each row for EPS and CP, respectively. The mean for the corner boxes is calculated from the centre temperature in boxes marked no. 3, 7, 11, 15, 19 and 23 in Figure 13 and from boxes no. 1, 8, 9, 13, 17 and 24 in the same figure for the centre boxes.

[10] Guðjónsdóttir, M., Magnússon, H., Arason, S., Ólafsdóttir, G., Bogason, S. 2007. *Geymsluþolstilraunir á þorskbitum: Áhrif ofurkælingar, pæklunar og gaspökkunar á eðlis- og efnaeiginleika þorskvöðva.* Matís report 50-07.

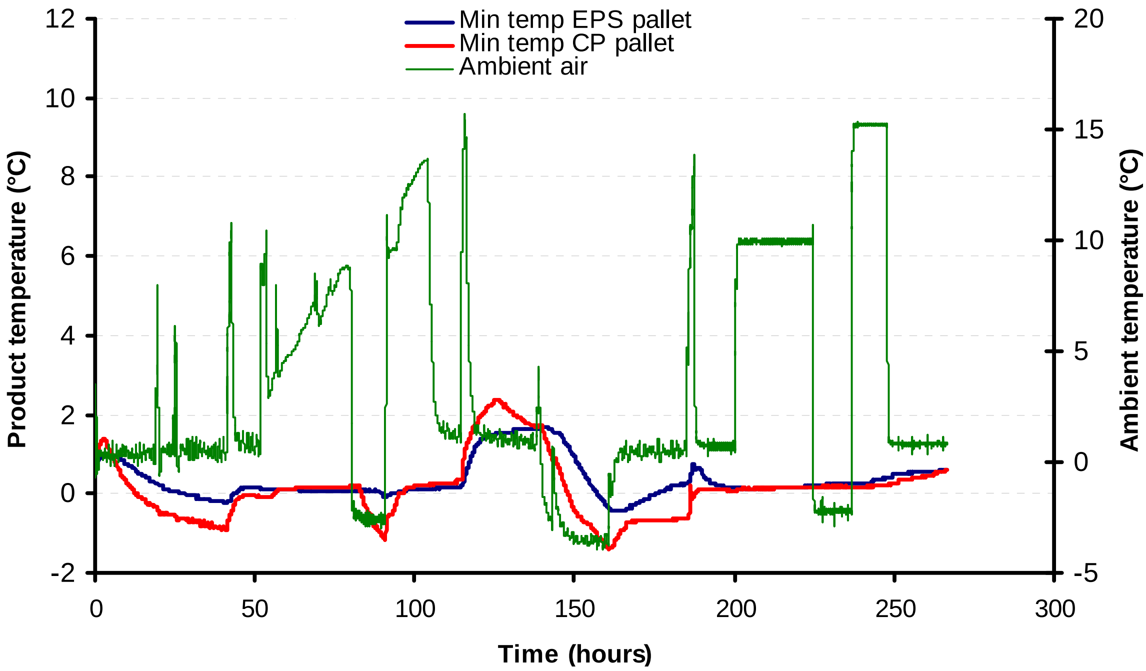


Figure 27. Minimum product temperature on the two pallets. The ambient temperature is calculated from three surrounding temperature loggers (no. 1195782, 69490910 and 1075629).

