Cod Farming in Nordic Countries
21 September, Reykjavík, Iceland

Optimised chilling during processing and transport of fresh fish

Björn Margeirsson
Project Manager at Matis ltd. and Ph.D. Student at University of Iceland
bjornm@matis.is

Acknowledgements

- **National Project “Hermun kæliferla”**
  - AVS R&D Fund
  - Technology Development Fund
  - University of Iceland Research Fund

- **Samstarfsaðilar:**

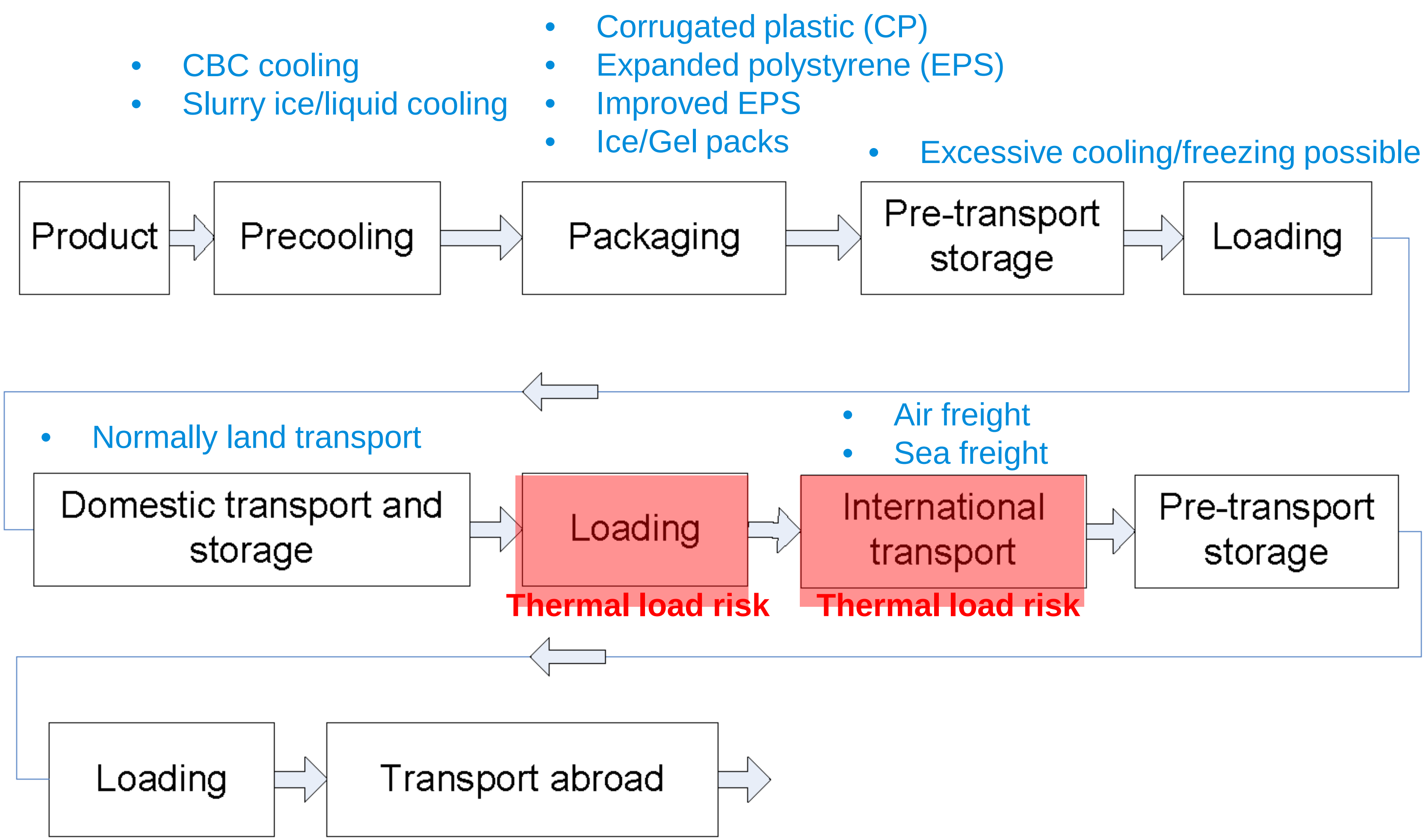
Festi/Völusteinn/Eskja

- **EU-project “Chill-on”**

Agenda

- Background
- Precooling (chilling during processing)
  - CBC (Combined Blast and Contact) cooling
  - Slurry ice/liquid cooling
- Chilling during transport
  - Temperature control – air vs. sea transport
  - Optimised insulated packaging
- Conclusions

Background



Simplified flowchart for processing and transport of fresh fish products

Precooling

Reduce the product temperature to around -1 °C pre-transport

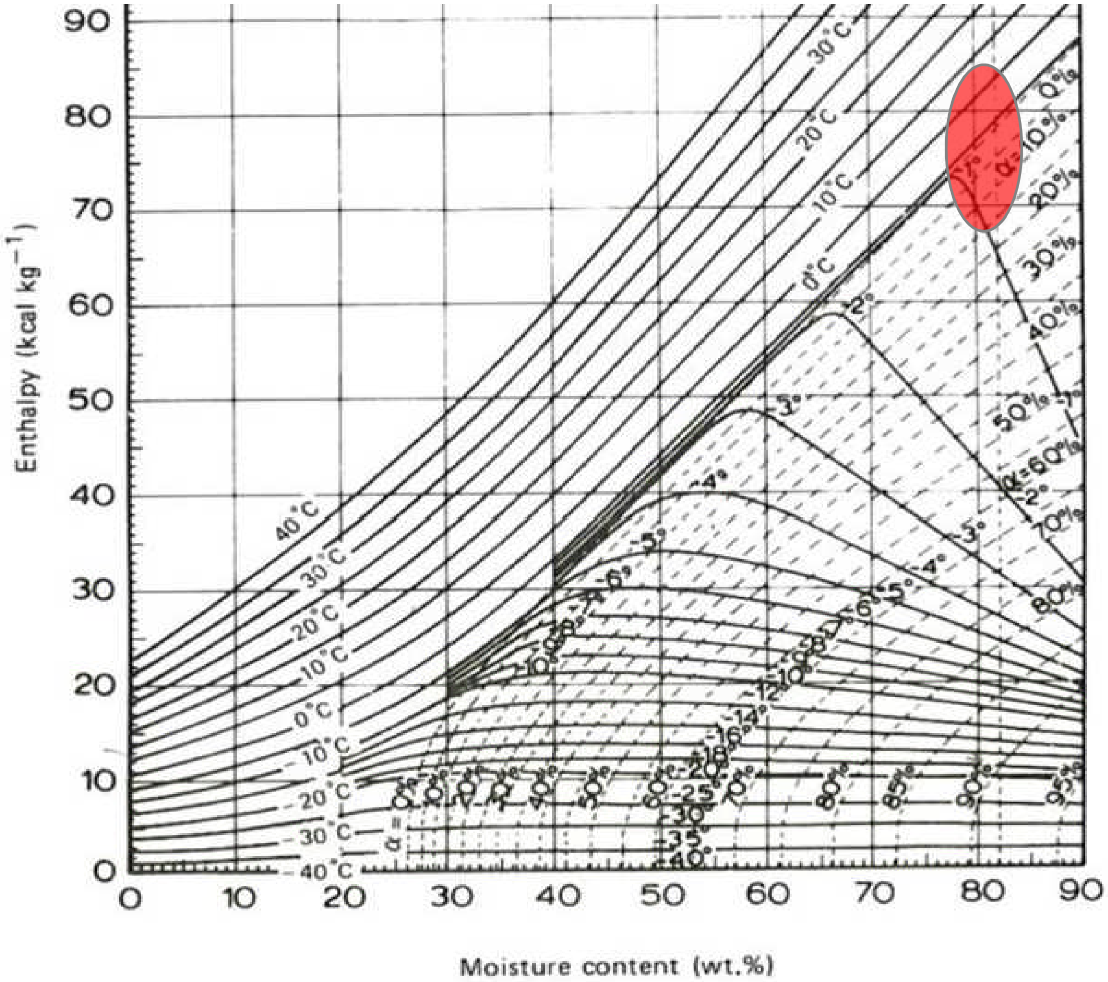
By superchilling the fish loins pre-transport, minor part of the product’s water content is frozen (5-15%)

