DANISH
TECHNOLOGICAL
INSTITUTE

IMPULSE SALES COOLER

Final Report

Elforsk project No. 340-037

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This project was carried out in co-operation with Vestfrost A/S, Danish Technical University (IPU), COOP, PepsiCo and Danish Technological Institute.

Energy & Climate
Centre for Refrigeration and Heat Pump Technology

Summary

In the past years, the use of impulse coolers has increased considerably and it is estimated that at least 30.000 are installed in shops in Denmark. In addition, there are many small barrel-shaped can coolers. Most impulse coolers are open, which results in a large consumption of energy, and the refrigeration systems are often quite inefficient. A typical impulse cooler uses app. 5 - 8 kWh/day corresponding to a consumption of energy in the magnitude of 60 GWh/year.

For several years, the Danish company Vestfrost A/S has produced an impulse sales cooler in the high-efficiency end and the energy consumption of the cooler is measured to be 4.15 kWh/day. The POS72 cooler formed the baseline of this project.

This project started at the beginning of 2008, in co-operation with Vestfrost A/S, IPU (Institute for Product Development at the Danish Technical University), COOP (big Danish supermarket chain), PepsiCo (big supplier of soft drinks) and Danish Technological Institute (DTI) who chaired the project.

At the start-up meeting in 2008, several ideas were discussed with the objective to reduce energy consumption and to use natural refrigerants. Among the ideas were better air curtains, removable lids, better condensers, use of R600a refrigeration system and better insulation. Three generations of prototypes were built and tested in a climate chamber at Danish Technological Institute and the third generation showed very good performance: the energy consumption was measured to 2.215 kWh/day, which is a 47% reduction compared to the baseline.

That was achieved by:

- Improving the cold air cycling system including the air curtain.
- Using the natural refrigerant R600a (isobutane) and the Danfoss NLE9KTK compressor, which has better efficiency compared to the compressor in the baseline product.
- Using a box type condenser without fins (preventing dust build-up) and with a relatively high surface area.
- Improving the insulation value of the plastic cabinet by reducing turbulence in the air gap between the plastic walls and improving the insulation value of the EPS moulded insulation surrounding the refrigeration system at the bottom of the cooler.
- Preventing short-circuit of warm air around the condenser.
- The improvements are cost efficient and will not add much to the cost of the cooler.

The development project has resulted in a unique impulse sales cooler using natural refrigerant and a refrigeration system, which consumes about half the amount of energy compared to the previous Vestfrost impulse cooler and less than half of the energy compared to other types of impulse sales coolers.

Among other interesting results the following can be mentioned:

- The lid test on the third generation of prototypes only showed small improvements (app. 11 % decrease in energy consumption).
- Test with night power shut off (turned off 8 hours) showed a 34.5 % decrease in power consumption of the second open prototype.

Contents

1. Introduction

This project started at the beginning of 2008, in co-operation with Vestfrost A/S, IPU (Institute for Product Development at Danish Technical University), COOP (big Danish supermarket chain), PepsiCo (big supplier of soft drinks) and Danish Technological Institute, (DTI) who chaired the project.

The project has received funds from Elforsk after approval from the Danish Energy Agency. Small impulse sales coolers are normally open and they are often placed close to the cash register in supermarkets, at gas stations, in kiosks or other places. They contain cold drinks and apply to an impulsive purchase of cold drinks and that is how they have obtained their name.

In the past years, the use of impulse coolers has increased considerably and it is estimated that at least 30.000 are installed in shops in Denmark. In addition, many "can coolers" are small barrel-shaped coolers. Most impulse coolers are open, which results in an enormous energy consumption, and the refrigeration systems are often quite inefficient. A typical impulse cooler uses app. 5 - 8 kWh/day corresponding to a consumption of energy in the magnitude of 60 GWh/year. Appendix A presents a survey of impulse sales coolers that were on the Danish market in 2008 and confirms the typical energy consumption of the individual impulse sales coolers.

Figure 1: An impulse cooler made by Vestfrost A/S with logo from PepsiCo. The cooler POS72 forms the baseline of this project.

This project deals with the following initiatives that will make the coolers less energy consuming:

- Reduced air infiltration and heat transmission to the cooler – without the cooler losing its "impulse-purchase-appeal".
- Optimised energy efficiency of the cooler by designing an energy-efficient cooling system with natural refrigerants.

The implementation of these measures can lead to an energy savings potential of about 50% (corresponding to 30 GWh/year).

A large number of impulse coolers are produced in Denmark. The most important Danish manufacturer is Vestfrost A/S who produces app. 40.000 impulse coolers annually at the factory in Esbjerg (however, a large amount of them are "can coolers").

The objective of this project was to create technological development that ultimately would result in the production and marketing of an energy-efficient and environmentally friendly cooler that could fulfil the expectations and declared environmental policy of potential customers (i.a. distributors of soft drinks, chocolate and similar goods).

1.1. Background

The reason for this project was:

- Greater focus on the electricity consumption of coolers placed in supermarkets, gas stations and kiosks.
- Declared policy of several producers of soft drinks to stop purchasing equipment with HFC refrigerants and instead purchase energy-efficient equipment.
- There is an increasing market for small bottle coolers (impulse coolers) as well as a potential for improved energy efficiency. The coolers are very energy consuming due to inefficient refrigeration systems and open cabinets. The project will also help bring energy consumption into focus.
- Restrictions and bans on HFC refrigerants due to their contribution to global warming.
- Vestfrost A/S wants to emphasise this business segment as they believe it will become a future strategic business area.
- Together with Danish Technological Institute, Vestfrost A/S has already developed and tested large bottle coolers (400 litres with glass doors) with R600a (isobutane) and CO_2 as refrigerant and has good experience with both types of refrigerant. A field-test of 18 bottle coolers with R134a, R600a and CO_2 as refrigerant has just been finalised (in co-operation with Carlsberg). The result shows that hydrocarbon bottle coolers are app. 28% more energy-efficient compared to R134a. It also shows that CO_2 bottle coolers are app. 12% more energy-efficient compared to R134a.
- In the light of the above-mentioned test, Carlsberg has decided to purchase bottle coolers based on hydrocarbons for several markets including Scandinavian countries.

For many years, Vestfrost A/S has been Denmark's largest manufacturer of refrigerators and freezers. Vestfrost A/S has implemented a strategy for moving the production of certain appliances to countries with inexpensive manpower. The production of some coolers (with small production figures) is currently being moved to a factory in Hungary while the mass produced units will continue to be produced at the factory in Esbjerg. The production in Esbjerg will mainly concentrate on commercial products such as wine coolers, bottle coolers, vaccine coolers and merchandising impulse coolers produced in great numbers. Vestfrost A/S has had great success with several of these product categories especially bottle coolers, wine coolers and vaccine coolers including the SolarChill vaccine cooler. App. 300 persons are employed at Vestfrost A/S in Esbjerg and 80 persons are employed at the factory in Hungary.

1.2. Objective

The objective of the project is to create technological developments that will result in more energy-efficient impulse coolers compared to existing products.

1.3. Definition

This project focuses on the actual impulse coolers that most frequently are open coolers with great exposure of goods. In appendix A there is a list of data and photos of a wide range of the coolers from different producers.

The project does not comprise "can coolers", which are small barrel-shaped coolers that often are covered with a plastic lid. Vestfrost A/S also has a large production of these coolers and has carried out a lot of work to reduce the electricity consumption.

1.4. Covers

There is a growing trend towards more impulse coolers in shops and usually they are open. Although night covers often are delivered with the coolers, they are rarely used. In the past years, many merchandising impulse coolers have been placed close to cash registers e.g. in supermarkets, kiosks and gas stations.

1.5. Environmental impact

Appendix A comprises data and photos of 12 different impulse coolers of different sizes and design. The energy consumption varies from between 5.2 kWh/day to 26.6 kWh/day. Most often the consumption is 7 – 8 kWh/day. That is quite a lot and it should be possible to reduce the consumption considerably without compromising the sales result.

It should also be possible to achieve a reduced consumption of energy in the area of 50% corresponding to savings in Denmark in the order of 30 GWh/year.

In addition, the use of natural refrigerants is preferred, which also would contribute to reducing the environmental impact.

1.6. Project content

1. Collection of experience: Collection of data for different types of impulse coolers and measurement of energy consumption on a number of appliances. Interview with purchasers and users of impulse coolers.
2. Set-up of mathematical model and energy balances for impulse coolers. Identification of the most important reasons for the energy consumption and issues that make impulse coolers energy-efficient. In the light of the measurements and the model, a benchmark was set up for a given impulse cooler and a corresponding benchmark was determined for the same impulse cooler with a glass lid, where there is absolutely no infiltration of air or humidity.
3. Possible solutions for reducing and eliminating air infiltration without hampering the "impulse effect". Possible areas.

4. Possible solutions for creating a "state-of-the-art" refrigeration system based on natural refrigerants. Possible areas.
5. Production of prototypes.
6. Test of prototypes in climate chamber (testing according to EN-441/ISO-23953). The result will be compared with the test result of a traditional HFC impulse cooler from Vestfrost.
7. Evaluation of environmental impact, sales impact and financial analysis of the manufactured prototypes.
8. Reporting and presentation of results to potential purchasers and users and at refrigeration technological conferences.

At a later point, the objective will be to ripen the product, market the product and finally put it into production.

1.7. Project performers

The project has been carried out by Vestfrost A/S, Danish Technical University, IPU, COOP, PepsiCo and Danish Technological Institute. Danish Technological Institute and IPU have contributed with theoretical input. Vestfrost A/S has procured the relevant components and constructed the prototypes. Danish Technological Institute has participated in the dimensioning groundwork to carry out tests on the refrigeration system and the finished coolers and prepared project reports. COOP and PepsiCo participated in the start-up meeting and gave their input to the project.

The following persons participated in the technical development work and the tests:

Finn Tolle, Vestfrost A/S
Bent Christensen Vestfrost A/S
Kenneth Tonder, Vestfrost A/S
Morten Skovrup, IPU DTU
Per Henrik Pedersen, DTI (project manager)
Marcin Blazniak Andreasen, DTI
Hans Walloe, DTI

In addition, the following persons participated in the project steering group:

Torben Lauridsen, Vestfrost A/S
Hans Christian Larsen, COOP
Emad Jafa, PepsiCo
Soycan Dirik, PepsiCo

Mr. Jorgen Borup facilitated the funding from Elforsk/the Danish Energy Association (Dansk Energi).

1.8. Budget

The expenses of Danish Technological Institute and IPU were covered (almost) 100% by subsidies from Elforsk. Vestfrost A/S covered a large part of its own expenses in the project.

Hours	DTI	IPU	Vestfrost	Pepsi	COOP	Total
1. Collection of experience	100	10	200	50	50	410
2. Model and energy balances	170	40	200			410
3. Possible solutions concerning air infiltration	140	20	250	50	50	510
4. Possible solutions concerning refrigeration system	140	20	250			410
5. Production of prototypes			350 + expenses: DKK 100.000			350 + expenses
6. Test of prototypes	175		200			375
7. Evaluations	75	10	100	50	50	285
8. Dissemination	50		50			100
Total	850	100	1600	150	150	2850

1.9. Distribution of project results

The project results will be reported to Elforsk. In addition, the developed coolers will be shown to the public and to potential customers. The result will also be shown at refrigeration technological conferences. Vestfrost A/S will then prepare the sales material and market the coolers (this activity is beyond the budget).

1.10. Steering committee

A steering committee was set up with representatives from Elforsk, IPU, Vestfrost A/S, PepsiCo, COOP and Danish Technological Institute.

2. Baseline: Existing POS72 cooler

The refrigeration system of the Vestfrost POS 072R cooler is located at the bottom of the appliance. The refrigeration system generates cold air that is supplied to the cold compartment by fans to keep the drinks cold. The air is returned through the space between the inner and outer plastic cabinet and to the evaporator, where it is cooled once again.

The cooler is equipped with a lid, which can be placed in a narrow slit at the rear of the cooler and when the store closes the lid can be placed on top of the cooler. However, it has been mentioned that lids are rarely placed on the coolers after business closing hours.

Figure 2: Vestfrost POS 072R cooler with Pepsi logo. The lid is placed in a narrow slit at the rear end. Only the end of the lid can be seen on this photo.

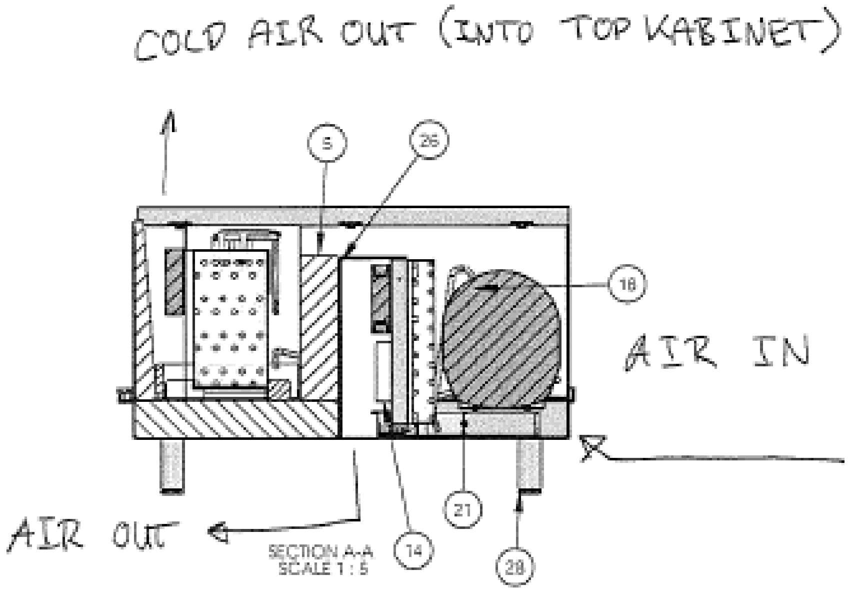


Figure 3: The refrigeration system is placed at the bottom of the cooler. In this figure, the compressor is placed on the right-hand side beside the condenser, which is air cooled by two DC fans. The evaporator is placed on the left-hand side and two DC fans distribute the cold air inside the drink compartment.

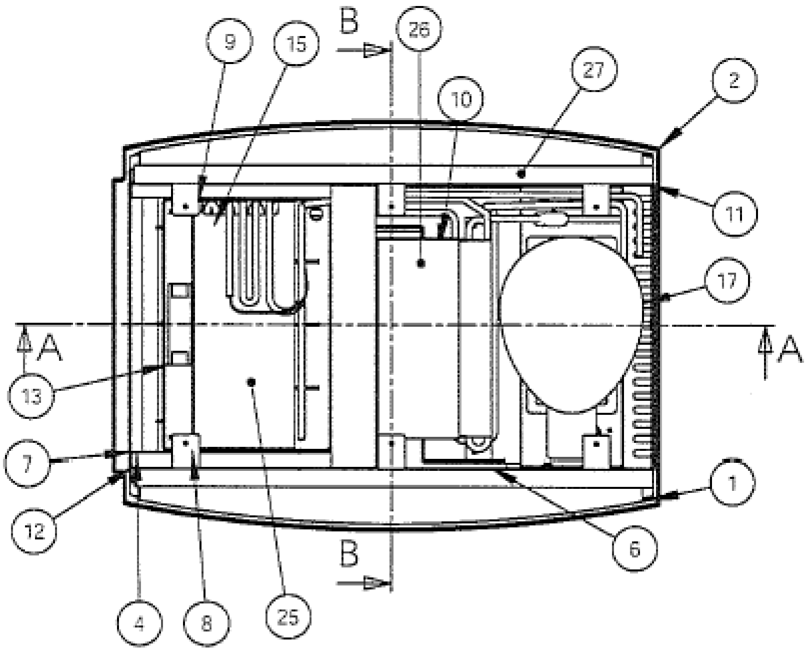


Figure 4: The refrigeration system seen from above.