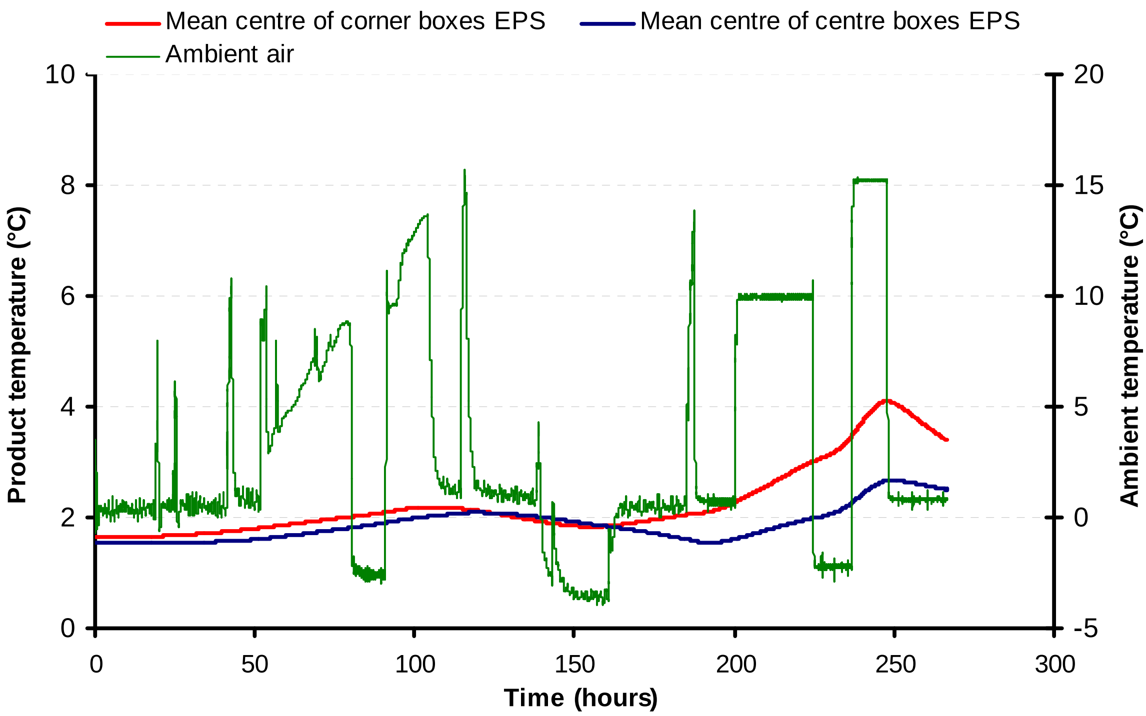


Figure 28. Temperature in the centre of EPS boxes situated in corners vs. in the centre of the stack, mean of six rows (1,2,3,7,11,12 in Figure 13). The ambient temperature is calculated from three surrounding temperature loggers (no. 1195782, 69490910 and 1075629).

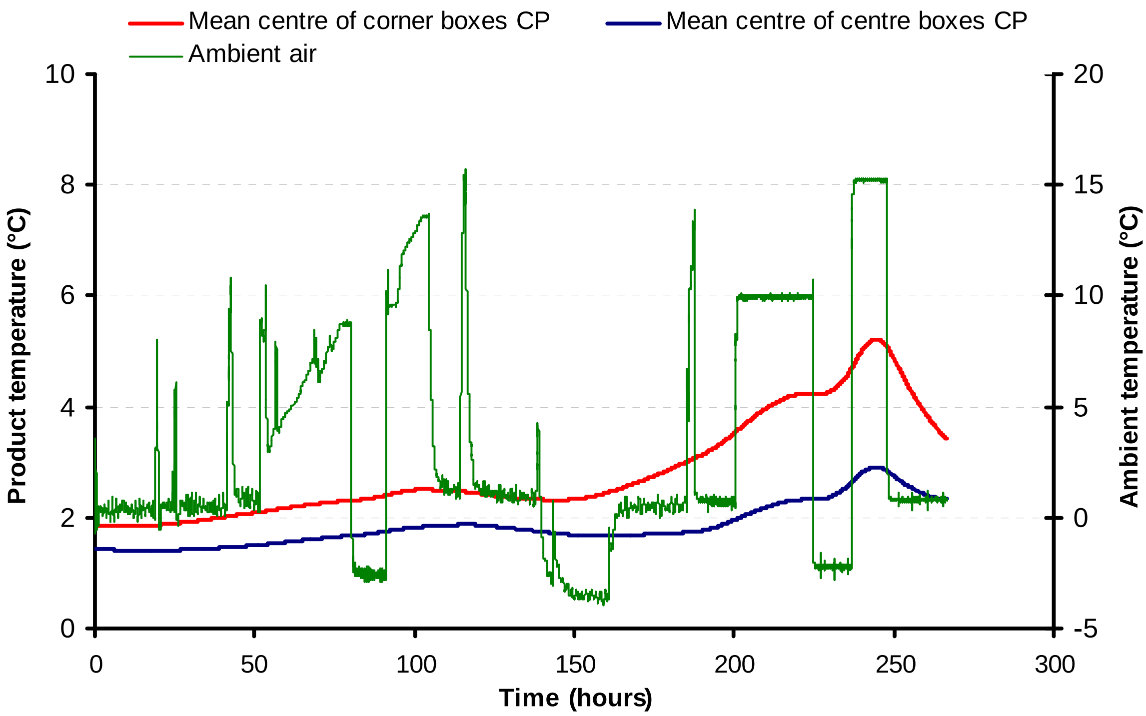


Figure 29. Temperature in the centre of CP boxes situated in corners vs. in the centre of the stack, mean of six rows (1,2,3,7,11,12 in Figure 13). The ambient temperature is calculated from three surrounding temperature loggers (no. 1195782, 69490910 and 1075629).