Protection against thermal load during distribution

Two possible precooling methods:

- **CBC (Combined Blast and Contact cooling)**
- **Slurry ice / liquid cooling**

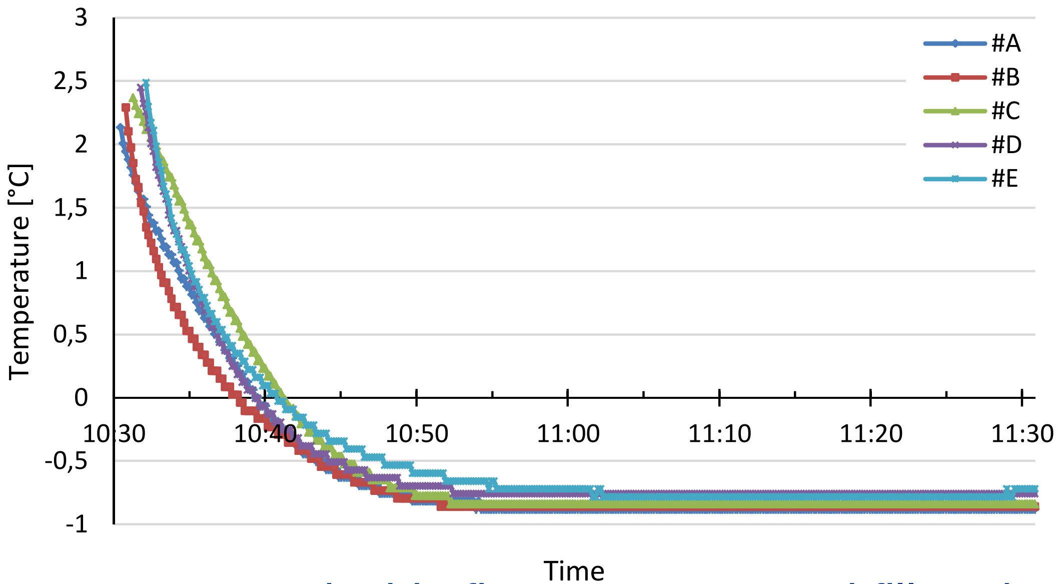
Precooling - thermodynamics



Enthalpy diagram for lean fish muscle (Rha, 1975), α is the proportion of frozen water in the fish fillet

Ref: RHA, C. (1975) Thermal properties of foods. IN RHA, C. (Ed.) *Theory, Determination and Control of Physical Properties of Food Materials.* Dordrecht, Boston, Reidel Publishing.

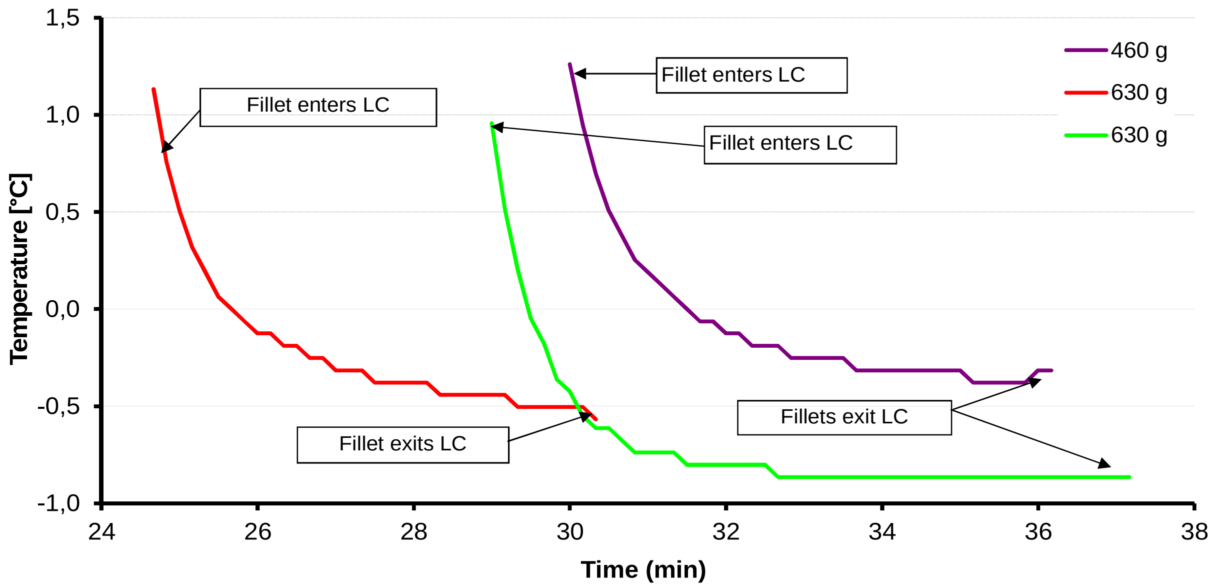
CBC cooling



- Immersed in weak brine / slurry ice for around 10 min before the actual CBC cooling (LC+CBC)
- Efficient (8-10 min from 4 °C to -1 °C)
- Stable air temp. (~ -8 to -7 °C)

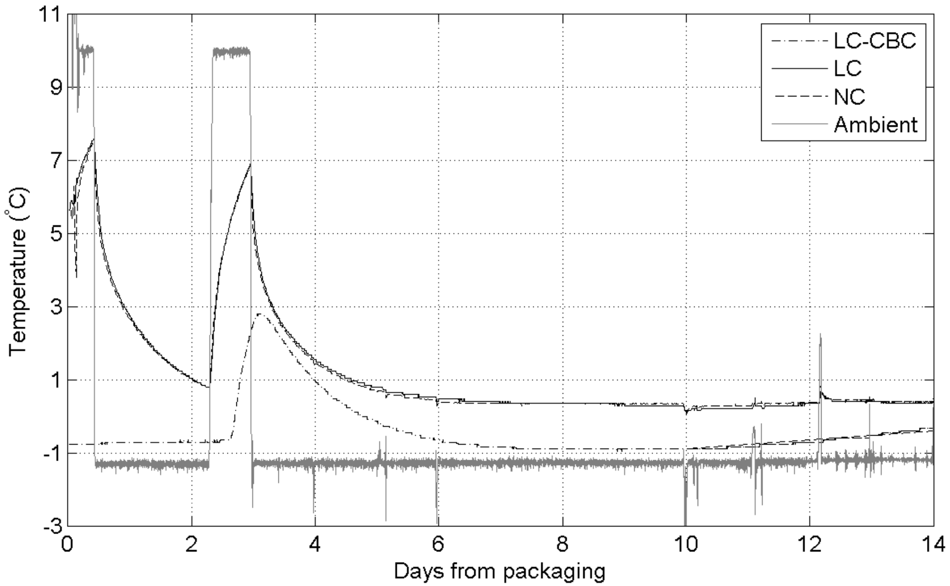
Temperature inside five 400-600 g cod fillets (#A, #B, #C, #D, and #E) transferring through a CBC cooler (Skaginn, Akranes, Iceland).

Slurry ice / liquid cooling



- Quite efficient (6-10 min from 4 °C to -1 °C to 0 °C)
- Possible problems with the temp. control of brine
- Risk of cross-contamination

Precooling and storage life



Product and ambient temperature during storage. LC: Liquid cooling, NC: No cooling, LC-CBC: LC followed by combined blast and contact cooling

Freshness period and maximum shelf life according to sensory evaluation. Processed 2 days post catch.