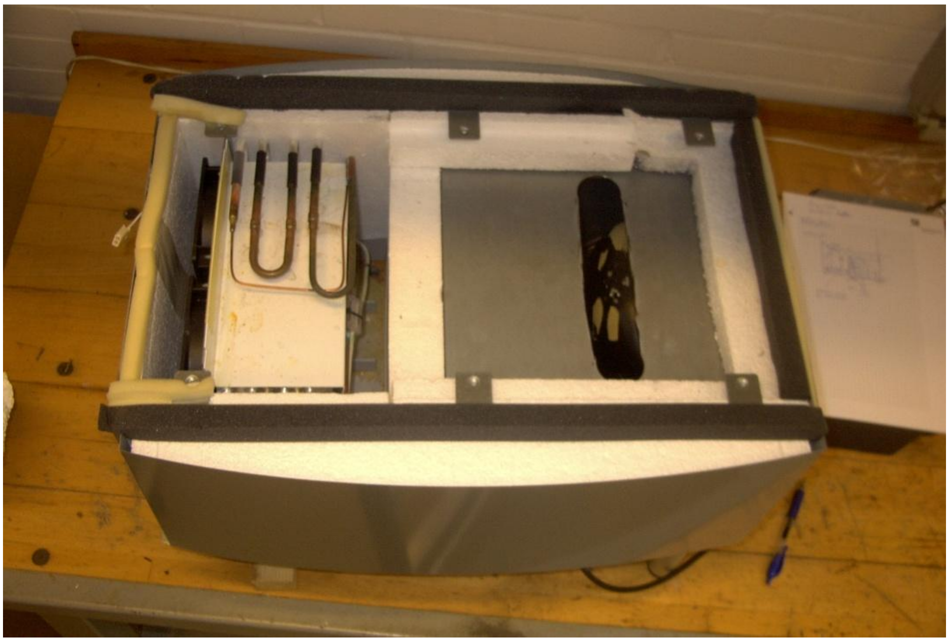


Figure 5: The refrigeration system is compact and part of it is insulated with EPS foam.

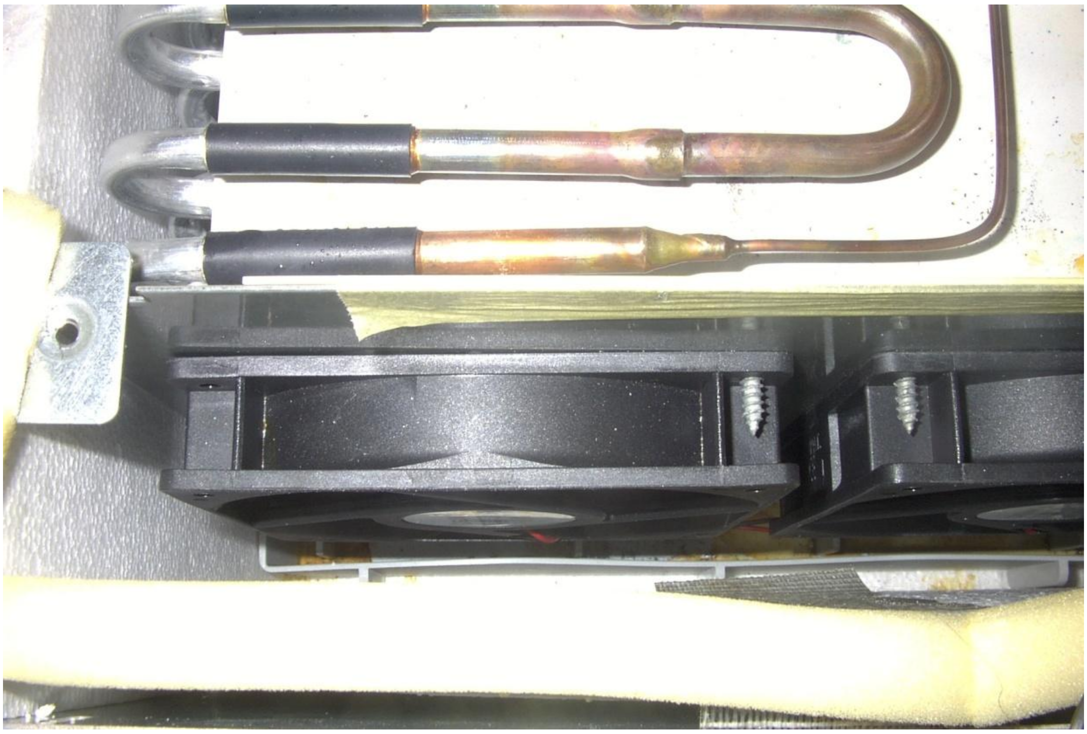


Figure 6: Top of evaporator. The refrigerant injection is placed in the middle of the photo. The two DC fans can also be seen.

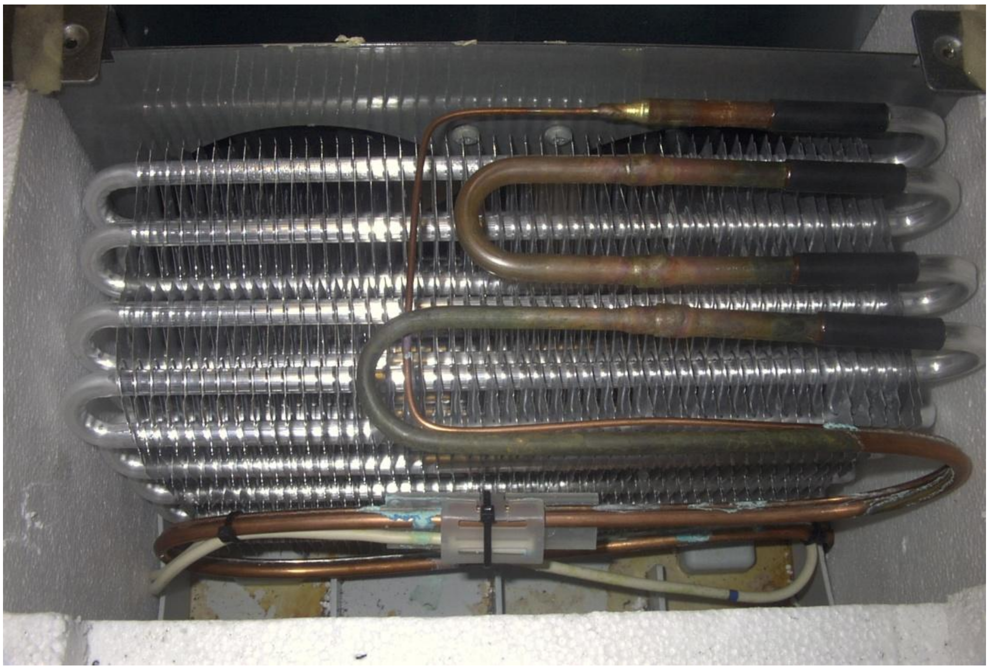


Figure 7: Evaporator after the top plate has been removed.

Figure 8: Evaporator.

Figure 9: The refrigeration system after dismantling of insulation and steel enclosure.

Figure 10: The compressor: NL10MF from Danfoss. R134a.

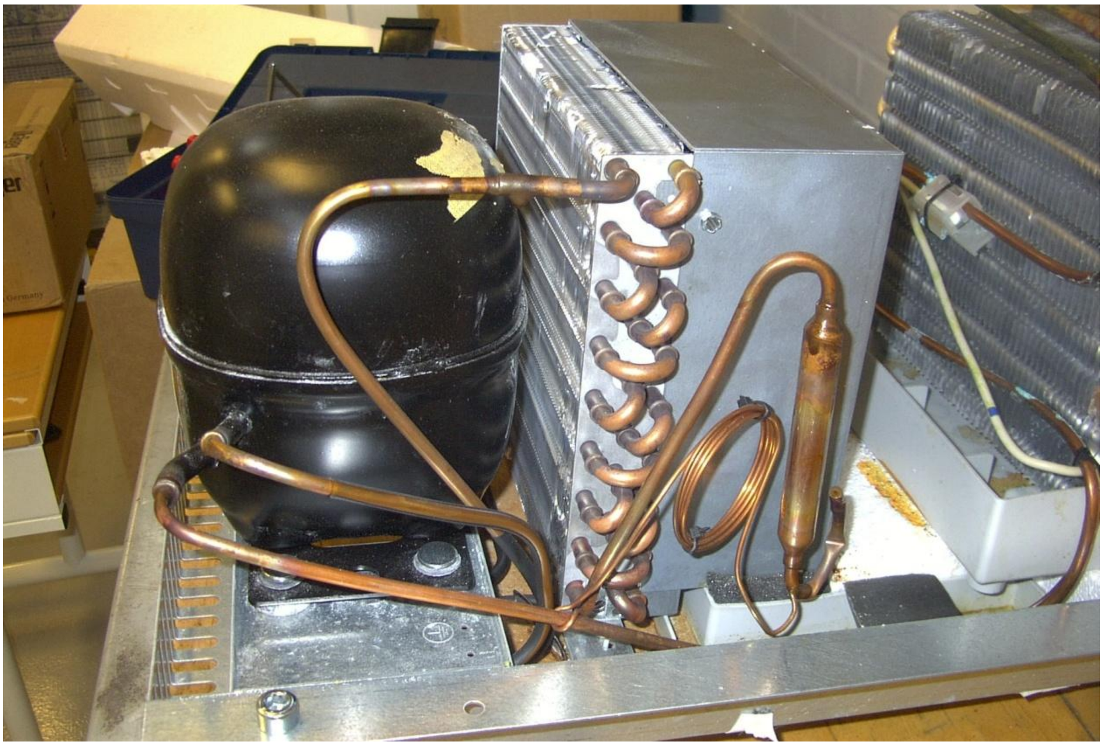


Figure 11: Condenser, filter and capillary tube.

Figure 12: The two DC fans on the evaporator.

Temperature control: The electronic thermostat measures the temperature of the air coming from the drink compartment (just before the evaporator). A sensor is located in that place.

Defrosting: The electronic thermostat defrosts the evaporator every 6 hours. The refrigeration system is stopped and the evaporator fans circulate the air until the ice has melted. One sensor at the bottom of the evaporator informs the thermostat when the temperature has reached a certain level. The water drips to a container under the condenser/compressor, where the water evaporates using energy from the warm side of the refrigeration system.

Evaporator fan: 2 * Sunon KD2412PTS3-6A DC24V, 3.1 W
Condenser fan: Two identical fans: SUNON KDE2409PTB1_6.
Compressor: Danfoss NL10 MF. Refrigerant: R134a.
Light: 4 * LED-light at the top of the drink compartment
A transformer is placed beside the condenser fans.

2.1. Test in climate chamber

The first impulse cooler was delivered to DTI by Vestfrost A/S. The cooler was placed in the climate chamber at DTI in Taastrup and the test was carried out at 25°C ambient temperature. The objective was to get a first impression of the energy consumption and to compare the situation with and without a lid.

The cooler was filled with 96 * 330 ml soft drink cans according to a loading plan from Vestfrost A/S. We must admit that the cans were in disorder as the bottom of the cooler was a little soft (please see photo).

Figure 13: The impulse cooler with soft drink cans. The cans were in disorder as the cooler floor was soft.

The test was conducted by the initial thermostat setting from the factory (in accordance with the instruction manual).

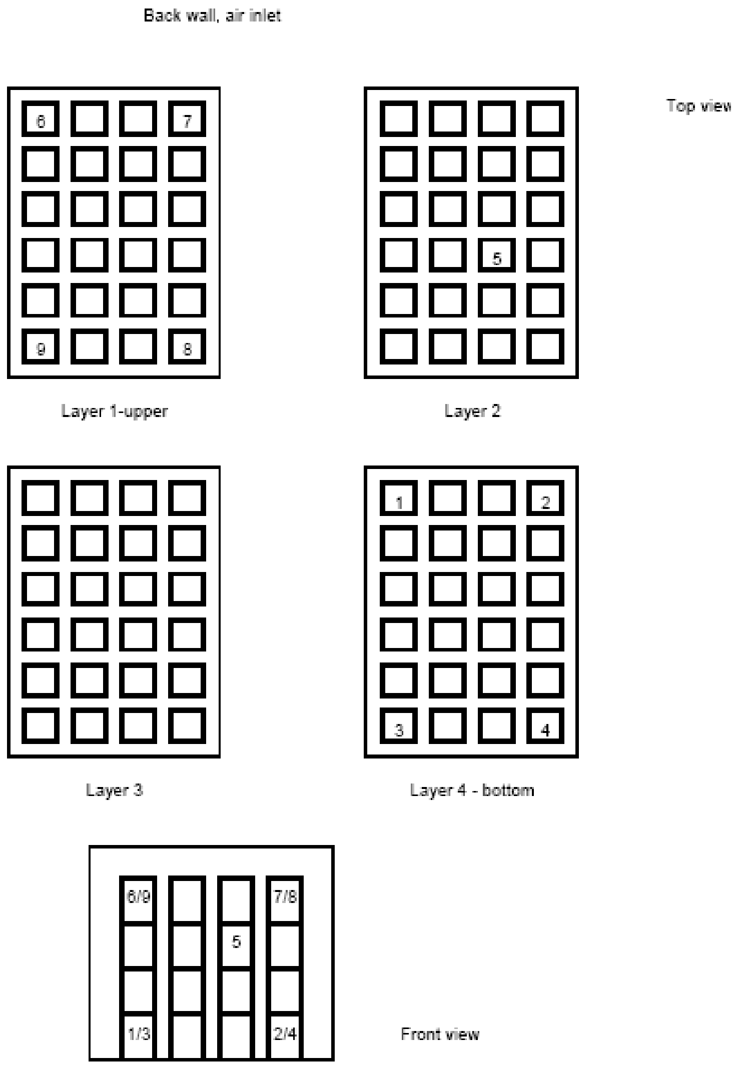
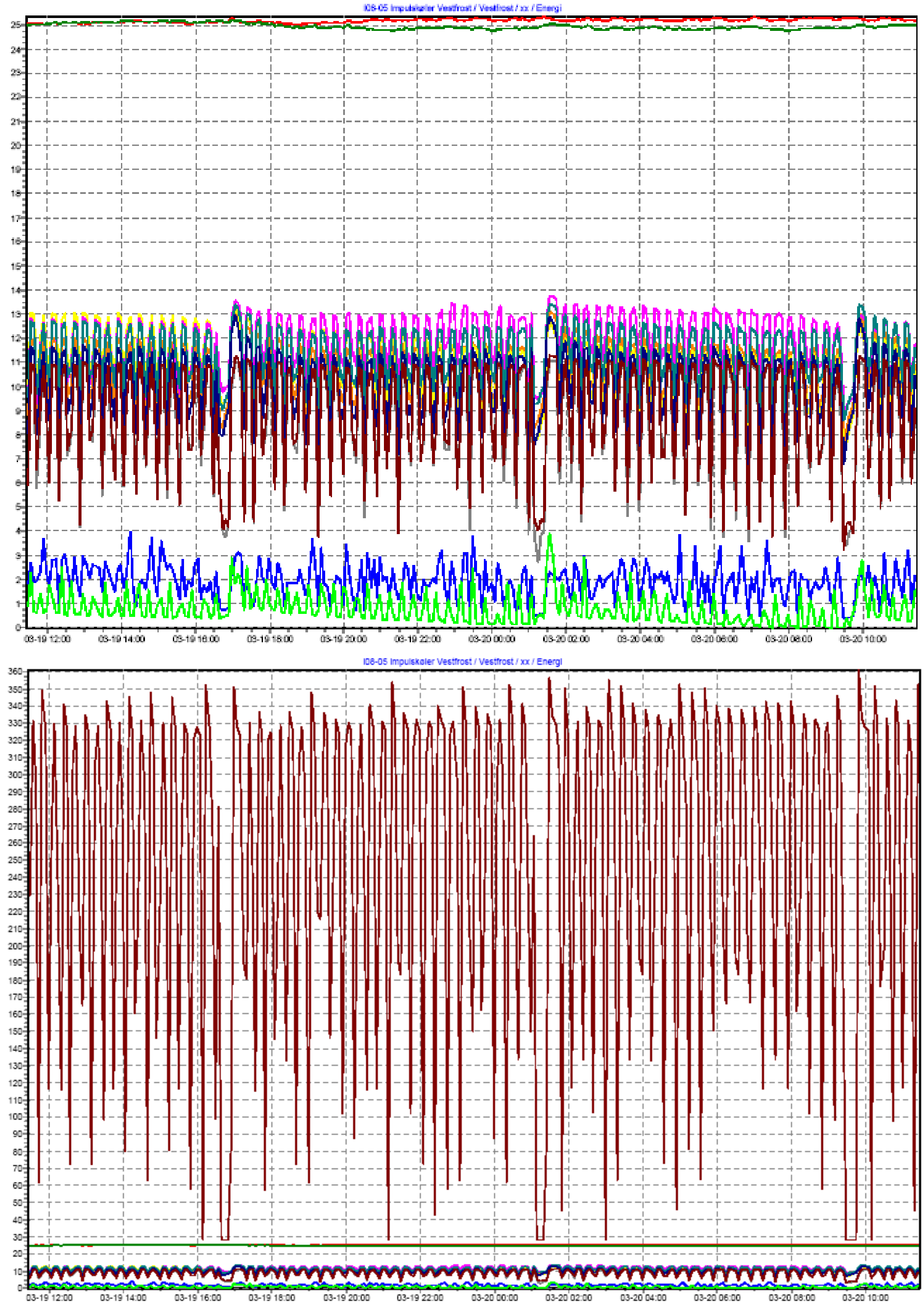