4 Conclusions

- Experiments with free standing boxes revealed that using frozen cooling mats in fish boxes is an effective way to protect fresh fish fillets against temperature abuse.
- Insulating performance of EPS is significantly better than of CP, independent of usage of cooling mats. The difference in insulating performance between the two packaging types is exaggerated when cooling mats are used.
- Temperature abuse causes similar temperature increase in fresh fillets stored in **EPS** boxes **without** a cooling mat as in fresh fillets stored in **CP** boxes **with** a cooling mat.
- Experiments with whole pallets of fresh fish fillets confirm that fillets packed in CP are much more easily influenced by ambient temperature fluctuations than fillets packed in EPS. The mean temperature rise for a whole 300 kg pallet can be twofold using CP rather than EPS, given that the movement of surrounding air is considerable and its temperature is 10 °C.
- In dynamic temperature conditions, the temperature distribution in a whole pallet of fish fillets can be far from homogeneous. The product temperature difference can easily exceed 6-8 °C depending on the order of magnitude of the temperature fluctuations and their durations.

5 Acknowledgements

This work was supported by the EU-project Chill on (project no. FP6-016333-2), AVS Research Fund, TÞS Research Fund and University of Iceland Research Fund.

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Appendix A

Cooling unit ("unit cooler") in climate chambers – technical data.

GEA

Küba
Kältetechnik GmbH

Ref.: Matis
Cold Room: Hermir 1-3

Unit cooler KÜBA SGBE 071C
Article: 4015.071

Capacity Qo [kW]	Air inlet TL1 [°C]	Air outlet TL2[°C]	Evapor. Temp. to [°C]	Temp. diff. DT1 [K]	Superheat- T. toh [°C]	Refrigerant	Speed n [min-1]
3,65	-25,0	-28,7	-33,0	8,0	-27,8	R404A	1360

Technical datas:

Air flow:	2460 m³/h	Type calculation follows:		el. defrost:	230V-1 /400V-3-Y
Air throw:	20,0 m	at speed of 1360 min-1		Coil:	1,73 kW
Surface:	22,9 m²	Qo (DT1=8,0 K):	3,65 kW	Drip tray:	0,29 kW
Fin Spacing:	7,0 mm	toh (DT1=8,0 K):	-27,8 °C	Total:	2,02 kW
Tube volume:	5,7 l	to (DT1=8,0 K):	-33,0 °C		

Fan(s):

1 Pieces: 230±10% V-1-50/60Hz; IP44		Operating data per Fan		Motor plate per Fan	
Blade diameter:	400 mm	Op. mode: 50 Hz		Op. mode: 50 Hz	
Range of temp.:	-40 up to +45 °C	Speed:	1362 min-1	Speed:	1360 min-1
Sound power:	75 dB(A)	Capacity:	205 Watt	Capacity:	210 Watt
Lpa at 10 m:	44 dB(A)	Cur. intake:	0,90 A	Cur. intake:	0,95 A

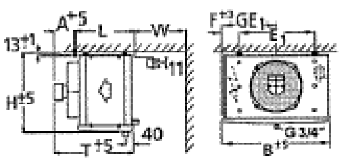
Sound level LpA refers to installation outside (as per DIN 45635)

Dimensions and weight: **Materials:**

Connection On:	10* mm	Net weight:	42,0 kg	Tubes:	Copper
Connection Off:	22 mm	Gross weight:	53,0 kg	Fins:	Al
*=multiple-injection with KÜBA-CAL Distributor		h. ab. sea level	0 m	Casing:	Al ; RAL 9018

version 2008.01

H = 560 mm
B = 915 mm
T = 640 mm
L = 495 mm
F = 143 mm
A = 150 mm
W = 300 mm



E1 = 630 mm; GE1= 458 mm;
Volume packed H =800 mm; Volume packed B =1130 mm; Volume packed T =820 mm;
Categorization as per pressure equipment directive (PED): category " 0" for fluid group "" 2" at max. allowable pressure of PS=32 bar.
Execution hints and dimensional changes for options can be found in the catalogue.
Please also note our general hints for mounting and operation.
Important: In case of use of frequency converters for speed control please read our regulations.