Group	Freshness period	Storage life	Mean temp. (°C)
LC-CBC	4-6 days	12-13 days	-0.4 (13 days)
LC	4-5 days	7-10 days	1.1 (10 days)
NC	3-6 days	6-10 days	1.1 (10 days)

Ref: Magnússon et al. (2009) Matís report 23-09

Precooling and storage life

Group	Freshness period (days)	Storage life (days)
CBCC-RTS-GP	7-9	9-10
CBCC-RTS	7-9	9-10
LC-RTS-GP	6-7	8-9
NC-RTS-GP	7-9	10+
CBCC-S-GP	7-9	12-13
CBCC-S	8-9	12-13

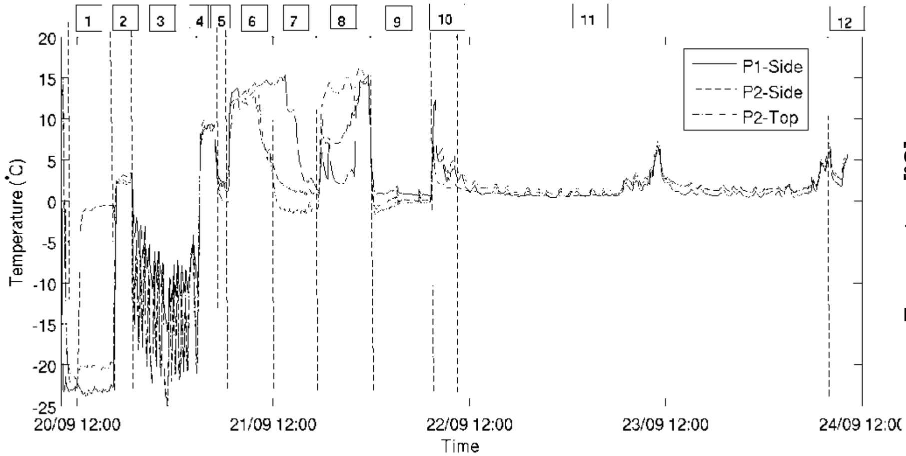
Freshness period (days) and maximum shelf life (days) according to sensory evaluation (CBCC: Combined blast and contact cooling, RTS: Real temperature simulation, LC: Liquid cooling, NC: No cooling, GP: Gel pack, S: Storage at -1 °C)

Mean product temperature and standard deviation during storage

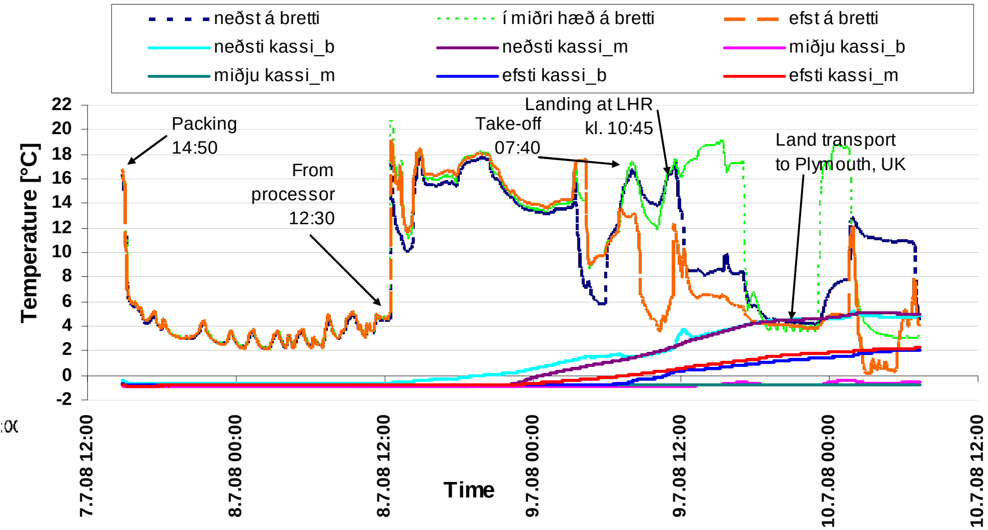
	group	mean (°C)	stdev (°C)
A	CBC-RTS-GP	-0.1	0.3
B	CBC-RTS	0.2	0.5
C	LC-RTS-GP	0.4	0.6
D	NC-RTS-GP	1.1	0.5
E	CBC-S-GP	-0.3	0.3
F	CBC-S	-0.2	0.2

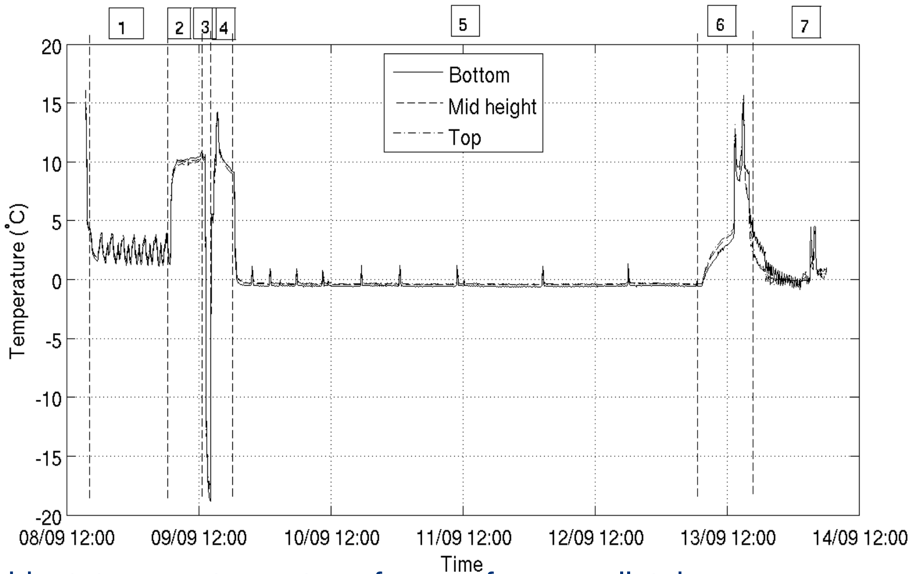
Ref: Martinsdóttir et al. (2010) Matís report 18-10

Temperature control during air- and sea transport

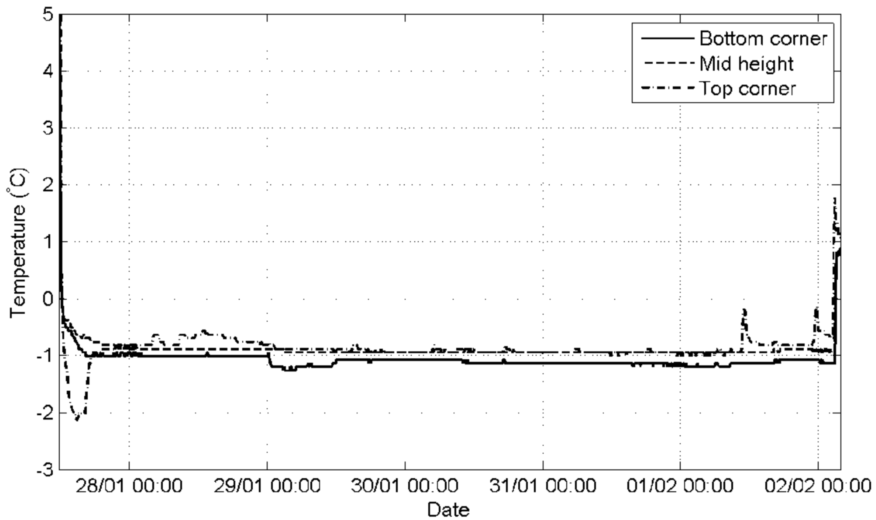


Air transport temperature profiles (Mai et al., 2011)





Ambient temperature at surfaces of one pallet in a sea transport chain from Iceland to France in September 2009.