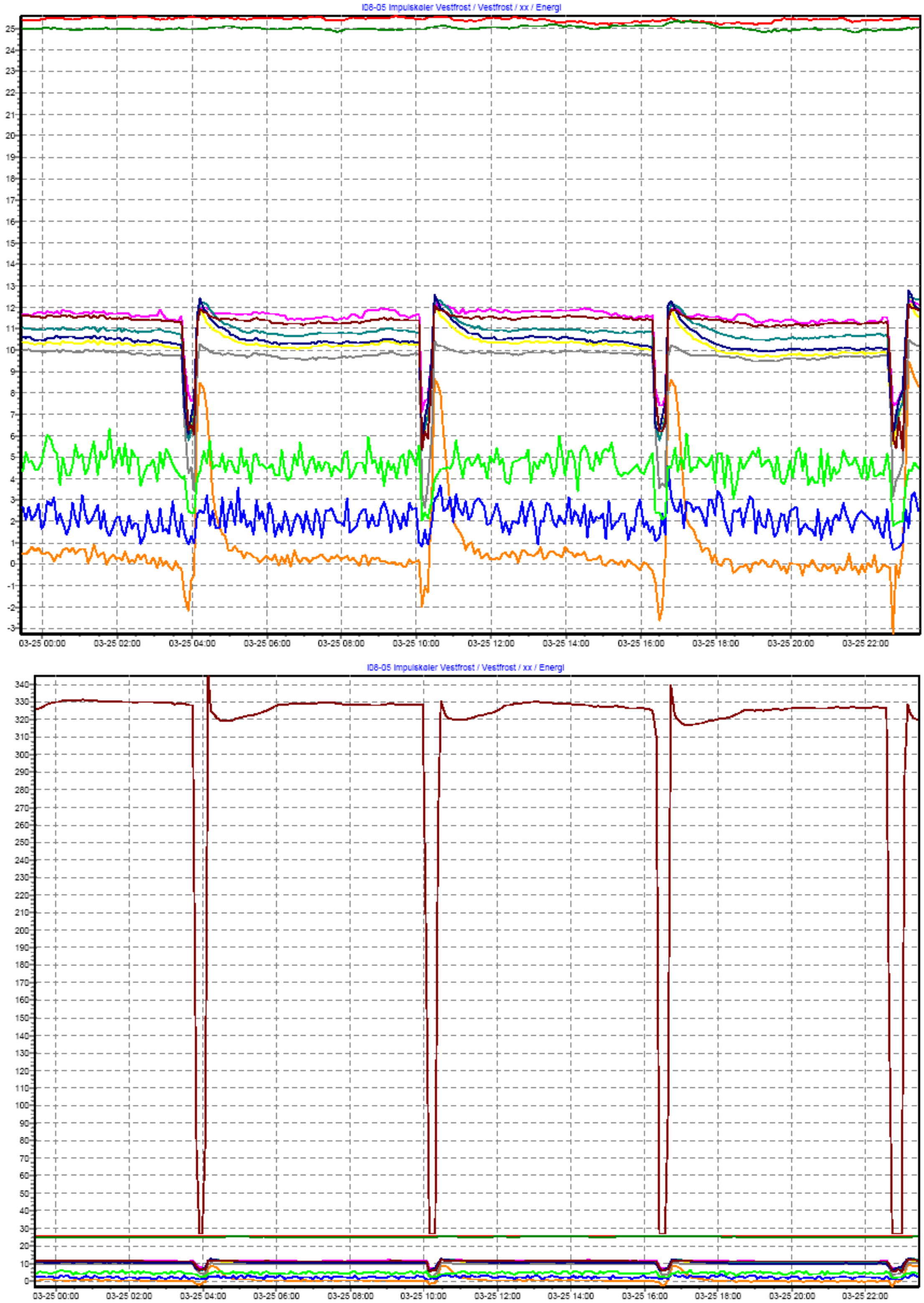
Figure 14: Loading plan including the temperature measurement points.

2.2. Test with lid



Graph 1: The upper curve shows the temperatures in the measuring points (cans) during the test. The lower curve shows the effect (and the temperatures). Test with lid on. Note that the cooling system was turned on and off by the thermostat about 27 times between two defrosting periods (6 hour).

2.3. Test without lid



Graph 2: Test without lid. Note that the refrigeration system constantly was in operation between the defrosting periods. The upper curves are the temperatures inside the cooler and the lower curve is the effect (and temperatures).

Measuring points	Data sources		
Start		17-03-2008 17:24	24-03-2008 14:28
Stop		18-03-2008 17:29	25-03-2008 14:33
Duration		24:04 [HH.MM]	24:04 [HH.MM]
Ambient temperature			
Average temperature		25,1	25,3
Left	Z:\KFS\ANVILLE\09\01	25,2	25,5
Right	Z:\KFS\ANVILLE\09\02	24,9	25
Appliance			
Average temperature		8,7	7,9
Can 1	Z:\KFS\ANVILLE\15\01	11,1	0,9
Can 2	Z:\KFS\ANVILLE\15\02	10,3	10,2
Can 3	Z:\KFS\ANVILLE\15\03	2	2,1
Can 4	Z:\KFS\ANVILLE\15\04	8,6	9,6
Can 5	Z:\KFS\ANVILLE\15\05	10,4	11,5
Can 6	Z:\KFS\ANVILLE\15\06	11,6	10,8
Can 7	Z:\KFS\ANVILLE\15\07	10,1	10,4
Can 8	Z:\KFS\ANVILLE\15\08	8,7	11,2
Can 9	Z:\KFS\ANVILLE\15\09	5,4	4,6
Compressor			
Voltage	Z:\KFS\PM100\12\VRMS	229,1	228,4
Power	Z:\KFS\PM100\12\WATT	235,6	312,6
Running time	Z:\KFS\PM100\12\WATT	100	100
Energy	Z:\KFS\PM100\12\WH	5664,1	7505,7
Energy consumption/24h	Z:\KFS\PM100\12\WH	5644,8	7480,2
		Lid assembled	No lid

Table 1: Summary of measurements.

2.4. Summary of measurements

The energy consumption of the impulse cooler with lid on at 25^{0}C was measured to 5.65 kWh/24h.

The energy consumption of the cooler without lid on was measured to 7.48 kWh/24h. The same level appeared in a test on another impulse cooler, which DTI carried out for a brewery in 2006. The energy saving obtained by using a lid is in the magnitude of 25%.

The temperatures of the drinks during testing were a little high. However, it would be possible to set the thermostat to a colder position, which would result in colder drinks when the lid is on. The temperatures of the cans were from 0 – 12^{0}C. The temperatures were similar to the temperatures of the cans during testing with and without lids - except for measurement point 1, which during the test with lid was 11^{0}C and during the test without lid was 1^{0}C. The reason for the big span in temperature might be due to the disorder of the cans during testing. The results were discussed at a project meeting held in March 2008 at DTI and it was decided to ship two new coolers to DTI for the test. It was also decided to use test cans taped as “six packs” to ensure better organisation during testing. The bottle cooler was shipped back to Vestfrost A/S.

The 2 new coolers were filled with taped “six packs” and the tests were performed in June 2008.

Figure 15: In test 2 and 3 the baseline coolers were tested with cans taped in “six packs” to prevent disorder of the cooling load.

Measuring points	Datakilder	
Start		15-06-2008 08:14
Stop		16-06-2008 08:14
Duration		24:00 [HH.MM]
Ambient temperature		
Average temperature		25,3
Left	Z:\KFS\ANVILLE\15\01	24,9
Right	Z:\KFS\ANVILLE\15\02	25,6
Appliance		
Average temperature		5,3
Can 1	Z:\KFS\ANVILLE\15\03	3,7
Can 2	Z:\KFS\ANVILLE\15\04	5,6
Can 3	Z:\KFS\ANVILLE\15\05	4,1
Can 4	Z:\KFS\ANVILLE\15\06	5,6
Can 5	Z:\KFS\ANVILLE\15\07	4,6
Can 6	Z:\KFS\ANVILLE\15\08	5,2
Can 7	Z:\KFS\ANVILLE\15\09	6,2
Can 8	Z:\KFS\ANVILLE\15\10	5,7
Can 9	Z:\KFS\ANVILLE\15\11	6,6
Compressor		
Voltage	Z:\KFS\PM100\12\VRMS	230,9
Power	Z:\KFS\PM100\12\WATT	165,8
Running time	Z:\KFS\PM100\12\WATT	100
Energy	Z:\KFS\PM100\12\WH	3987,1
Energy consumption/24h	Z:\KFS\PM100\12\WH	3986,6

Table 2: Results from test 2.

Measuring points	Data sources	
Start		20-06-2008 23:39
Stop		21-06-2008 23:39
Duration		24:00 [HH.MM]
Ambient temperature		
Average temperature		25,2
Left	Z:\KFS\ANVILLE\15\01	24,7
Right	Z:\KFS\ANVILLE\15\02	25,6
Appliance		
Average temperature		4,6
Can 1	Z:\KFS\ANVILLE\15\03	3,1 / min. 2,25
Can 2	Z:\KFS\ANVILLE\15\04	4,4
Can 3	Z:\KFS\ANVILLE\15\05	3,3
Can 4	Z:\KFS\ANVILLE\15\06	5
Can 5	Z:\KFS\ANVILLE\15\07	3,9
Can 6	Z:\KFS\ANVILLE\15\08	4,8
Can 7	Z:\KFS\ANVILLE\15\09	5,8
Can 8	Z:\KFS\ANVILLE\15\10	4,8
Can 9	Z:\KFS\ANVILLE\15\11	6,2 / max. 6,44
Compressor		
Voltage	Z:\KFS\PM100\12\VRMS	230,9
Power	Z:\KFS\PM100\12\WATT	180
Running time	Z:\KFS\PM100\12\WATT	100
Energy	Z:\KFS\PM100\12\WH	4311,8
Energy consumption/24h	Z:\KFS\PM100\12\WH	4311,3

Table 3: Results from test 3.

Test 2 and 3 show that the baseline coolers performed much better than the cooler in test 1. The can temperatures varied from 2.25 C to 6.6 C and the energy consumption was 4.0 kWh/24h and 4.3 kWh/24h, respectively, for the two coolers.

3. First generation of prototypes

At the start-up meeting held on 24 April 2008 at DTI, a number of ideas were discussed for a new version of the POS72 impulse cooler:

Reduced air infiltration:
- Better air curtain?
- Vestfrost idea: Removable lid
- Reduce air leakage in refrigeration machine

Reducing other heat loads:
- Better insulation

Improved cooling system:
- Use state-of-the-art R600a compressor: NLE15KTK.2 (26 % better COP)
- Use R290 compressors (NL7CN or TL5CN)?
- Improved condenser and evaporator?
- Improved air cooling and condenser?
- Improved cold air flow?
- Others?

Pepsi thinks the cooler should be open. "Open air coolers" increase sales by 30%. Pepsi is interested in a night cover. Automatically removable lids might be expensive.

Pepsi also questioned the idea of a removable lid. It is not part of the Pepsi test procedure. There was a discussion concerning the sleeping mode, where the cooler is allowed to warm up during night-time. Pepsi mentioned that this is not part of the Pepsi test procedure. Pepsi said that it would be better to investigate improved air curtains. Perhaps improved geometry and higher air velocity would help?
It is important that the curtain covers the total open area.
COOP mentioned that they recommend timers mounted on the coolers to cut off power during closing time. This configuration is in use in COOP supermarkets. A timer costs 7 USD.

Variable speed compressors
IPU proposed the use of a variable speed compressor. That would result in another big saving, due to low speed and high efficiency at normal working conditions, and high speed and high cooling capacity during pull down.
Pepsi questioned variable speed compressors because of the price (additional 120 USD), which will give a price increase of app. 25%.
IPU calculated that additional costs would be saved within 0.6 year because of electricity savings.
The discussion ended with the following: We might have a second prototype version with a variable speed compressor. But the first prototype will have a fixed speed compressor.

Isobutane or propane
Isobutene (R600a) as well as propane (R290) are candidates for the prototype and later produced versions of the new cooler.

Isobutane: The Danfoss NLE15KTK.2 has a 26% better COP (at -10°C/ + 55°C) compared to the present compressor. The cooling capacity is slightly smaller.

Propane: The Danfoss NL7CN has a cooling capacity slightly higher compared to the present compressor. The COP at -10°C/+45°C is quite high, but not directly comparable to the values of other compressors, because it is given for a lower condensing temperature (+45°C and not +55°C). We might have data from Danfoss, which could be directly comparable to isobutene and HFC compressors.
Danfoss TL5CN is also a possibility. It has a slightly smaller cooling capacity compared to the present compressor and the COP is slightly smaller compared to the previously mentioned propane compressor.
Vestfrost is also interested in trying to use propane as refrigerant. Vestfrost has for years produced a lot of isobutene units.

Air flow
DTI will have a look at the possibility of improving the air curtain with another geometric and/or changed air flow. That will be carried out by using CFD. DTI will also investigate a more sophisticated CFD model including the cooling of drinks during pull down. If Pepsi has a model for that it could be integrated in the DTI model. We discussed the potential leakage between the warm and cold side in the refrigeration system and Vestfrost A/S presented the idea of introducing a water lock to prevent the problem.

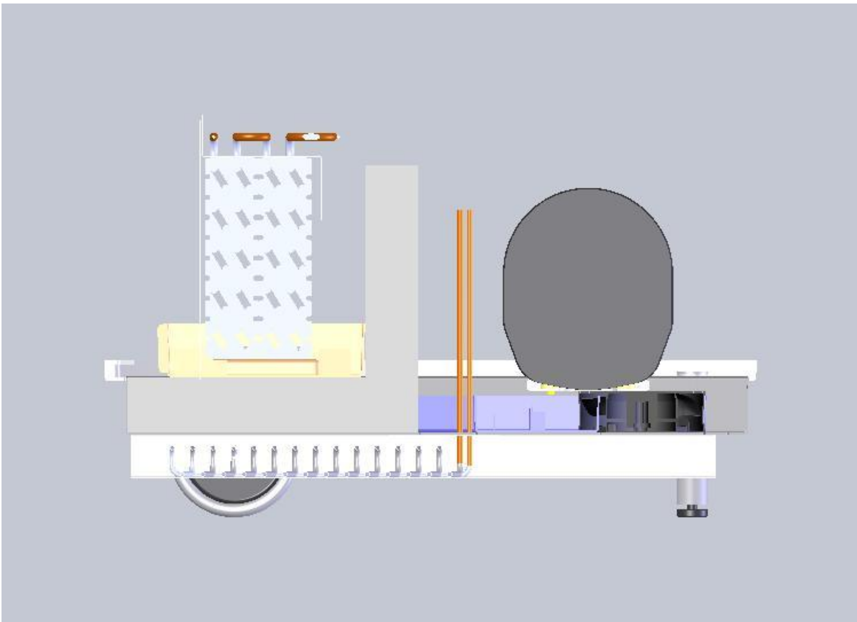


Figure 16: Vestfrost A/S presented a new concept for the refrigeration system, which would reduce the leakage between the warm and cold side, and it would also reduce the short-circuit of intake and exhaust air on the warm side of the unit. It also includes a new condenser, which is easier to clean with a vacuum cleaner, as well as a new concept for the fans.

3.1. Production and test of the first generation of prototypes

The first generation of prototypes (one with R134a and one with R600a refrigerant) were equipped with a new type of condenser made from smooth steel pipe, which is easy to clean.

Both prototypes were in poor working condition because the heat transmission area of the condenser was too small and the condenser temperature was too high. Especially the R134a cooler was hot on the condenser side.

Both coolers were running 100% of the time.

When the first tests had been carried out it was decided to stop the tests and to ship the coolers back to Vestfrost A/S.

4. Second generation of prototypes

4.1. Improved coolers

Vestfrost A/S improved the condenser and built a new R600a cooler. Vestfrost made the strategic decision to drop the R134a cooler and to concentrate future work on R600a natural refrigerant.

The new cooler had a condenser with a higher heat transmission area as well as improved cooling of the compressor. The airflow inlet and outlet at the condenser side were also separated to prevent short-circuit of the airstream.

The compressor in the cooler was the Danfoss NLE15KTK.2 for isobutene (R600a).

The cooler was installed at DTI in February 2009 and tested in February and March 2009.

Measuring points	Data sources		
Start		28-02-2009 13:19	01-03-2009 18:06
Stop		01-03-2009 13:19	02-03-2009 18:06
Duration		24:00 [HH.MM]	24:00 [HH.MM]
Ambient temperature			
Average temperature		24,9	24,8
Left	Z:\KFS\ANVILLE\03\01	25	24,9
Right	Z:\KFS\ANVILLE\03\02	24,7	24,7
Appliance			
Average temperature		2,1	2,1
Can 1	Z:\KFS\ANVILLE\03\03	0,5	0,5
Can 2	Z:\KFS\ANVILLE\03\04	2,9	2,8
Can 3	Z:\KFS\ANVILLE\03\05	0,8	0,8
Can 4	Z:\KFS\ANVILLE\03\06	2,9	2,9
Can 5	Z:\KFS\ANVILLE\03\07	1,2	1,2
Can 6	Z:\KFS\ANVILLE\03\08	1,8	1,8
Can 7	Z:\KFS\ANVILLE\03\09	3,6	3,6
Can 8	Z:\KFS\ANVILLE\03\10	2,2	2,2
Can 9	Z:\KFS\ANVILLE\03\11	3,2	3,2
Kompressor			
Voltage	Z:\KFS\PM100\12\VRMS	230,8	230
Power	Z:\KFS\PM100\12\WATT	170,7	169,3
Running time	Z:\KFS\PM100\12\WATT	100	100
Energy	Z:\KFS\PM100\12\WH	4072,7	4067,3
Energy consumption/24h	Z:\KFS\PM100\12\WH	4072,2	4066,9

Table 4: Improved second generation impulse cooler (test 6).

The bottle cooler was working fine and was able to carry out the job. It kept the 96 cans between freezing point and 4 °C. The energy consumption was app. 4.07 kWh/24h, which is similar to the original cooler (test 2 and 3).

4.2. Improved air curtain

A CFD program was created to calculate the air loss from the air curtain at the top of the cooler. The air loss and hence the air infiltration by warm humid air gave rise to an additional electricity consumption because the air has to be cooled, most of the moisture has to be condensed and will be frozen at the evaporator surface.
A CFD calculation showed better performance with small geometric changes at the inlet and outlet air channels inside the cooler (at the cold side). The changes should reduce the air infiltration of warm ambient air into the cooler and reduce the energy consumption.

The CFD calculations showed that the cooler could be improved if the following improvements are carried out. They were incorporated in the second generation of prototypes and tested in the climate chamber at DTI:

- In test 7, additional small narrow slots were made at the inlet and outlet of the airflow. The slots were installed under the existing slots, which were placed in the upper region in the rear and front end of the cooler.
- Test 8 was performed as test 7, but with air guides at the "new" narrow air slots. The guides ensured that inlet air was pressed downwards in the cooler. That prevented the air from moving up over the columns of cans and from being mixed with the ambient air.
- In the standard cooler and in the previous prototypes, the air fan (for cold air into the cooler) runs 100% of the time. Theoretically it was not necessary to run the fans at the compressor OFF time. By stopping the fans at the same time as the compressor, the air infiltration would be reduced. On the other hand, it was necessary for the controller to receive a correct temperature signal, which corresponded to the actual can temperature. The solution was to develop a "pulse control" for the (cold air) fan, to reduce the warm air infiltration and to ensure a correct temperature signal for the electronic controller. It was possible to order electronic control which could be programmed for that purpose and the control was installed in the prototype in June 2009. The controller was programmed to stop the fan for three minutes and then run the fan for one minute, followed by a three minute standstill period etc. until the compressor started running (test 9).

The CFD calculations are explained more detailed in Appendix 3, where also additional CFD calculations for a vertical open cooler are described.

Test 7: Tests in the climate chamber showed only minor improvements as the energy consumption was measured to app. 4.0 kWh/24h.

Test 8: The test in the climate chamber showed no improvements with the air slots and the air guides installed. The explanation might be that the can columns were not in perfect order and the air passage area was smaller than expected on the basis of the ideal calculation.

Test 9: The test with the pulse control fan showed an 8% decrease in energy consumption. The relative running time of the compressor was about 72.5% and the pulse control worked the remaining 27.5%. That is not bad!

4.3. Automatic lid

An automatic lid was placed on the cooler. It worked by using the DTI door opening robot by moving a wooden plate placed on top of the cooler. The robot can be programmed and the following tests were conducted:

- Test 10 failed. For some unknown reason the pulse control did not work properly.
- Test 11: Closed lid. Pulse fan working, air guides and slots mounted.
- Test 12: As test 11 but with lid openings according to EN23953 (openings 12 hours a day, 6 openings per hour, 8 seconds per lid opening - except for the first lid opening, which lasted 3 minutes).
- Test 13: As test 12, but each lid opening lasted 30 seconds.
- Test 14: As test 13, but the cooler was shut off during the first 8 hours of the 12 hours of night-time.
- Test 15: Open lid. Air guides and slots were installed, pulse control was active. Power was shut off between 22.00 and 06.00 o'clock.

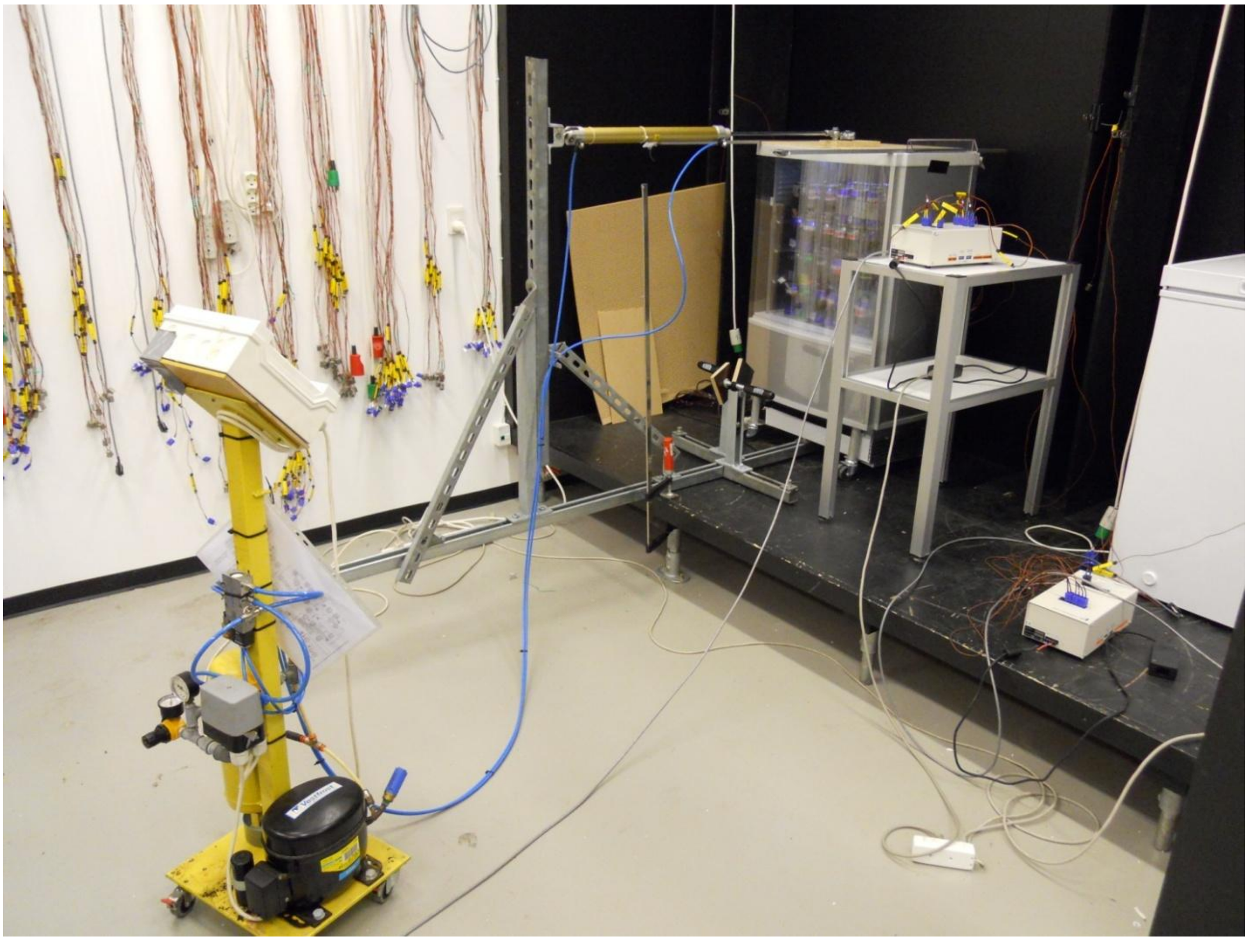


Figure 17: Automatic robot opening the lid. DTI also has a small video showing the automatic lid opening. The tests took place in a climate chamber at DTI, where accredited tests take place according to EN153.

The second generation of prototypes installed with (automatic) lids and tested according to EN23953 (European standard for refrigerated sales display coolers) + hydrocarbon refrigeration system + pulse control of fans, reduced the energy consumption from app. 4.0 kWh/day to 2.342 kWh/day. That was a reduction of 41.5%.

If the cooler additionally was turned off the first 8 hours of the 12 hour resting period, the energy consumption was 2.143 kWh/day, which was a reduction of 46.4%.

When the lid was open all the time and the electricity was shut off 8 hours during night-time (from 22.00 to 06.00), the electricity consumption was reduced from about 4.0 kWh/day to 2.621 kWh/day, which corresponds to a 34.5% saving. It should be mentioned that the warmest can was 13.5°C at 10.00 h.

5. Third generation of prototypes

It was observed in the first and second generation of prototypes that there is potential for improving the cooler if the condenser is improved. That was also the case for the original cooler, which was not easy to clean when dust came in between the condenser fins. The problem connected with cleaning was solved in the first and second generation of prototypes, but it was the impression that the surface area of the condenser could be bigger.

Therefore, a third generation of prototypes was built with a compact box type condenser without fins. The box type condenser will not create dust problems, as the dust will not block up and it is also possible to clean the condenser with a vacuum cleaner.

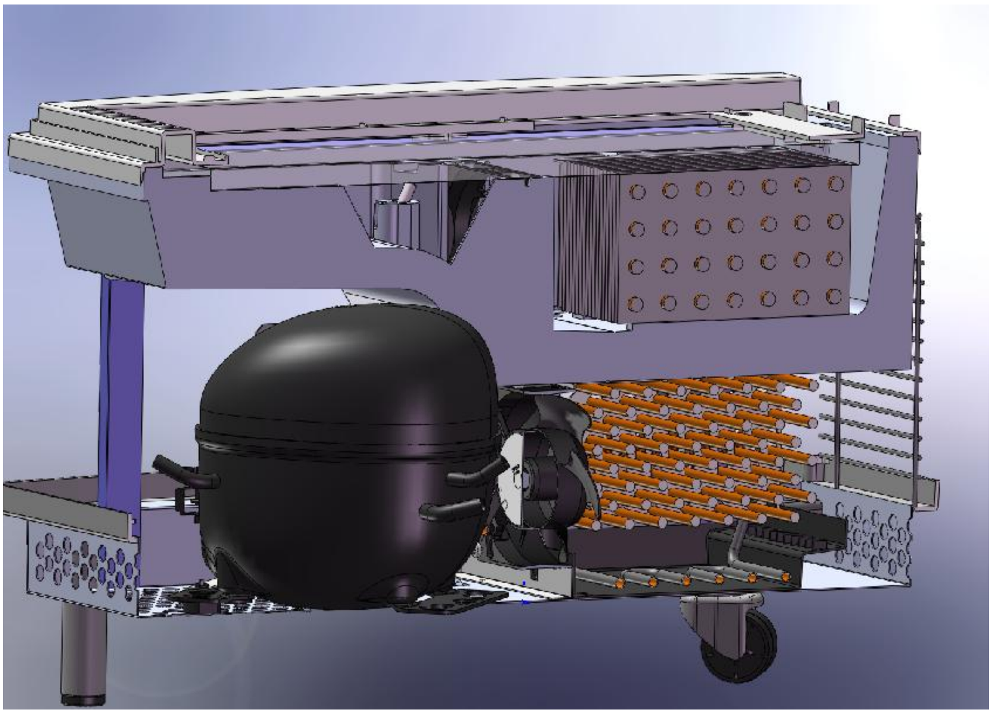


Figure 18: Illustration of the cooling system in the third generation impulse sales cooler. The cooler is supplied with a new box type condenser. This condenser is compact with smooth pipes that are easy to clean. The fan moves the cooling air from the front end and discharges it at the rear end of the cooler to prevent short-circuit of the air.

In the third generation prototypes, an additional improvement was carried out: the return air was prevented from mixing with the air into the air space between the plastic sheets at the side walls. That probably reduces the heat transfer through the walls.

Vestfrost A/S made some initial tests with a propane compressor (TL5CN for R290) but it did not work very well and it was decided to use a new compressor for isobutene (R600a): NLE9KTK. That is the compressor in the third generation of prototypes. The refrigerant charge is 110 grams of R600a.

Finally, the bottom of the cooler was improved by using a moulded piece of EPS foam instead of many small cut pieces. That reduced the air leakage between the warm and cold side and increased the insulation properties.

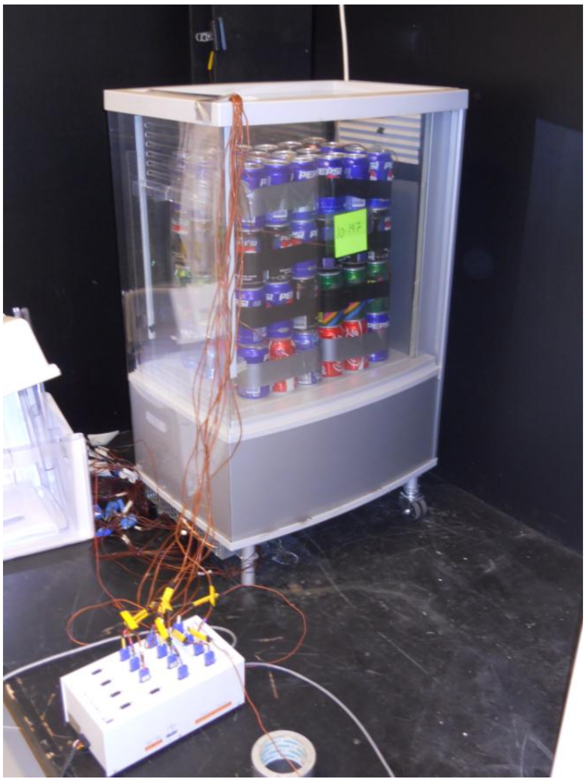


Figure 19: Third generation of prototypes at DTI climate chamber, July 2010. The cooler is equipped with R600a refrigeration system, improved condenser, improved air cooling system for condenser and compressor and improved air circulation system for the cold air.

Three tests were carried out with the third generation cooler. The prototype tested was not equipped with LED light.

Start	Data Sources	07-06-2010 07:32	13-06-2010 02:37	16-06-2010 12:47
Stop		08-06-2010 07:47	14-06-2010 02:57	17-06-2010 12:47
Duration		24:14 [HH.MM]	24:19 [HH.MM]	24:00 [HH.MM]
Ambient		25,2	25,4	24,8
Left	Z:\KFS\ANVILLE\23\01	25,1	25,3	24,6
Right	Z:\KFS\ANVILLE\23\02	25,3	25,5	24,9
Average		5,5	4,2	4,4
Can 6	Z:\KFS\ANVILLE\23\03	5,6	4,4	4,4
Can 7	Z:\KFS\ANVILLE\23\04	5,8	4,4	4,5
Can 8	Z:\KFS\ANVILLE\23\05	7,5	6,3	6
Can 9	Z:\KFS\ANVILLE\23\06	7,6	6,4	6,1
Can 5	Z:\KFS\ANVILLE\23\07	5	3,6	4
Can 1	Z:\KFS\ANVILLE\23\08	3,5	2,1	2,7
Can 2	Z:\KFS\ANVILLE\23\09	3,3	1,9	2,6
Can 3	Z:\KFS\ANVILLE\23\10	5,8	4,4	4,8
Can 4	Z:\KFS\ANVILLE\23\11	5,5	4,1	4,6
Compressor				
Voltage	Z:\KFS\PM100\12\VRMS	230,4	231,7	231,8
Energy consumption/24h	Z:\KFS\PM100\12\WH	1907,3	2022,6	1805,1
Thermostat position		Position 12:00	Position 01:30	Position 01:30
		Without lid	Without lid	With lid

Table 5: Results of test 16, 17 and 18.