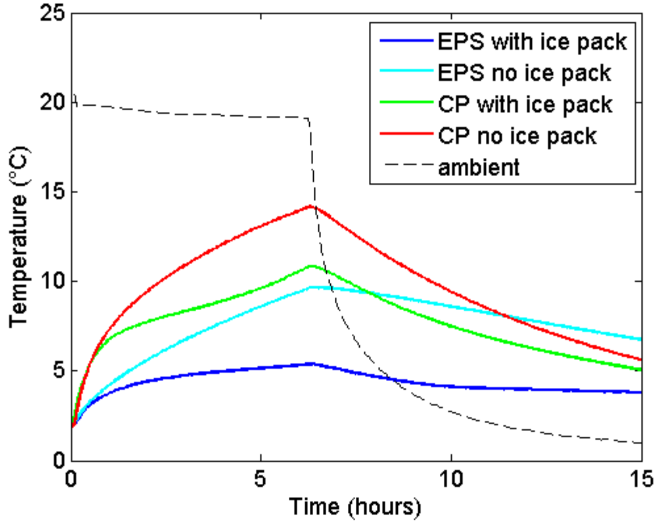


Amb. temp. during sea transp. from processor in Iceland to BS Mer, France.

Ref: Mai, N.T.T, Margeirsson, B., Margeirsson, S., Bogason, S., Sigurgísladottir, S., Arason, S. 2011.. Temperature Mapping of Fresh Fish Supply Chains – Air and Sea Transport. *Journal of Food Process Engineering*, doi: 10.1111/j.1745-4530.2010.00611.x.

Optimised insulated packaging - background

- **Research has shown that EPS protects fresh fish fillets better than CP packaging in case of dynamic storage/transport temperature**
- **Experimental and numerical simulation results showed that the EPS box could be improved with regard to maximum product temperature during thermal load. A new box was designed by Matís, Promens Tempra, University of Iceland and Wessex Institute of Technology**



Temperature evolution during temperature abuse trial with haddock fillets in free standing wholesale fish boxes

Ref: Margeirsson, B., Arason, S., Palsson, H. 2009. Matís report 01-09.

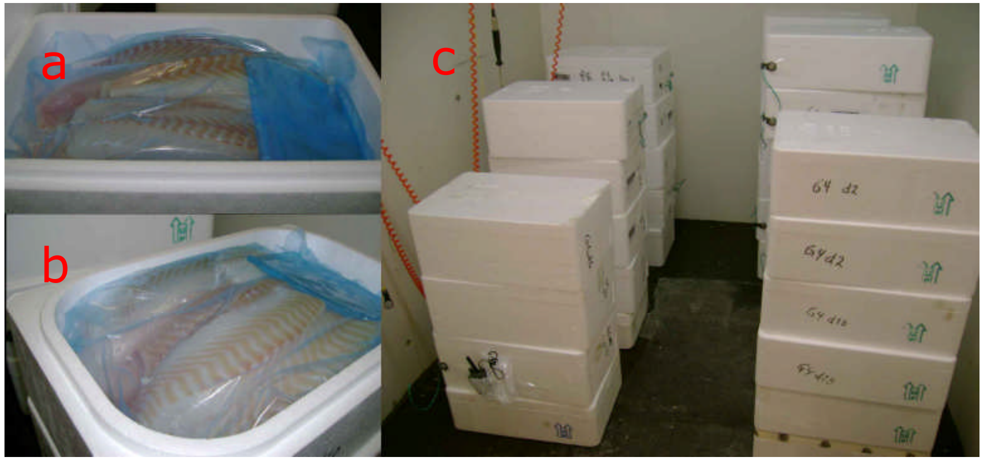
Aim

- The aim of the study was to experimentally and numerically compare the performance of two different types of EPS (expanded polystyrene) boxes in protecting precooled, fresh fish loins subjected to temperature fluctuations, simulating real conditions during air transport
  - effect of loin position inside the fish packages (corner vs. middle) was also investigated
- The performance was compared by
  - temperature monitoring
  - numerical heat transfer modelling
  - sensory evaluation
- One EPS box type was an improved version designed by utilising numerical heat transfer modelling (more rounded corners)

Ref: Margeirsson, B., Pálsson, H., Popov, V., Gospavic, R., Arason, S., Sveinsdóttir, K., Jónsson, M.Þ. 2011. Numerical Modelling of Temperature Fluctuations in Superchilled Fish Loins Packaged in Expanded Polystyrene and Stored at Dynamic Temperature Conditions. In: The 23rd IIR International Congress of Refrigeration, 21 – 26 August 2011. Prague, Czech Republic.

Experimental setup

- **Whole cod was caught, bled, gutted, washed and packed in ice in insulated tubs on board the trawler on 8 March 2010**
- **During processing the following day, the fillets were superchilled pre-packaging in a CBC (Combined Blast and Contact) cooler by Skaginn (Akranes, Iceland)**
- **Further treatment:**
  - **palletisation**
  - **chilled and frozen storage**
  - **transport in refrigerated trucks**
  - **dynamic temperature storage in air climate chambers (see figure)**



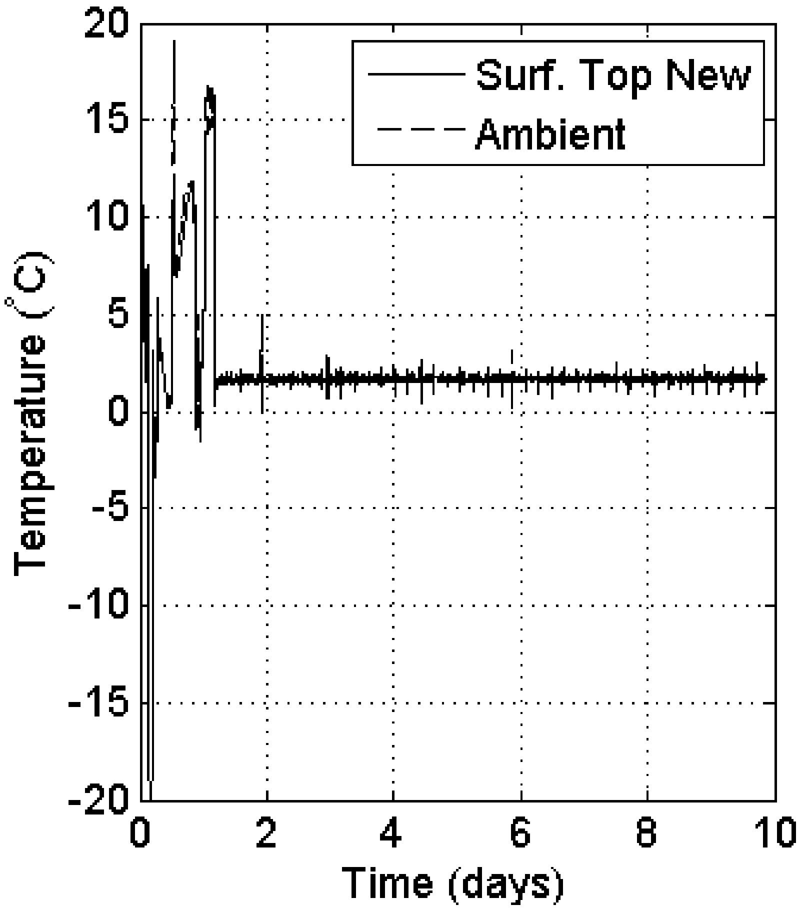
Superchilled cod loins in an old EPS box (a) and a new EPS box (b) with boxes piled up (c) during dynamic temperature storage.

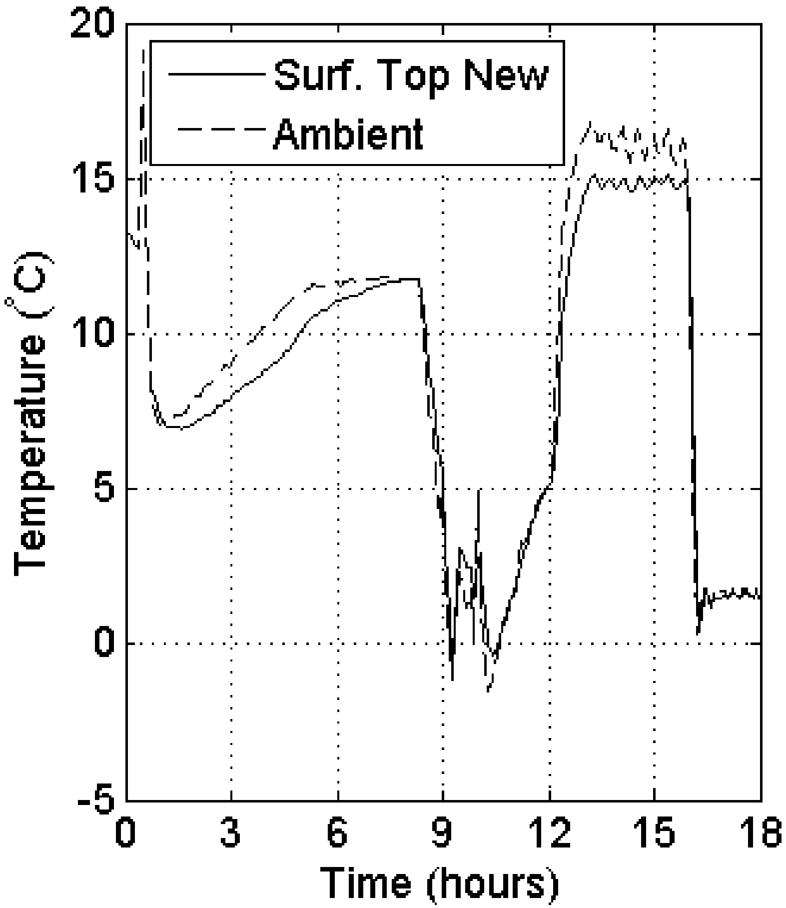
Properties of EPS boxes and gel pack

Box type	Inner dim. $L_i \times W_i \times H_i$ (mm)	Outer dim. $L_o \times W_o \times H_o$ (mm)	mass (g)
Old	355 x 220 x 110	400 x 265 x 159	205 ± 4
New	355.5 x 220 x 85 (rounded corners)	400 x 264.5 x 135	183 ± 1
Gel pack		160 x 125 x 6.3	125 ± 2

Box storage capacity: 5 kg

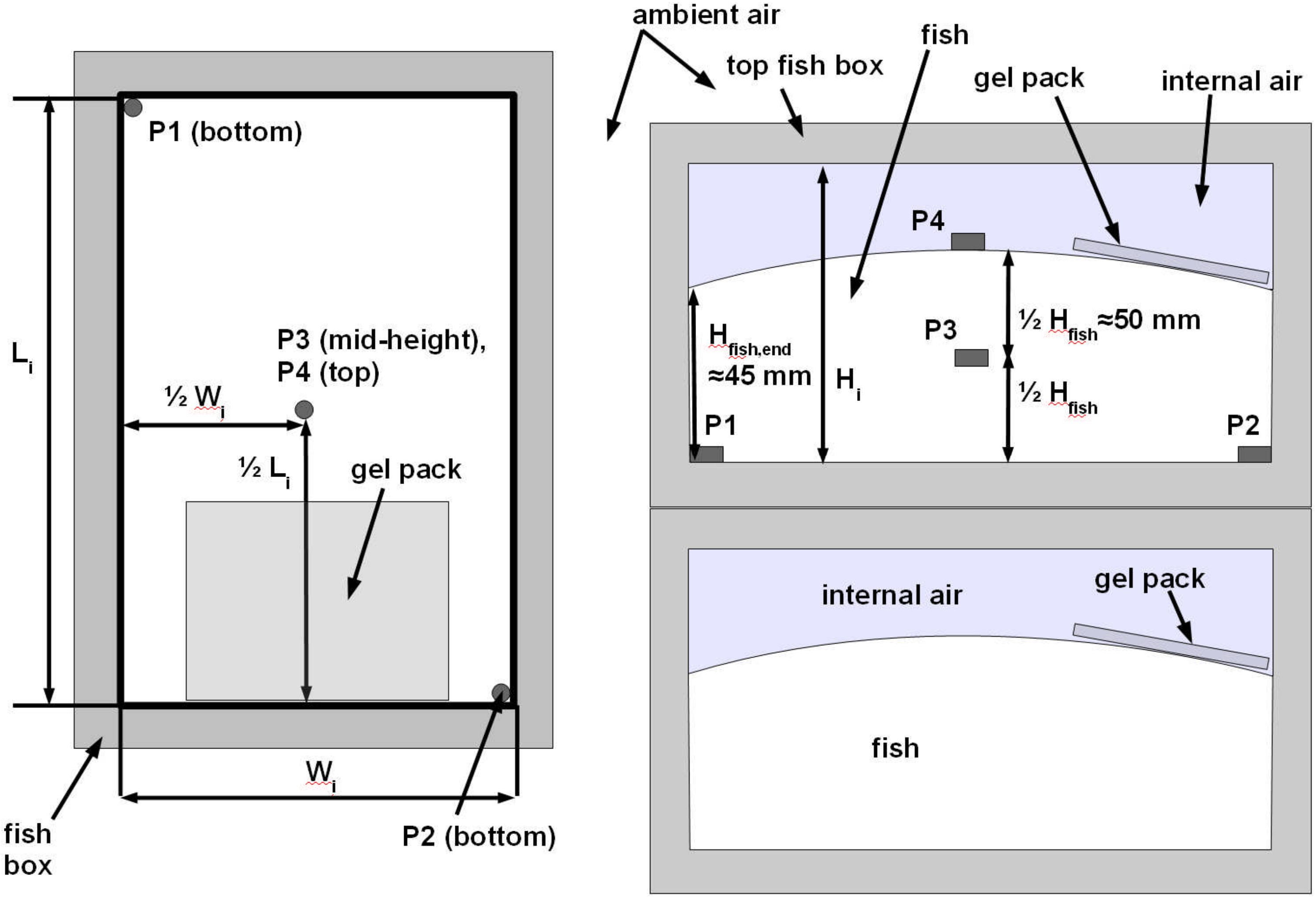
Environmental temperature post-packaging





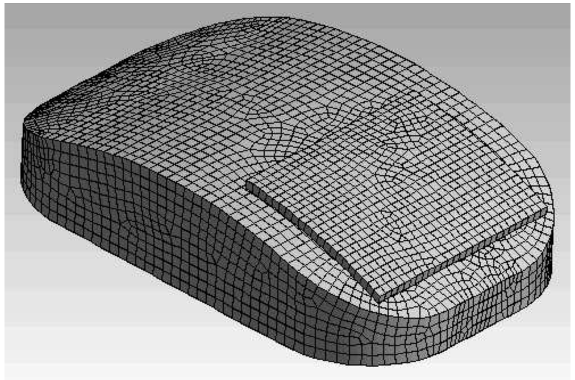
Environmental temperature. Left: during the first 10 days post-packaging, right: zoom-up of the dynamic temperature period in air climate chambers starting around 12 hours post-packaging.