- Test 16: The cooler was tested with open lids. The energy consumption was measured to 1.907 kWh/day
- Test 17: As test 16 – but with a colder thermostat setting. The energy consumption was measured to 2.023 kWh/day
- Test 18: As test 16 and 17, but with closed lid. The energy consumption was measured to 1.805 kWh/day

The third generation of prototypes worked well with reduced energy consumption, which was 1.965 kWh/day (average of test 16 and 17). This prototype had no LED light. In order to compare it with the other prototypes and the standard cooler 0.25 kWh/day must be added to the consumption. That results in an energy consumption of 2.215 kWh/day – or a reduction of about 47% (the average of test 2 and 3 is 4.149 kWh/day for the baseline cooler).

Influence of lid:
When the lid was placed on the cooler, the consumption was reduced by 0.218 kWh/day to an energy consumption of 1.805 kWh/day (+ 0.25 kWh/day for LED light). The saving obtained by adding the lid amounted to app. 11%.

Appendix A: Typical impulse coolers and their energy consumption

Manufacturers of commercial refrigerators and freezers are not committed to inform how much energy their products use. Therefore, a complete list stating the energy consumption of impulse coolers does not exist. Nevertheless, an attempt has been made to give an impression of the energy consumption of impulse coolers through the following information.

1. Westcool

The German company Westcool sells a wide range of refrigeration products and the energy consumption is stated in the company's catalogue which can be found on: www.westcool.de

The following information has been copied from the catalogue and all impulse coolers that are not refrigerated cabinets or "can coolers" have been included:

Impulse Cooler Enjoy 400+OF / Janus

ENJOY
SALES AB

Enjoy
600+OF

Enjoy
600 Janus

Ausstattung Enjoy 400+OF/ Janus

Steckerfertige Impulskühltruhe
Außenbehälter: solide Stahlblech /Kunststoff-Konstruktion
servicefreundliche Bauweise
Innenbehälter: lackiertes Stahlblech / Kunststoff
Modell Enjoy 600Janus mit 2 Verkaufsöffnungen
Umluftkühlung
manuelle Abtauung
Thermostat
Isolierung: 50 mm
fahrbar, Rollen

Artikel	Artikel-Nr.	Temperatur °C	Maße außen (innen) BxTxH in mm	Volumen Liter	Leistungs-aufnahme Watt	Energie-verbrauch kW/24 Std.	Gewicht kg	Preis Euro
Enjoy 400+OF		+3°C bis + 5°C	650x600x1490	250	600	12,0	68	**auf Anfrage**
Enjoy 400Janus		+3°C bis + 5°C	650x725x1490	285	750	15,0	65	**auf Anfrage**

Impulse Cooler Enjoy 600

Enjoy 600

Ausstattung Enjoy 600

Steckerfertige Impulskühltruhe
Außenbehälter: Stahlblech / Kunststoff
Innenbehälter: lackiertes Stahlblech / Kunststoff
servicefreundliche Bauweise
Umluftkühlung
automatische Abtauung
Thermostat
Isolierung: 50 mm

Artikel	Artikel-Nr.	Temperatur °C	Maße außen (innen) BxTxH in mm	Volumen Liter	Leistungs-aufnahme Watt	Energie-verbrauch kW/24 Std.	Gewicht kg	Preis Euro
Enjoy 600		+3°C bis +5°C	650x420x950	70	446	8,82	53	**auf Anfrage**

Impulsekühler AccessCooler


AccessCooler
mit Lichttop

Ausstattung AccessCooler

Impulskühltruhe steckerfertig
Außenbehälter: stabile Kunststoffkonstruktion,weiß
mit transparentem Polycarbonat-Glas
Innenbehälter: Aluminium
Umluftkühlung
automatische Abtauung
Rollen
Lichttop (bei Modell 1041...)

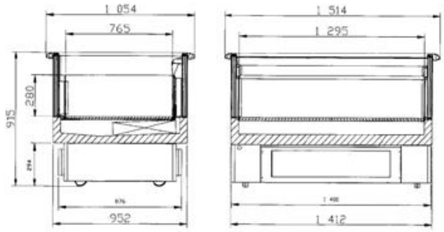
Artikel	Artikel-Nr.	Temperatur °C	Maße außen (innen) BxTxH in mm	Volumen Liter	Leistungs-aufnahme Watt	Energie-verbrauch kW/24 Std.	Gewicht kg	Preis Euro
ACCESS	104002103800	+2° C bis + 12°C	550x690x895 (470x585x495)	104/73	380	5,2	40.5	**auf Anfrage**
ACCESS	104116103800	+2° C bis + 12°C	550x690x1069 (470x585x495)	104/73	380	5,2	40.5	**auf Anfrage**

Kühl- / Tiefkühltruhe Norwell

Ausstattung Kühl- / Tiefkühlinsel Norwell 150

Steckerfertige Kühl- / Tiefkühlinsel
Umluftkühlung
Handlauf und Glaseinfassungen aus Aluminium, weiß
Umlaufende Glassichtflächen
Blenden und Sockelblende aus verzinktem Stahlblech
Sockelblende grau
Lenkrollen
Stapelhöhe bei allen Modellen: 280 mm
Automatische Abtauung und Tauwasserverdunstung
Vierseitige Beleuchtung unter dem Handlauf

Ausführung
Kühlinsel (Version Norwell 150 LRCM)
Kühl- / Tiefkühlinsel (Version Norwell 150 LRFCM
Tiefkühlinsel (Version Norwell 150 LRFFM)



Artikel	Artikel-Nr.	Temperatur °C	Maße außen BxTxH in mm	Volumen/ Ausstell-fläche m²	Leistungs-aufnahme Watt	Energie-verbrauch kW/24 Std.	Gewicht kg	Preis Euro
Norwell 150 LRCM	A41001	+2°C bis + 4°C	1514x1054x915	277 l / 0,98	1390	26,6	200	**auf Anfrage**
Norwell 150 LRFCM	A41003	+2°C bis + 4°C und -21°C - - 23°C	1514x1054x915	277 l / 0,98	2710	43,1	215	**auf Anfrage**
Norwell 150 LRFFM	A41000	-21°C bis - 23°C	1514x1054x915	277 l / 0,98	2390	43,1	215	**auf Anfrage**

2. Vibocold

The Danish company Vibocold sells a wide range of commercial refrigeration cabinets, including impulse coolers. Their catalogue can be seen on: www.vibocold.dk.

In the following, information has been copied about impulse coolers for which the energy consumption has been informed:

- Leveres som køl (*P*) eller frys (*N*)
- Integreret lystop (h: 115 mm)
- Rumdelere
- Termometer

* = filling height

Model:		*Impulse 70 P*	*Impulse 100 P*
Design:		Ventilated fridge	Ventilated fridge
Volume:	Litre	210	315
Outside measurement (WxDxH):	Mm	707x739x1058	1018x739x1058
Inside measurement (WxDxH):	mm	590x500x280*	890x500x280*
Temperature range:	°C	0 - +10	0 - +10
Energy consumption:	KwH/24t	7.1	7.9
Connecting power:	watt	710	880
Net weight:	kg	89	114
Product number:		*Impulse 70P*	*Impulse 100P*

Impulse cooler - POS 072 R

- Glas på 3 sider
- Rumdeler
- Hjul i bag + støtteben i front
- Natlåg som standard
- Kan dekoreres på alle 4 sider

Kapacitet
50 cl. - ca. 72 stk.
33 cl. - ca. 96 stk.

Model:	***POS 072 R***
Design:	Ventilated fridge
Volume:	80 litre
Outside measurement:	W:400xD:600xH:940 mm
Inside measurement:	W:300xD:490xH:540 mm
Temperature range:	+2 - +8°C
Energy consumption:	6.7 KwH/24t
Connecting power:	320 watt
Net weight:	52 kg
Product number :	***POS 072 R***

Impulse cooler - SLIM

• Grå som standard
• Justérbare ben i front + hjul i bag

Kapacitet
50 cl. - ca. 70 stk.
33 cl. - ca. 120 stk.

Model:	***SLIM***
Design:	Ventilated fridge
Volume:	94 litre
Outside measurement:	W:676xD:436xH:955 mm
Inside measurement:	W:564xD:293xH:572 mm
Temperature range	+2 - +10°C
Energy consumption:	8.3 KwH/24t
Connecting power:	530 watt
Net weight:	85 kg
Product number:	***SLIM***

Impulse cooler - SOT 110 SAX

- Håndtag på bagsiden
- Rumdeler som standard
- Aftageligt, låsbart låg
- 2 hjul i bag + stillefødder i front
- Indvendig ventilation

Kapacitet
50 cl. - ca. 72 stk.
33 cl. - ca. 108 stk.

Model:	***SOT 110 SAX***
Design:	Ventilated fridge
Volume:	110 litre
Outside measurement:	W:611xD:441xH:915 mm
Inside measurement:	W:538xD:335xH:482 mm
Temperature range:	+2 - +7°C
Energy consumption:	6.1 KwH/24t
Connecting power:	242 watt
Net weight:	66 kg
Product number:	***SOT 110 SAX***

Impulse cooler - Svaba 150 P

- Kan leveres som køl (*P*), frys (*N*) eller omstilbar (*N/P*)
- Automatisk afrimning
- Stabelhøjde: køl 210 mm & frys/omstilbar 170 mm
- Natlåg (kun frys)
- Hæve bund - 3 niveauer
- Termometer

Model:		***Svaba 150 P***	***Svaba 150 N/P***
Design:		Ventilated fridge	Ventilated fridge
Volume:	litre	274 litre	274 litre
Outside measurement (WxDxH):	mm	1546x1042x905	1546x1042x905
Inside measurement (WxDxH):	mm	1380x778x260	1380x778x260
Temperature range:	°C	0 - +10	0 - +10 / ÷14 - ÷18
Energy consumption:	Kwh/24t	18,2	31,4
Connecting power:	watt	1530	2050
Net weight:	kg	152	152
Product number:		***Svaba 150 P***	***Svaba 150 N/P***

Impulse cooler - Svaba 200 P

- Kan leveres som køl (*P*), frys (*N*) eller omstilbar (*N/P*)
- Stabelhøjde: køl - 210 mm & frys/omstilbar - 170 mm
- Natlåg (kun frys)
- Hæve bund - 3 niveauer
- Termometer

Model:		***Svaba 200 P***	***Svaba 200 N/P***
Design:		Ventilated fridge	Ventilated fridge
Volume:	litre	375	375
Outside measurement:	mm	2046x1042x905	2046x1042x905
Inside measurement:	mm	1880x778x260	1880x778x260
Temperature range:	°C	0 - +10	0 - +10 / ÷14 - ÷18
Energy consumption:	Kwh/24t	25.2	36.1
Connecting power:	watt	2000	2900
Net weight:	kg	229	229
Product number:		***Svaba 200 P***	***Svaba 200 N/P***

Impulse cooler - VPD-10

- Kan leveres som køl eller frys
- Integreret lystop (h: 150 mm)
- Hjul
- Rulletermometer

Model:	***VPD-10***
Design:	Ventilated fridge
Volume:	146 litre
Outside measurement:	W:980xD:800xH:1045 mm
Inside measurement:	W:835xD:575xH:275 mm
Temperature range	÷1 - +5°C
Energy consumption:	8.0 KwH/24t
Connecting power:	449 watt
Net weight:	123 kg
Product number:	***VPD 10***

3. Vestfrost

Added to that comes Vestfrost's impulse coolers and the following information has been found on their homepage: (www.vestfrost.dk):

VESTFROST

The energy consumption is app. 5.5 kWh/24h.

DIMENSIONS	
Measurements	
Width (cm)	**60**
Width x Depth, cm	**60x40**
Width x Depth, inch	**23.6x15.6**
Depth (cm)	**40**
Height (cm)	**94**
Height, inch	**37,0**
Volume	
Net volume, cu.ft.	**2,8**
Net volume, litre	**72**

TECHNICAL SPECIFICATIONS	
0.330 litre cans	**96**
0.355 litre cans	**90**
0.50 litre bottles	**72**
20 oz. bottles	**66**

Appendix B: Energy balances

Energy balance of the present cooler. This appendix is written by Marcin Blazniak Andreasen, DTI

In the following, a preliminary calculation of the energy balance on the present cooler design is carried out. The following heat inputs are depicted:

- Q1 – Infiltration
- Q2 – Heat input through the cabinet walls
- Q3 – Heat input from the condenser side
- Q4 – Heat input through the EPS foam
- Q5 – Electricity for the internal fans
- Q6 - Light

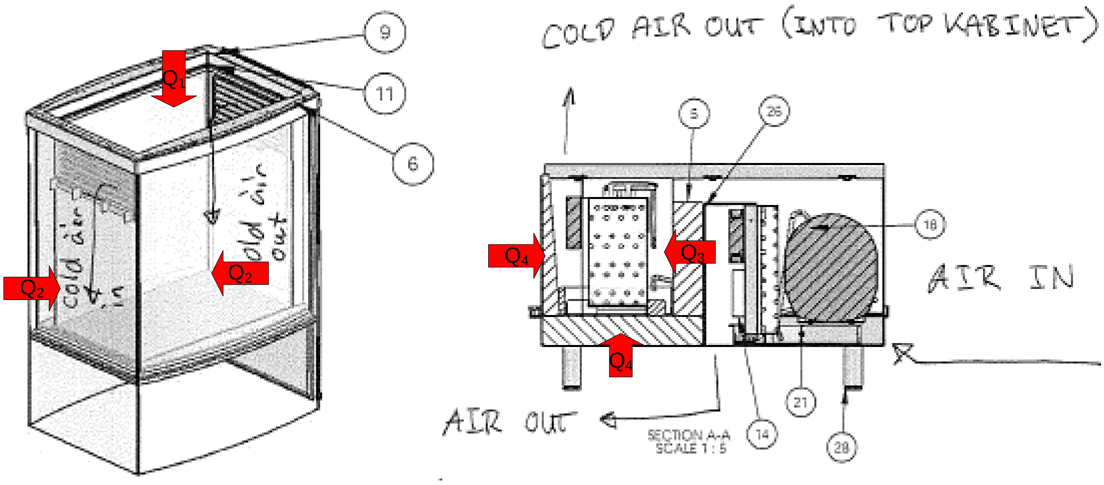


Figure 1: Definition of the heat input.

Some initial tests have been carried out on the impulse cooler in the climate chamber. The product temperature and power consumption have been monitored at a fixed ambient temperature and relative humidity of the air. For direct comparison, the following investigations are carried at the same working conditions see table 1.

Ambient air temperature	25°C
Ambient air relative humidity	60%

Table 1: Working conditions.

Q1 – Infiltration

A simplified CFD model of an impulse cooler is prepared. The purpose of the model is to estimate how big an influence the infiltration has on the total cooling requirement. The model focuses only on the infiltration and does not take the heat input through the cabinet walls into account. That will be elaborated on separately in the document.

The simplified model is shown in figure 2. The overall dimensions of the simulated cooler are the following WxLxH = 400mm X 600mm X 600mm. 6 inlet and outlet channels are located on each side of the cabinet. The cooling air is directed towards the product at an angle of 45 degrees.

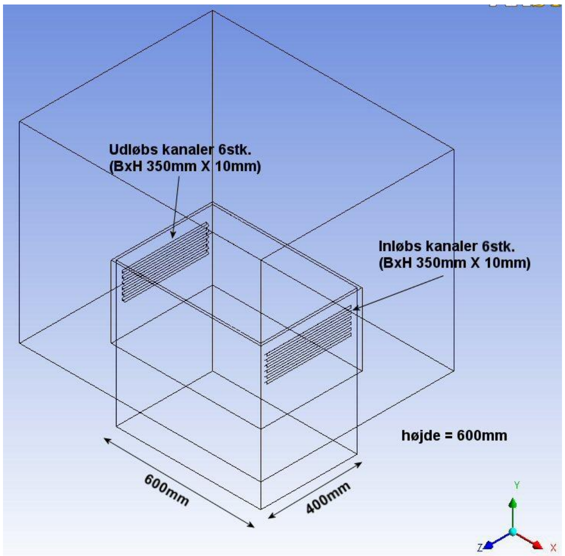


Figure 2: Model of the impulse cooler.

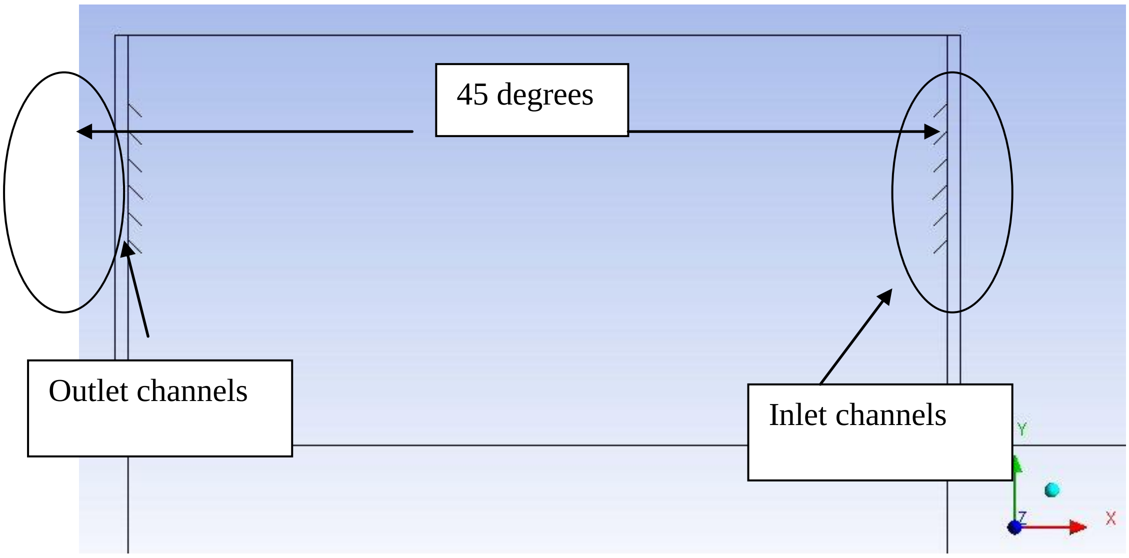


Figure 3: Model of the impulse cooler.

2 axial fans are located on the evaporator backside as shown in figure 4.

Figure 4: Axial fans.

In figure 5, the fan characteristics are shown. The total amount of circulated air is not yet known. For the initial study, a cooling air flow of $76m^3/h$ is depicted responding to $0.63m^3/min.$ per fan. That will be elaborated on later. Furthermore, in the initial study the temperature of the cooling air flow after the evaporator is set to 0 degrees C. In table 2, the working conditions are summarized.

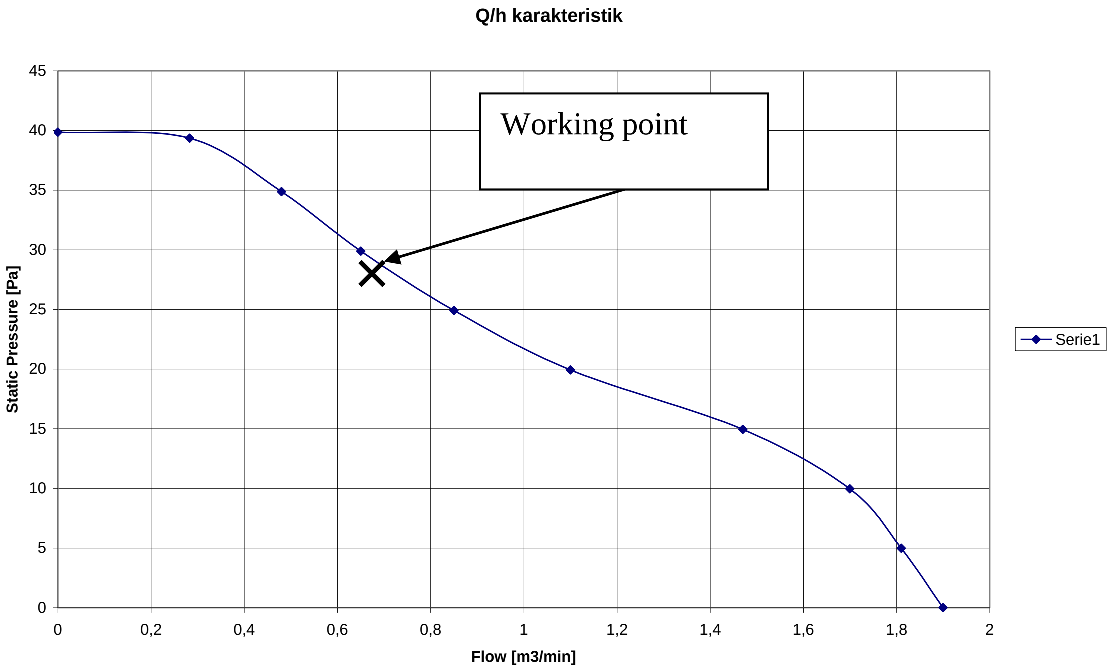


Figure 5: Fan characteristics (Sunon KD2412PTS3-6A).

Cooling air flow	76 m3/h
Cooling air temperature after the evaporator	0°C

Table 2: Working conditions.

It is difficult to define how much resistance randomly packed bottles will create in the cabinet. In the test lab, the impulse cooler had been loaded with cans as shown in figure 6. This packing order of the canes will create a large resistance for the cooling air. To meet the test setup, the initial investigations were carried out on a fully packed cabinet where the permeability resistance is high.

Figure 6: A closely packed cabinet.

In the figures below, the temperature distribution and velocity profiles are shown. The temperature distribution is shown in two planes perpendicular to each other as shown in figure 7. The estimated cooling capacity needed to compensate for the infiltration is shown in table 3.

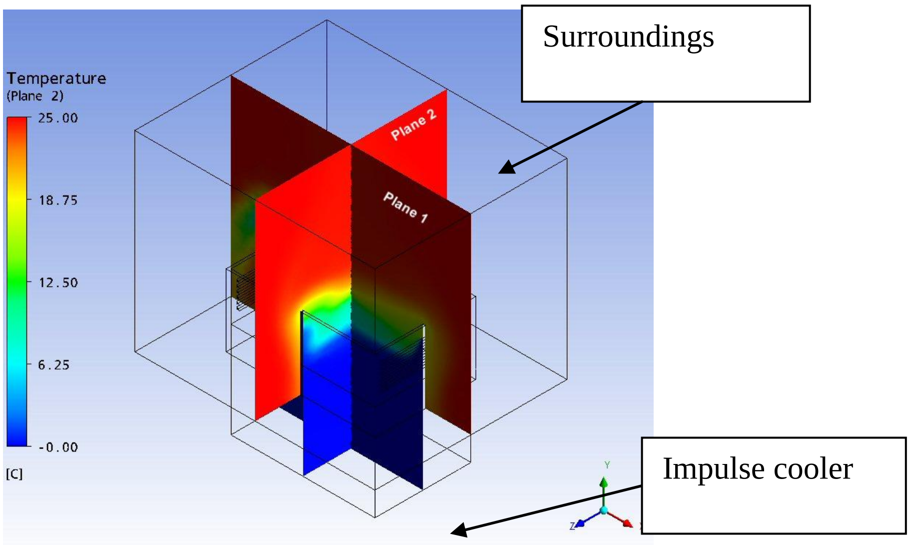


Figure 7: Plane designation.

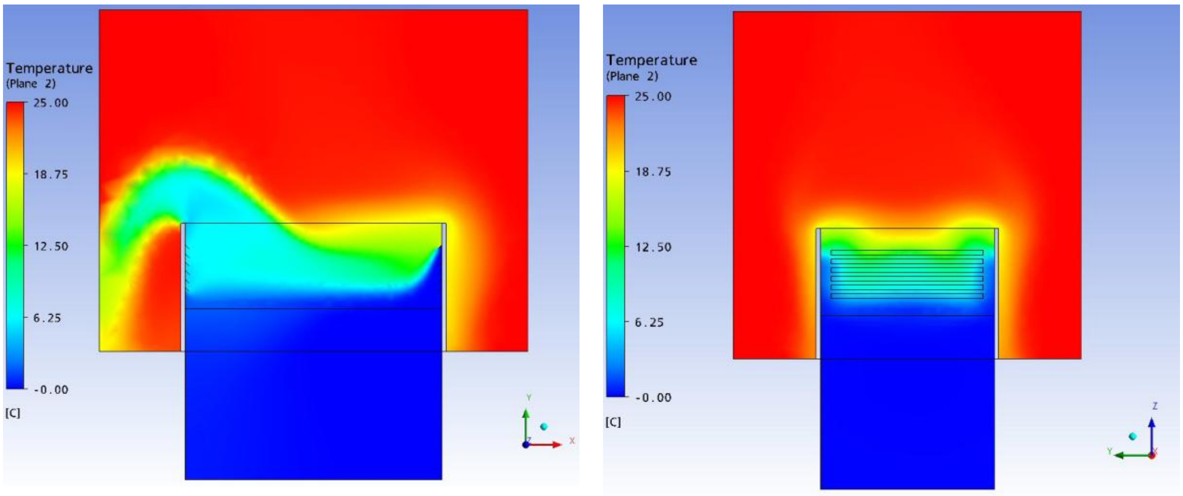


Figure 8: Temperature distribution; to the left Plane 1, to the right Plane 2.

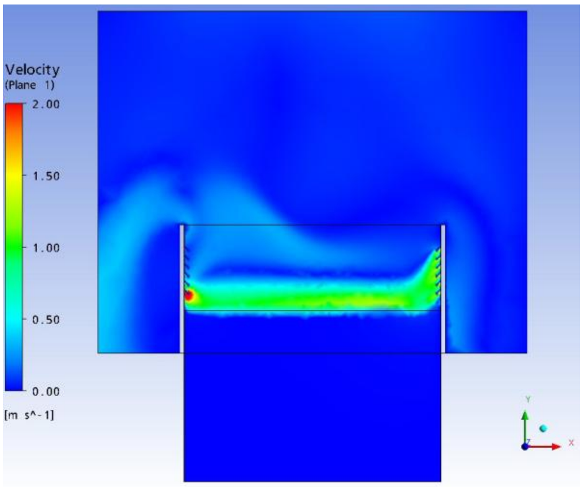


Figure 9: Velocity distribution.

The CFD simulations have shown somewhat bouncy behavior of the flow field. However, the cooling requirements seem to reach a level as shown in table 3.

	Full cooler
Total cooling air flow	76 m^3/h
Infiltration	19 %
Air cooling	80.5 W
Water condensation	101 W
Ice formation	13.5 W
Total	195 W

Table 3: Cooling requirements to compensate for the infiltration.

Q2 – Heat input through the cabinet walls

In the cabinet, there are two large and two small cabinet walls (see figure below). The cabinet walls have three layers of plastic, as shown in the sketch below. The stagnant air in the outer gap will work as an insulating layer. In table 4, the calculated heat input is shown. In Appendix A the calculation procedure is shown.

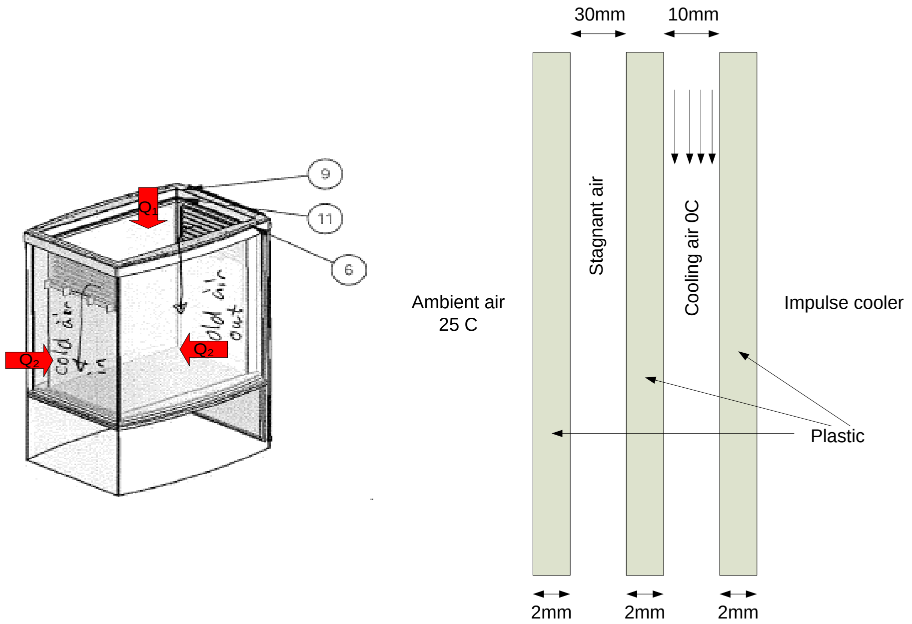


Figure 10: Definition of the heat input.

T_inside	0 C
T_outside	25 C
Q_total	44 W

Table 4: Heat input through cabinet walls.

Q3 – Heat input from the condenser side

The condenser side is located next to the evaporator side and separated by 0.05 m of EPS_foam. Making a conservative calculation of the heat load, when only the thermal resistance through the insulating material is taken into account shows that the heat input from the condenser side is low (as shown in table 5).

However, during testing and reassembly of the impulse cooler it has been observed that there is a risk of suction of false ambient air from the condenser side; especially around the water collecting tray. Suction of false ambient air will load the cooling system further. The amount of false air suction is not yet known.

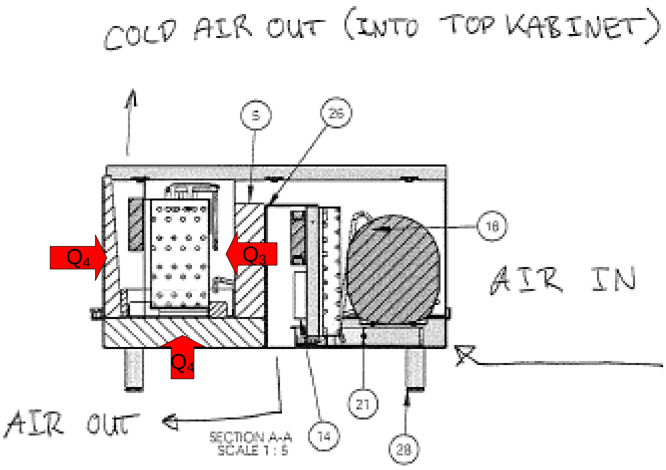


Figure 11 Definition of the heat input.

T_evaporator	0 C
T_condenser	25 C
k_eps foam	0.026 W/mK
Foam thickness	0.05m
Contact area	0.3m * 0.25m
Q_total	1 W

Table 5: Heat input from the condenser side.

Q4 – Heat input through the EPS foam

The condenser is insulated from the ambient air with 0.05m of EPS foam. Making a conservative calculation of the heat load, by taking into the consideration only the thermal resistance through the insulating material, shows that the heat input from the surroundings is low, as shown in table 6.

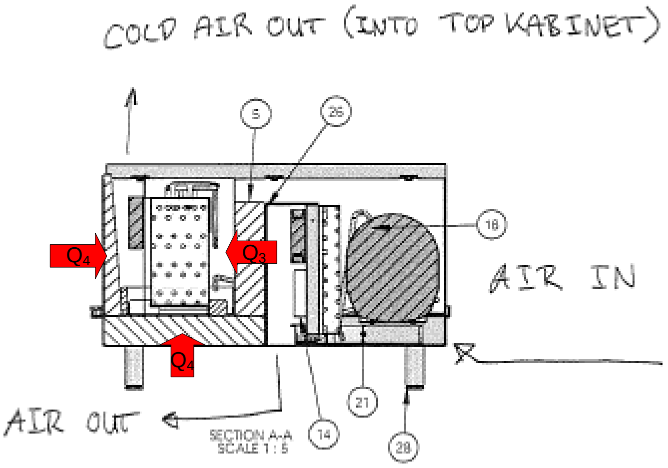


Figure 12: Definition of the heat input.

T_evaporator	0 C
T_ambient	25 C
k_eps foam	0.026 W/mK
Foam thickness	0.05m
Contact area left and right side	0.3m * 0.3m
Contact area end cover	0.4m * 0.3m
Contact area bottom	0.3m * 0.4m
Q_total	5.4 W

Table 6: Heat input through the EPS foam.

Verification with experimental measurements

Summing up – cooling load, theoretical calculation

In table 7 the calculated total heat load is given. The biggest uncertainty in the calculations is the infiltration, and heat input from the evaporator side (as false air leakage is observed).

	Full freezer
Q1 – Infiltration	195 W
Q2	44 W
Q3	1 W
Q4	5.4 W
Internal fans	2 x 3.1 W
Light	
Total	251.6 W

Table 7: Total cooling requirements – preliminary theoretical calculations.

Experimental measurements

During the tests in the laboratory, the power consumption was measured to 173 W (4.0 and 4.3 kWh / 24h). A small part of this is electric energy for fans, light, electronic thermostat and transformer. This part sums up to approx. 27 W. The remaining part (146 W) is used by the compressor.

The evaporating temperature is not known at present, however, with a point of departure in an evaporating temperature of -10C a COP value of 1.39 is expected to be found. That gives a cooling capacity of 203 W, which is a little lower than calculated theoretically.