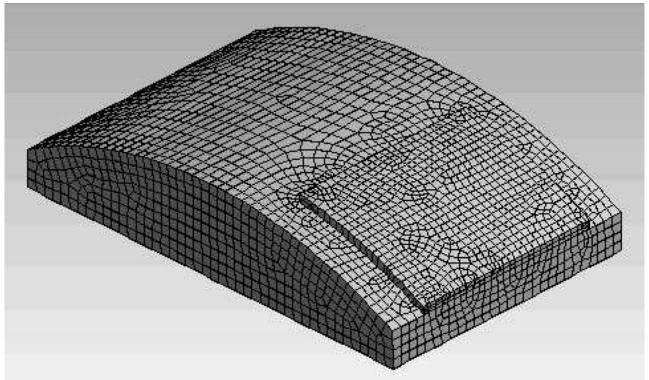
Product temperature mapping



Positions of temperature loggers inside fish boxes: in horizontal plane (d), in vertical plane (e)

Numerical modelling





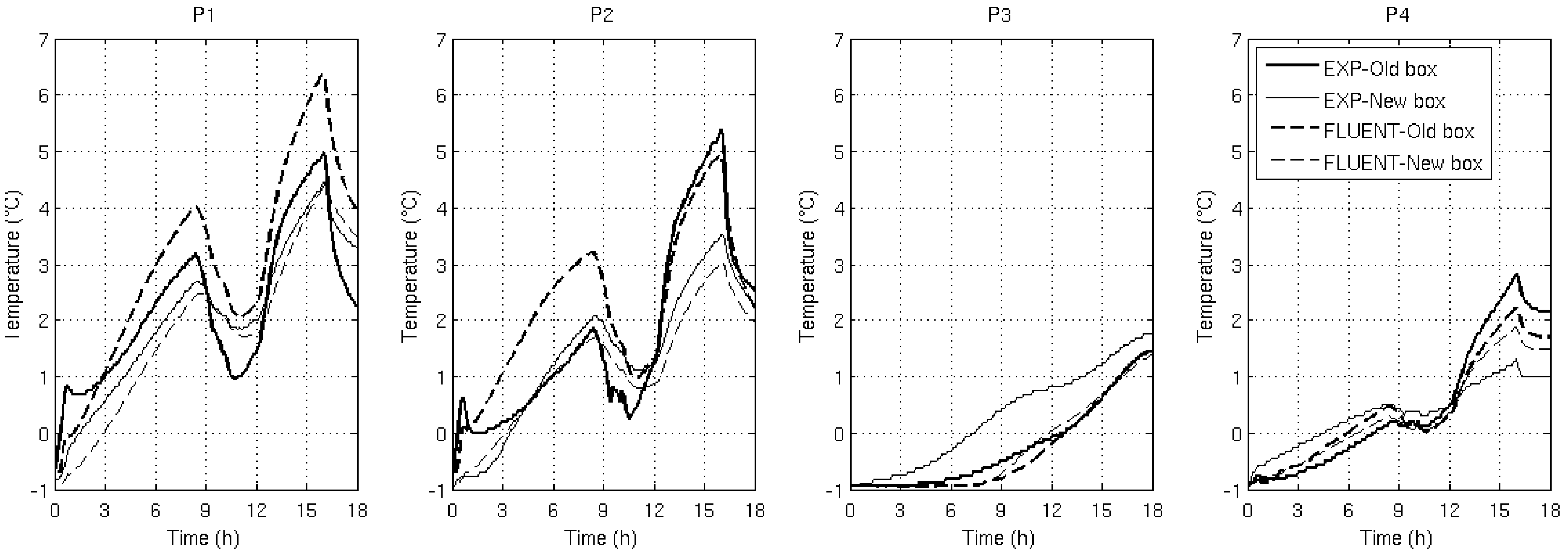
Computational mesh for the fish and gel pack inside the new box (top) and the old box (bottom)

- Software: ANSYS FLUENT
- Domain: top box of each pile including fish, air and gel pack
- Conduction and radiation inside box
- Outside radiation (S2S-radiation model)
- Phase change of the gel pack was considered by using the melting/solidification model in FLUENT
- Phase change of fish: $T_{f,i}$=-0.92 °C (-0.91 according to Rahman (2009))
- Initial conditions: $T_{New,init}$ = -0.93 °C,$T_{Old,init}$ = -0.94 °C
- Boundary conditions:
  - h_{side} = 3.0 $Wm^{-2}K^{-1}$
  - h_{top} = 2.1 $Wm^{-2}K^{-1}$
  - insulated box bottom
  - $\varepsilon_{amb} = \varepsilon_{box}$ = 0.9
  - non-ideal surface contact between adjoining surfaces

Rahman, MS. 2009, Prediction of Ice Content in Frozen Foods, *In*: Rahman, MS. *Food Properties Handbook*, 2nd ed. CRC Press, Boca Raton, FL: 193-206.

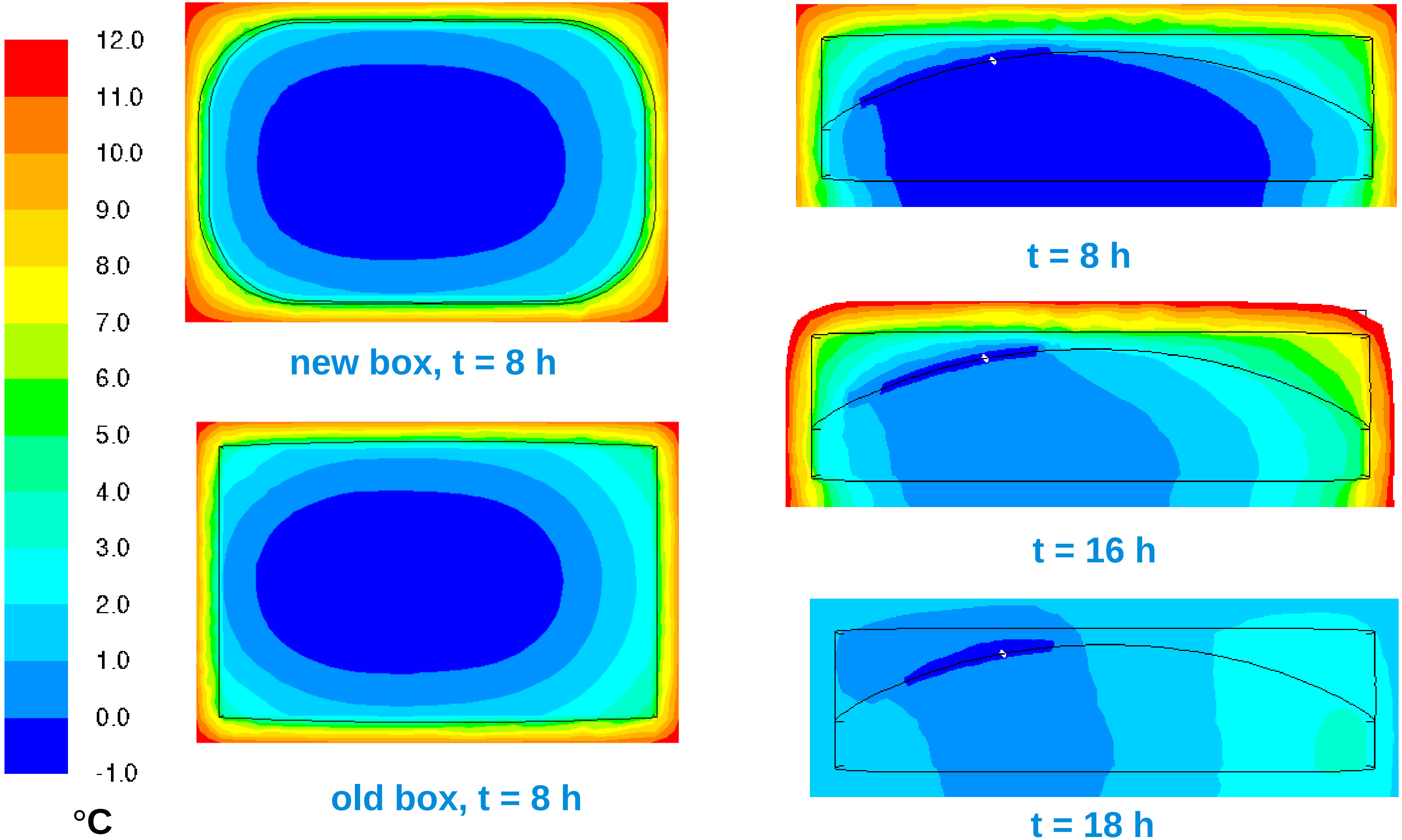
Results – product temperature

EXP: experimental results
FLUENT: simulation results



Comparison between numerical results obtained with FLUENT and experimental results (EXP) for four selected positions inside the old and new boxes during the dynamic temperature period