EN 12900 Household (CECOMAF) 220V, 60Hz, fan cooling F_1

Evap. temp. in °C	-45	-40	-35	-30	-25	-23.3	-20	-15	-10	-6.7	-5	0	5	7.2	10	15	20
Capacity in W			109	166	233	258	312	406	518	603	650	807	989	1079			
Power cons. in W			143	187	232	248	278	325	373	405	421	470	518	540			
Current cons. in A			1.44	1.57	1.71	1.76	1.87	2.03	2.21	2.34	2.40	2.60	2.82	2.91			
COP in W/W			0.76	0.89	1.00	1.04	1.12	1.25	1.39	1.49	1.54	1.72	1.91	2.00			

Figure 13: Characteristic of the Danfoss NL10MF compressor.

Verification of the results

The experimental results and theoretical measurements show some deviations.

One of the uncertainties is the heat input from the condenser side. If the false air leakage is large it will have a large impact on the total cooling load. The two air circulating systems must be kept separated.

Another uncertainty is the evaporating temperature. Lower evaporating temperature will result in a lower COP value. However, a low evaporating temperature and a high temperature difference between the air cooling temperature and evaporating temperature is not welcome. That will indicate that the condenser surface is not utilized sufficiently, and an optimization of the air flow across the evaporator surface is required. Better utilization of the evaporator surface will result in an increased evaporation temperature and an increased COP value.

Appendix C: CFD calculations

C1: CFD calculations for open horizontal cooler

This appendix was written by Marcin Blazniak Andreasen, Danish Technological Institute

Model setup

A CFD model of a Vestfrost POS 072R open air cooler was constructed with the purpose of determining the infiltration of ambient air. Calculations on the original design were carried out and some first improvement suggestions are given in this status report.

The inner dimensions of the box are:

Height: 540 mm   Width: 300 mm   Length: 500 mm

The cooling air is distributed through the inlet manifold to the inlet gaps in the top, see figure 1. The dimensions of the inlet manifold are:

Width: 40 mm   Length: 300 mm

The dimensions of the inlet and outlet gaps are:

Width: 10 mm   Length: 280 mm

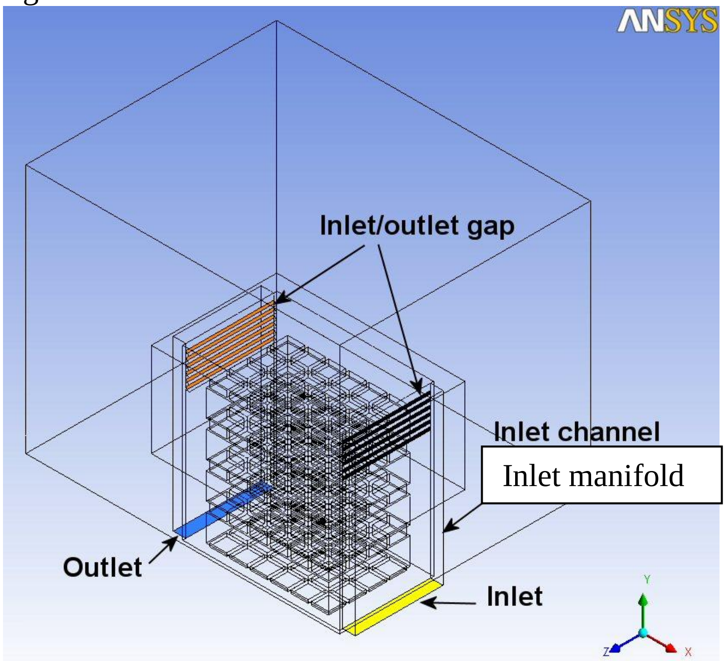


Figure 14: Designation of the different impulse cooler parts.

The geometry of the cans was simplified. The cans were modelled as shown in figure 2 and 3.

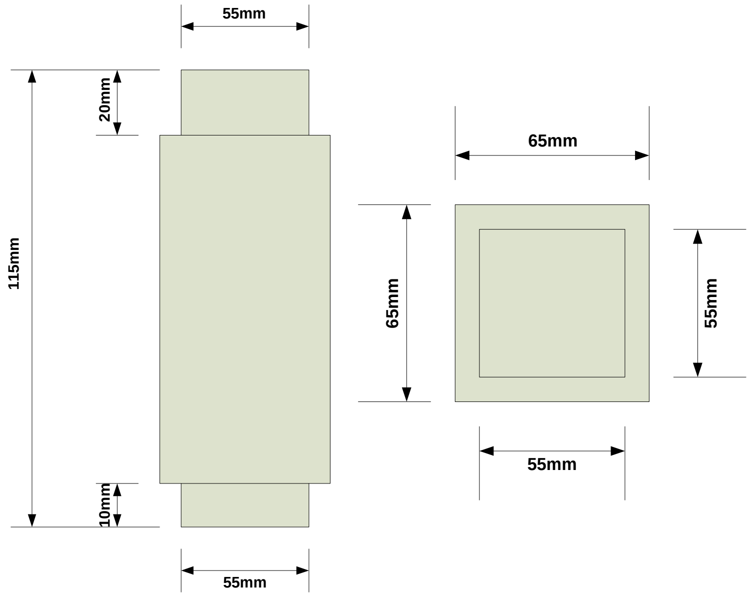


Figure 15: Dimensions of one can to the left side view. To the right top view.

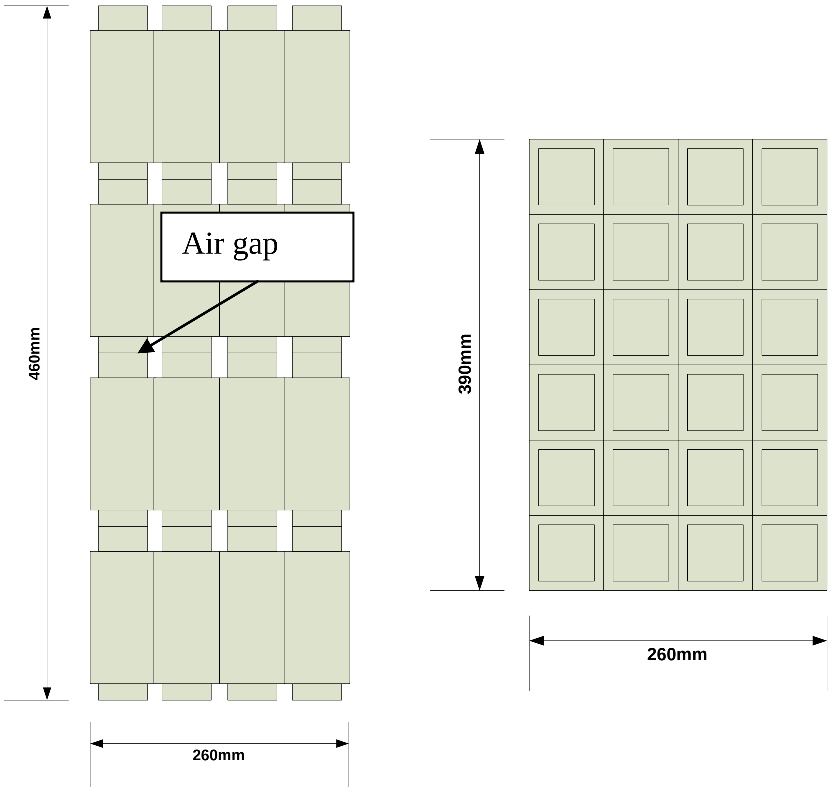


Figure 16: Total dimensions of closed packed cans. To the left side view. To the right top view.

The model of the impulse cooler with cans is shown in figure 4.

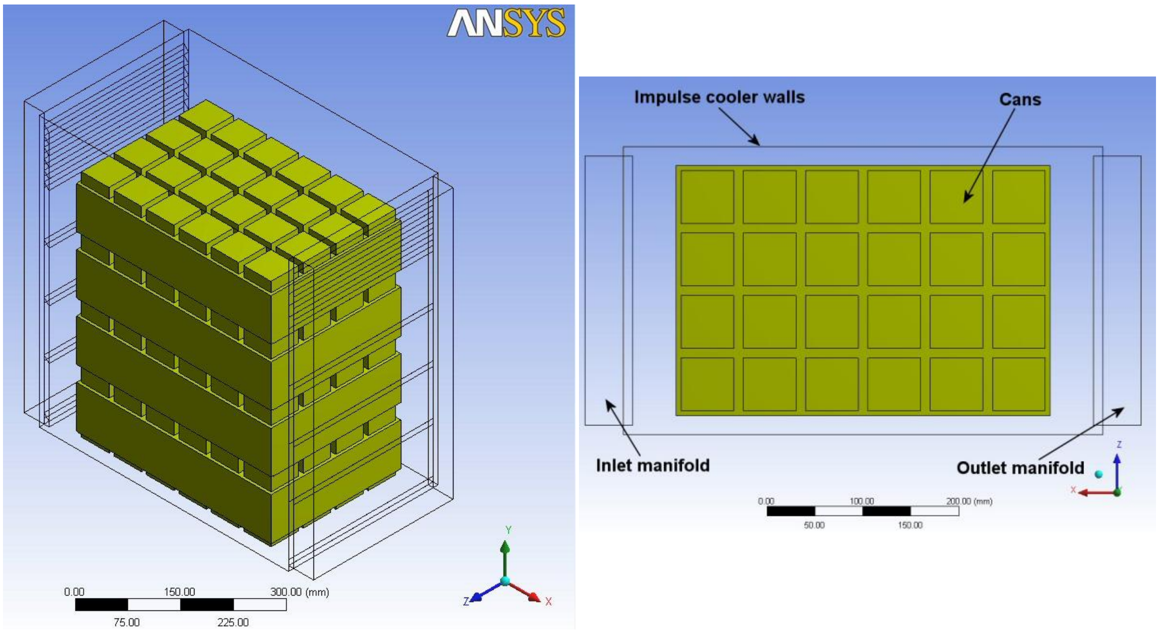


Figure 17: Impulse cooler with cans.

Results of the first simulations
Four simulations were carried out. One simulation was carried out on the original design and three simulations were carried out on three different design suggestions. A short description of the different designs is given below, see also figure 5 and 6.

- **Design 1:** 6 air gaps were evenly distributed across the entire height of the impulse cooler.

- **Design 2:** The 6 air gaps at the top from the original design were unchanged. 4 extra air gaps were added on both inlet and outlet manifold. All air gaps on the inlet and outlet manifold were equipped with covers.

- **Design 3:** The 6 air gaps at the top from the original design were unchanged. 4 extra air gaps were added on both inlet and outlet manifold. All air gaps on the inlet side were equipped with covers. The 4 new air gaps on the outlet side were not equipped with covers.

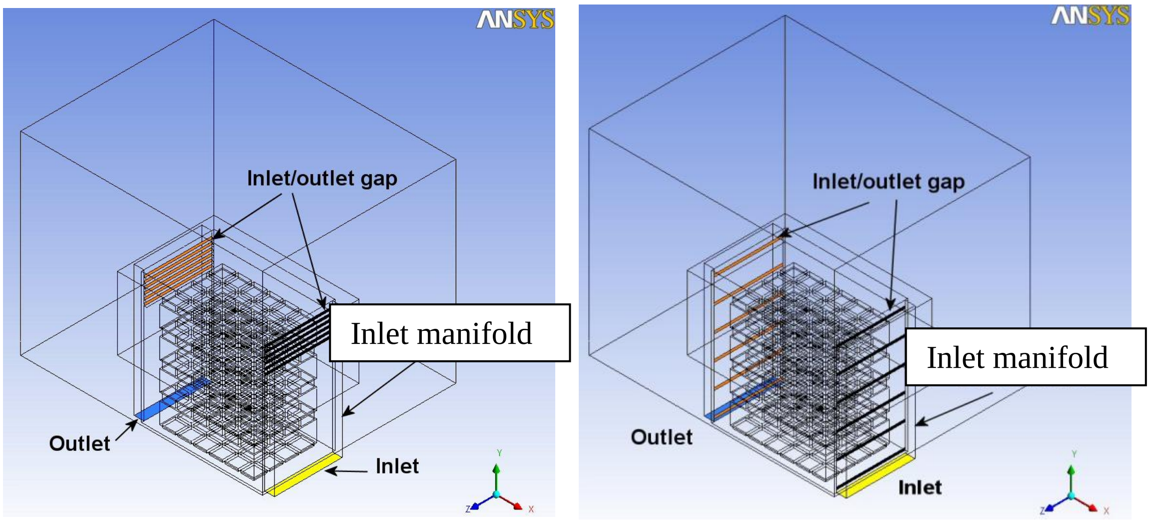


Figure 18: To the left the original design. To the right Design 1.

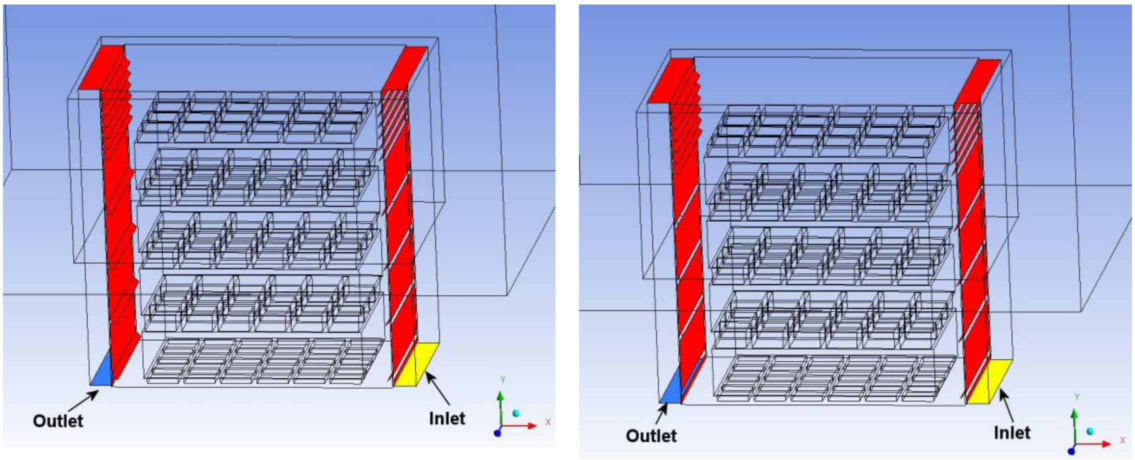


Figure 19: To the left Design 2. To the right Design 3.

Original design - Results

In figure 7 and 8 the temperature distribution and velocity profile is shown for the original design. The cooling capacity to compensate for the infiltration was 280 W.

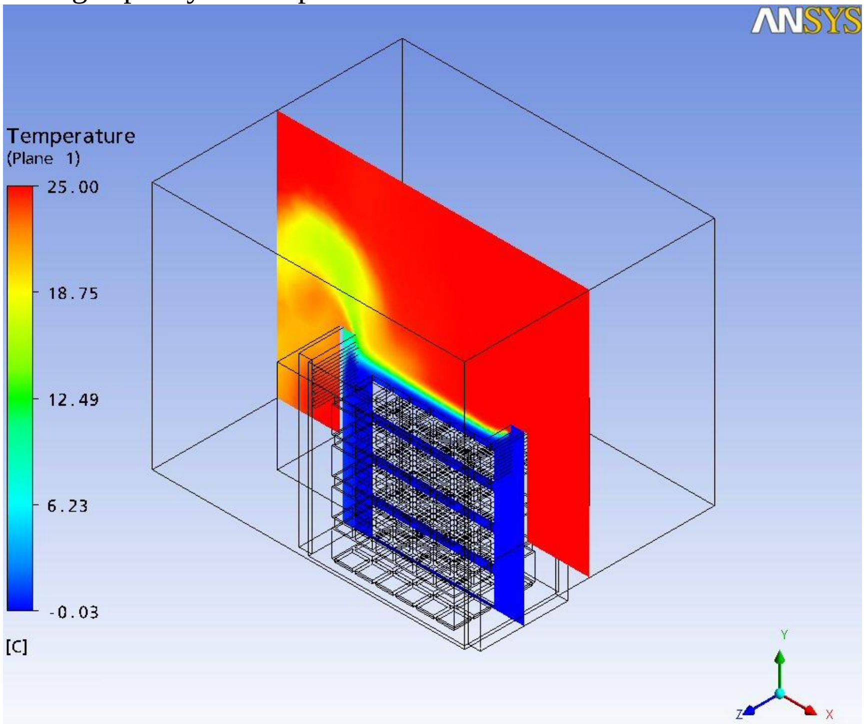


Figure 20: Original design temperature distribution.