FLUENT results - temperature contour plots



new box, t = 8 h

old box, t = 8 h

t = 8 h

t = 16 h

t = 18 h

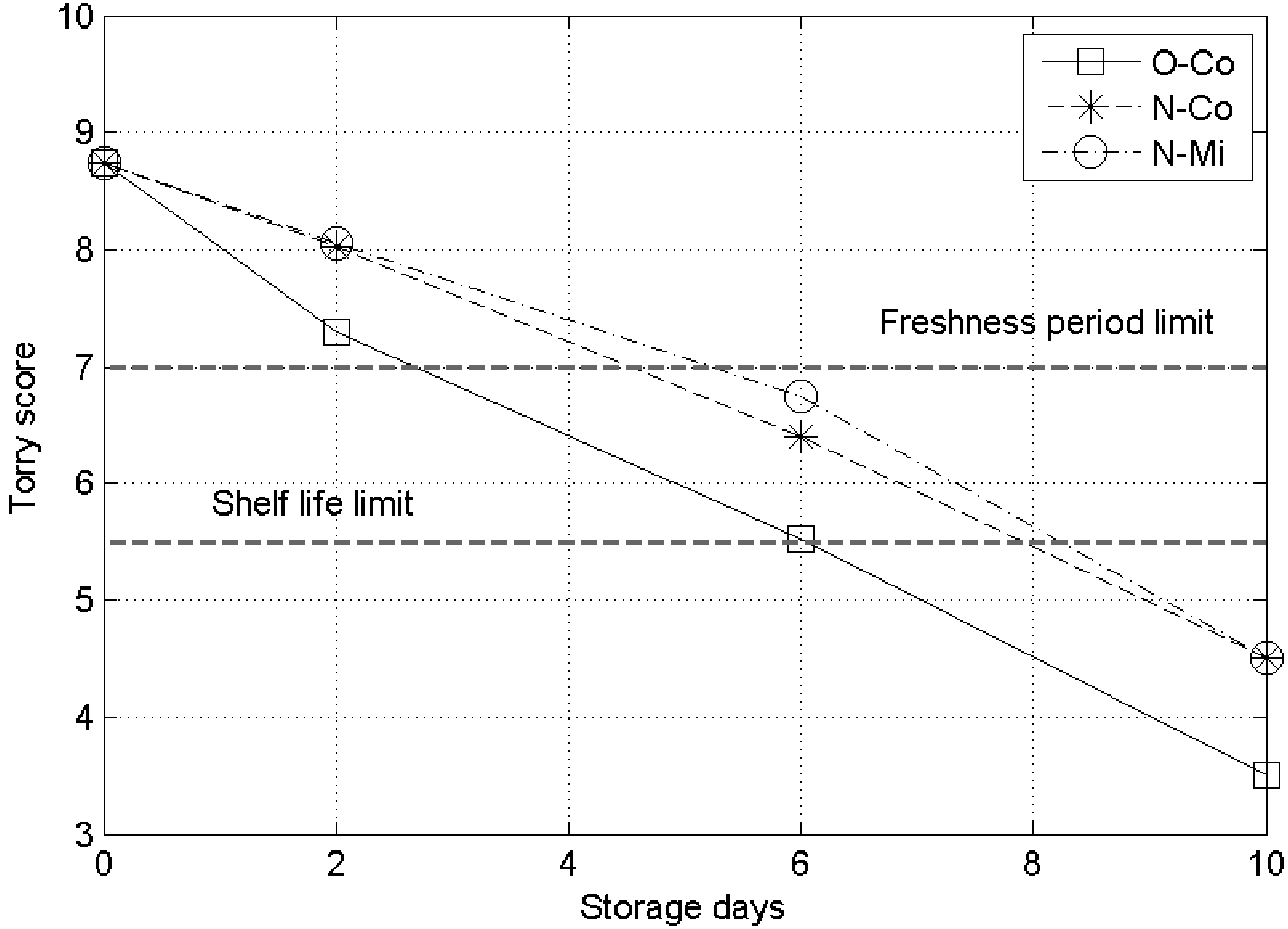
Results – FLUENT vs. experimental

Mean absolute error (°C) of simulation results for four positions

Position	Old box	New box
P1	0.9	0.3
P2	0.7	0.3
P3	0.1	0.6
P4	0.3	0.3
Overall	0.5	0.4

- **The model was very sensitive to the choice of $T_{f,i}$**
- **Peak in c_p around $T_{f,i}$**

Results – shelf life

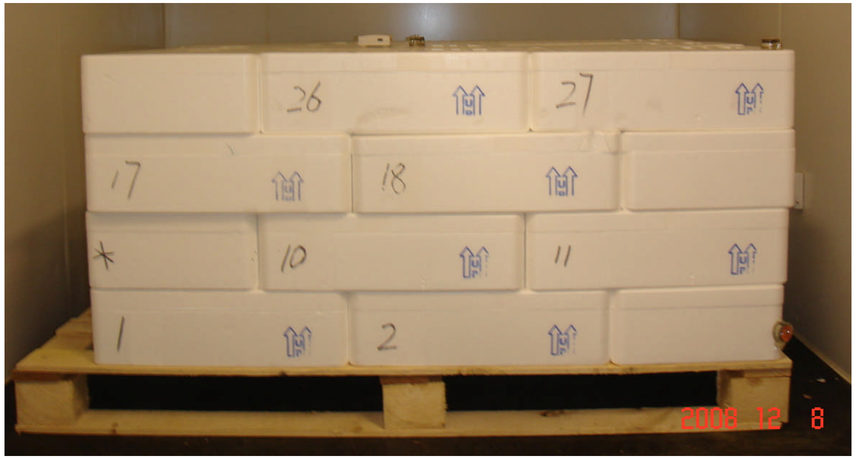


Mean Torry scores. O: Old box, N: New box, Co: Corner samples, Mi: Middle samples.

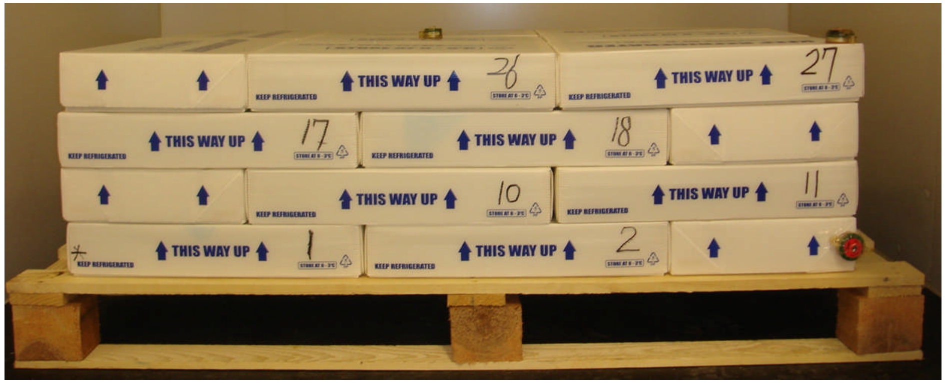
EPS packaging study - conclusions

- **The round corner box design proved better than sharp corner box design**
  - **lower maximum product temperature during thermal load**
  - **prolonged freshness period and storage life**
  - **more even product quality in each package**
- **Satisfactory agreement between modelling and experimental results**
  - **overall mean error 0.4 and 0.5 °C**
  - **sensitivity to initial freezing point of fish**
  - **the model can be used for cost effectively improve packaging design including gel pack**

EPS/CP packaging study, whole pallets - setup

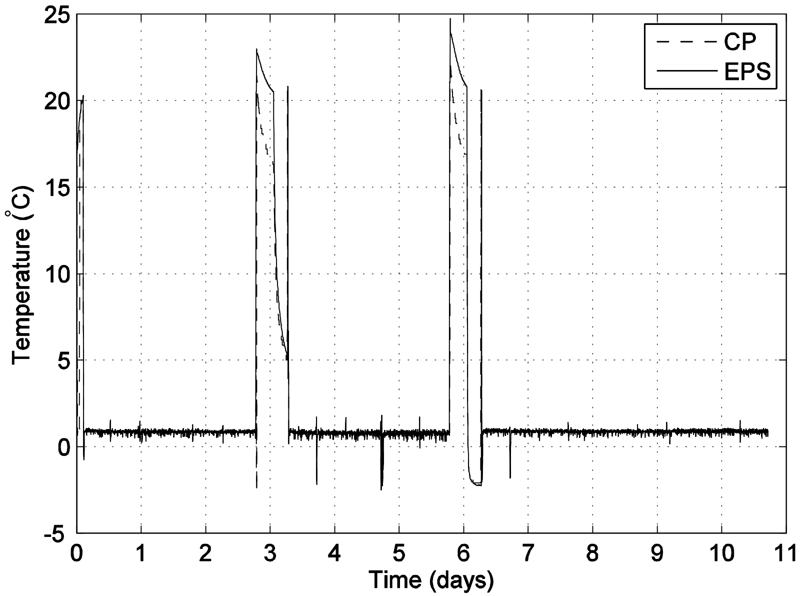


EPS pallet (old EPS box type)

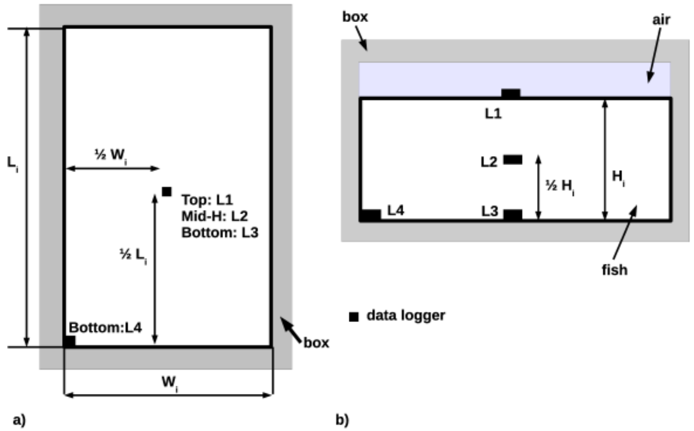


CP pallet

Ref: Margeirsson, B., Lauzon, H.L., Pálsson, H., Popov, V., Gospavic, R., Jónsson, M.Þ., Sigurgísladóttir, S., Arason, S.,. 2011. Temperature fluctuations and quality deterioration of chilled cod (*Gadus morhua*) fillets packaged in different boxes stored on pallets under dynamic temperature conditions. *International Journal of Refrigeration*. In press.

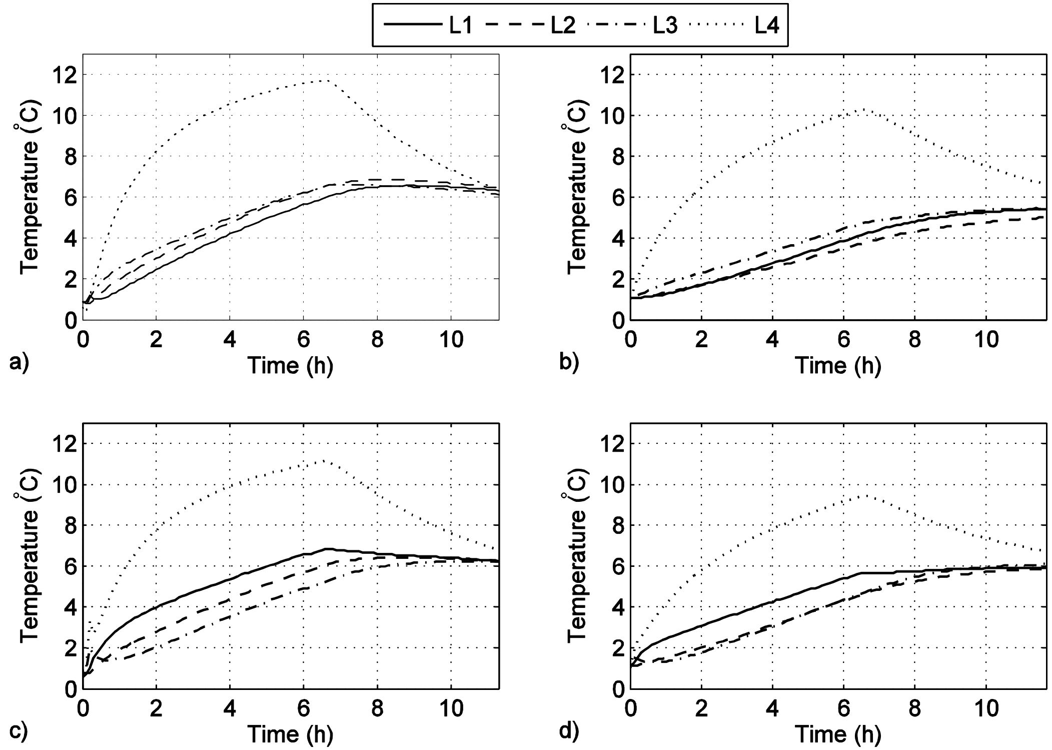


Ambient temperature profiles

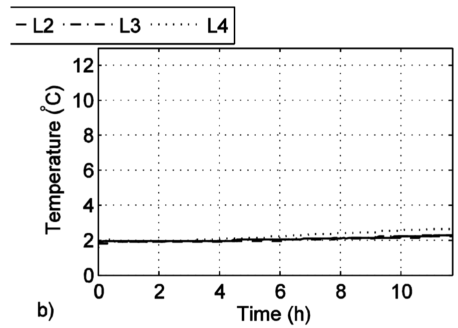


Positions of product temperature loggers

EPS/CP packaging study, whole pallets - Results



Product temperature evolution in two of the most temperature sensitive boxes on each pallet during the first dynamic period with no air blast chilling: a) Box CP-8 at bottom corner, b) Box EPS-8 at bottom corner, c) Box CP-32 at top corner, d) Box EPS-32 at top corner .



Prod. temp. in centre EPS box

Storage life of cod products determined by sensory or microbial analysis. ST: Steady storage temperature, DT: dynamic storage temperature, Mi/Co: samples taken from boxes at the middle/corners of the pallet stack.

Group	Storage life (days)
EPS-ST	11^a
EPS-DT-Mi	9^b
EPS-DT-Co	8^b
CP-ST	11^a
CP-DT-Mi	9.5^b
CP-DT-Co	8^b

- **1.5 – 3 days longer storage life for steady storage at -0.4 °C compared to dynamic temperature storage (two thermal load periods + steady storage at 1 °C)**
- **Up to 1.5 days difference between the storage life at the worst and best positions on the same pallet**
- **Higher maximum temps. for CP but similar storage life**

Overall conclusions

- Precooling can extend storage life by 1-4 days
- CBC cooling is safer, more efficient and stable than slurry ice / liquid cooling
- Ambient thermal load during air transport can shorten storage life by around 2-3 days compared to optimal sea transport conditions
- The design of EPS boxes manufactured by Promens Tempra has been improved by means of computational heat transfer modelling
  - extension of freshness period and storage life by 2 – 2.5 days for a simulated air transport chain
- Thermal protection of wholesale packaging is more important in case of single packages than in case of whole pallets
- Up to 1.5 days difference between the storage life of products within the same pallet for a simulated air transport chain

- **Further information: http://www.kaeligatt.is/**

Thank you for your attention!