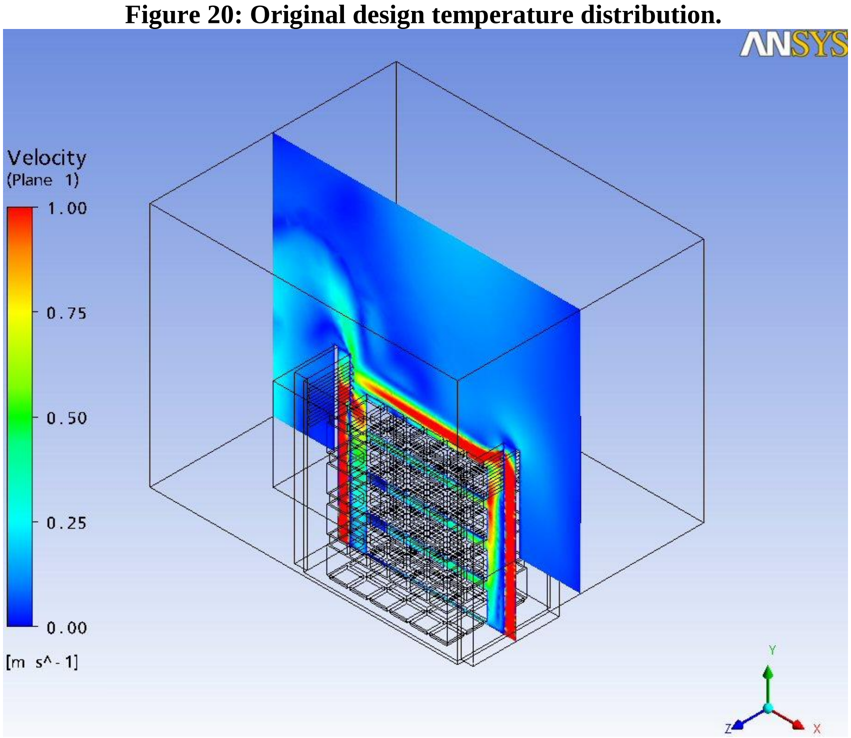


Figure 21: Original design velocity distribution.

Design 1 - Results

Design 1 with evenly distributed air gaps showed poor performance. The cooling air was pushed to the top causing an even larger infiltration. This was caused partly by the air flow direction in the inlet manifold (covers located on the inlet gaps might help), partly by the fact that the cans created resistance to the flow. The cooling capacity to compensate for the infiltration was 1400 W.

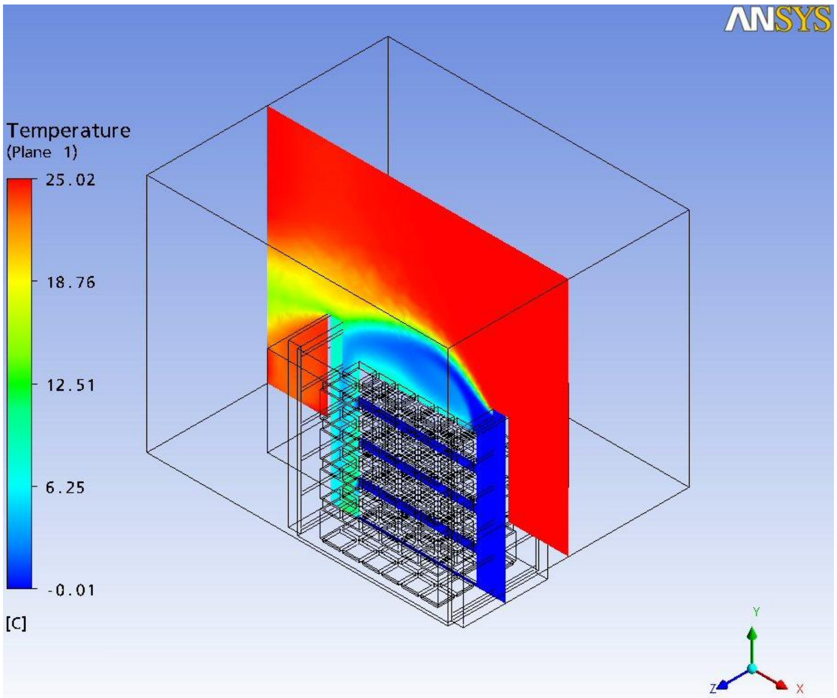


Figure 22: Design 1 temperature distribution.

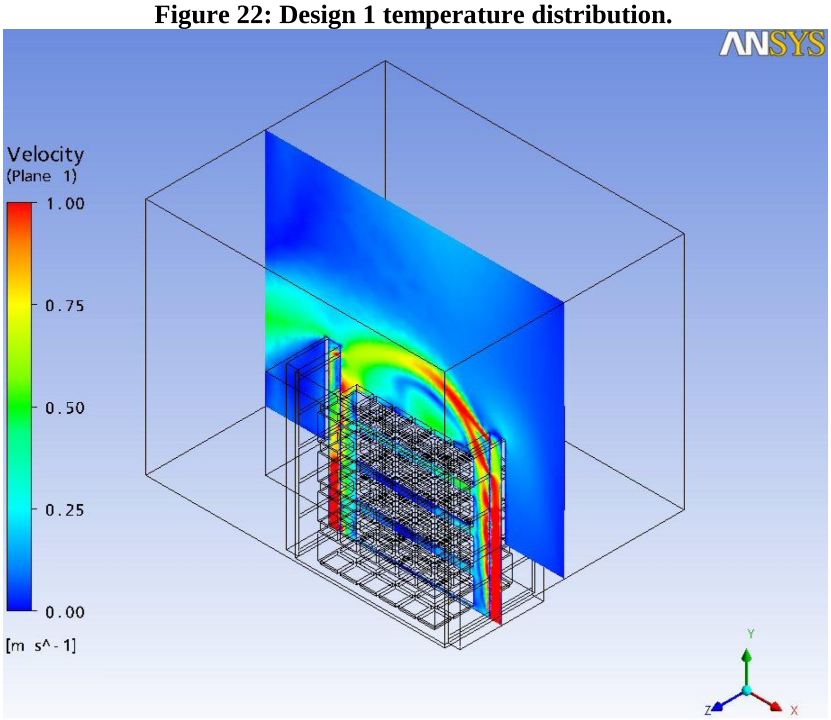


Figure 23: Design 1 velocity distribution

Design 2 – Results

As an attempt to evenly distribute the cooling air across the entire height of the impulse cooler, four extra air gaps were added. This means that less cooling air flew to the top of the impulse cooler, which means lower outlet velocities from the air gaps, lower turbulence and thereby lower infiltration. Design 1 showed that the inlet channels should be equipped with covers to prevent the cooling air from being pushed upwards; therefore all air gaps were equipped with covers. The cooling capacity to compensate for the infiltration was 235 W, i.e. reduction in relationship to the original design of approx.
45 W.

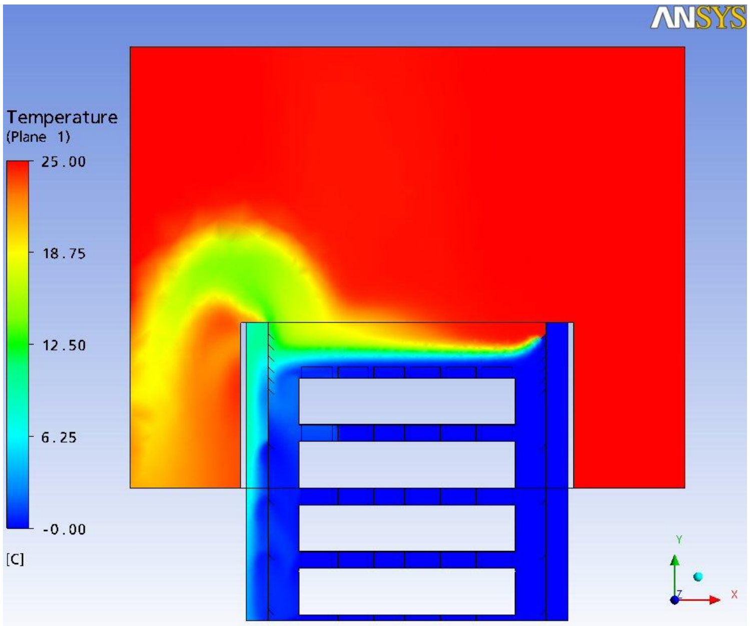


Figure 24: Design 2 temperature distribution.

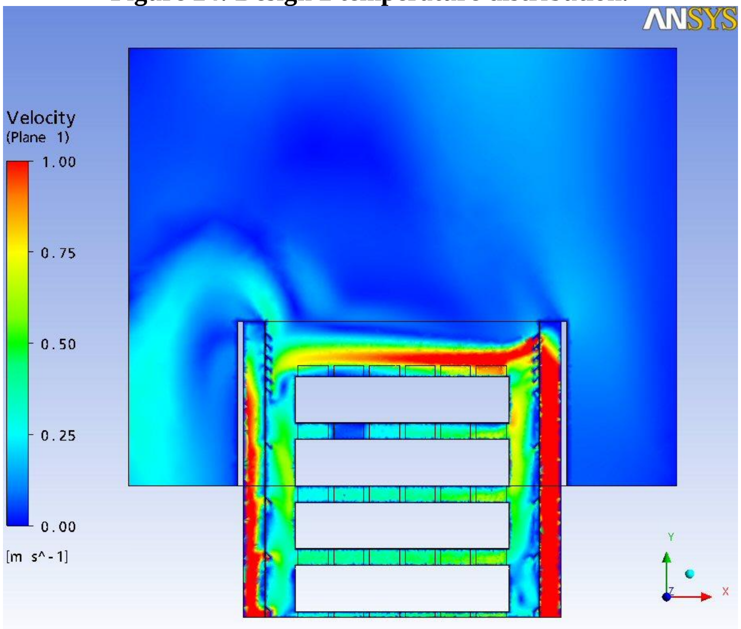


Figure 25: Design 2 velocity distribution.

Design 3 – Results

In this design all covers on the 4 extra air gaps on the outlet manifold were removed. This was done to reduce the inlet resistance to the outlet manifold and thereby push more air to the bottom. This turned out to have only a minor impact. The cooling capacity to compensate for the infiltration was 230 – 235 W, i.e. reduction in relationship to the original design of approx. 45-50 W.

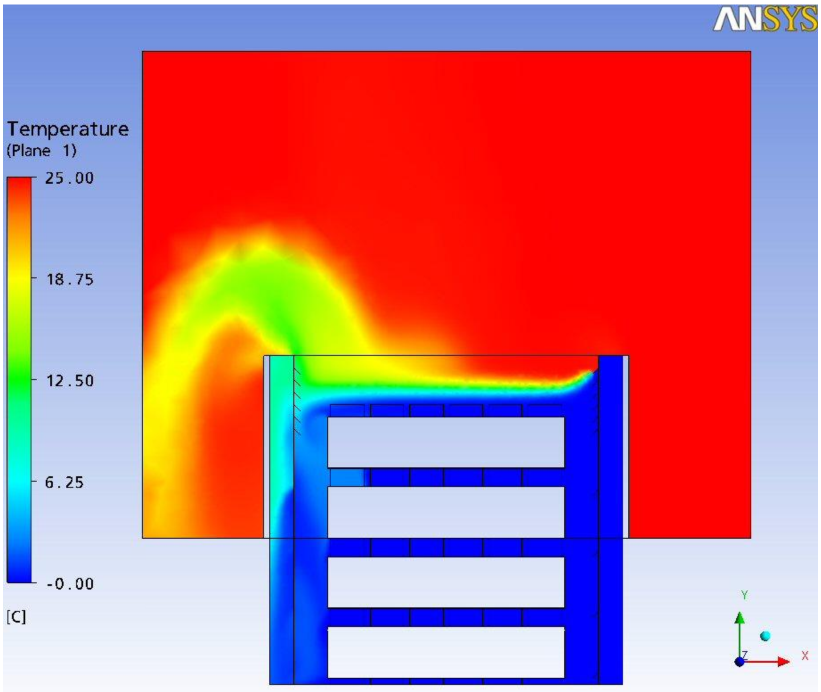


Figure 26: Design 3 temperature distribution.

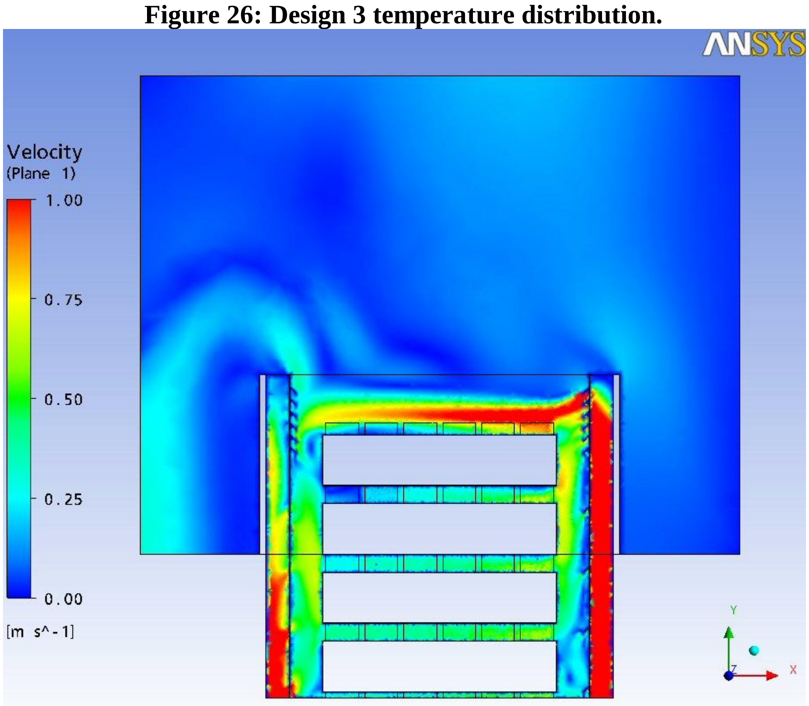


Figure 27: Design 3 velocity distribution.

Summing up

In table below the cooling capacities to compensate for the infiltration in the different design are shown:

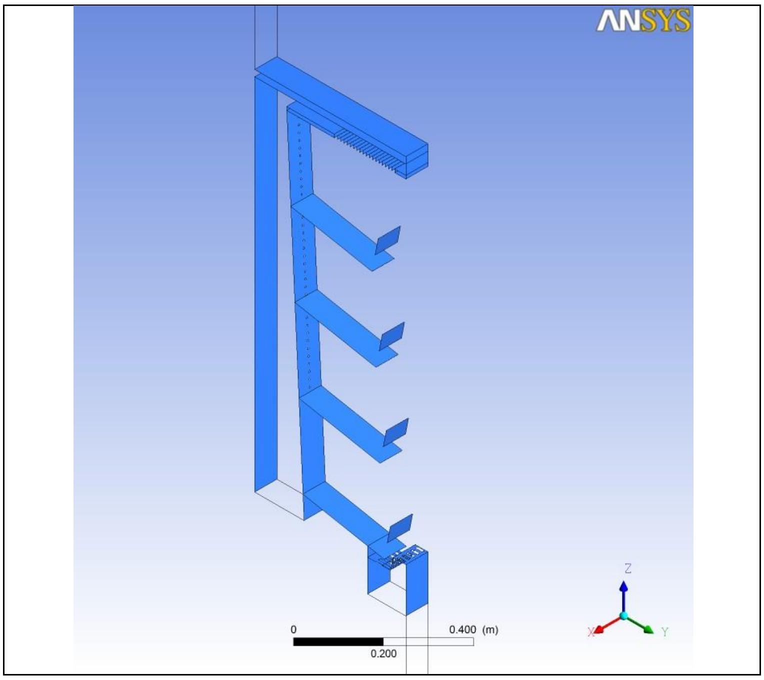
	Cooling capacity
Original	280 W
Design 1	1400 W
Design 2	235 W
Design 3	230 W - 235 W

C2: CFD calculations for vertical open cooler

This text is written by Bent Christensen, Vestfrost A/S. The calculations were made by Marcin Blazniak Andreasen, DTI

Summary:
There is a growing demand for open impulse coolers. This type of coolers has a high energy consumption. It is therefore important to optimize the construction so the energy consumption is as low as possible. This is a time consuming process, both building prototypes and testing them.
CFD calculations can shorten this process by indicating the best possibility to start with.
The open cooler with a vertical opening has the highest energy consumption. The CFD calculation shows that it is necessary with at least 100 mm from the bottles in front on the lowest shelf to the front of the cooler. In this area is the opening to the air outlet to the evaporator.
There shall be a fairly high air flow and shelves with closed bottoms to secure that the cold air is pushed all the way out to the front.
The airflow from the top doesn't have to be injected at a big distance from the bottles in the front.

Purpose:
CFD calculations on an open cooler with a vertical opening.
To see the influence on the temperature at the front and the outlet temperature with different smaller changes. The calculation was taken out on a small part of the open cooler.

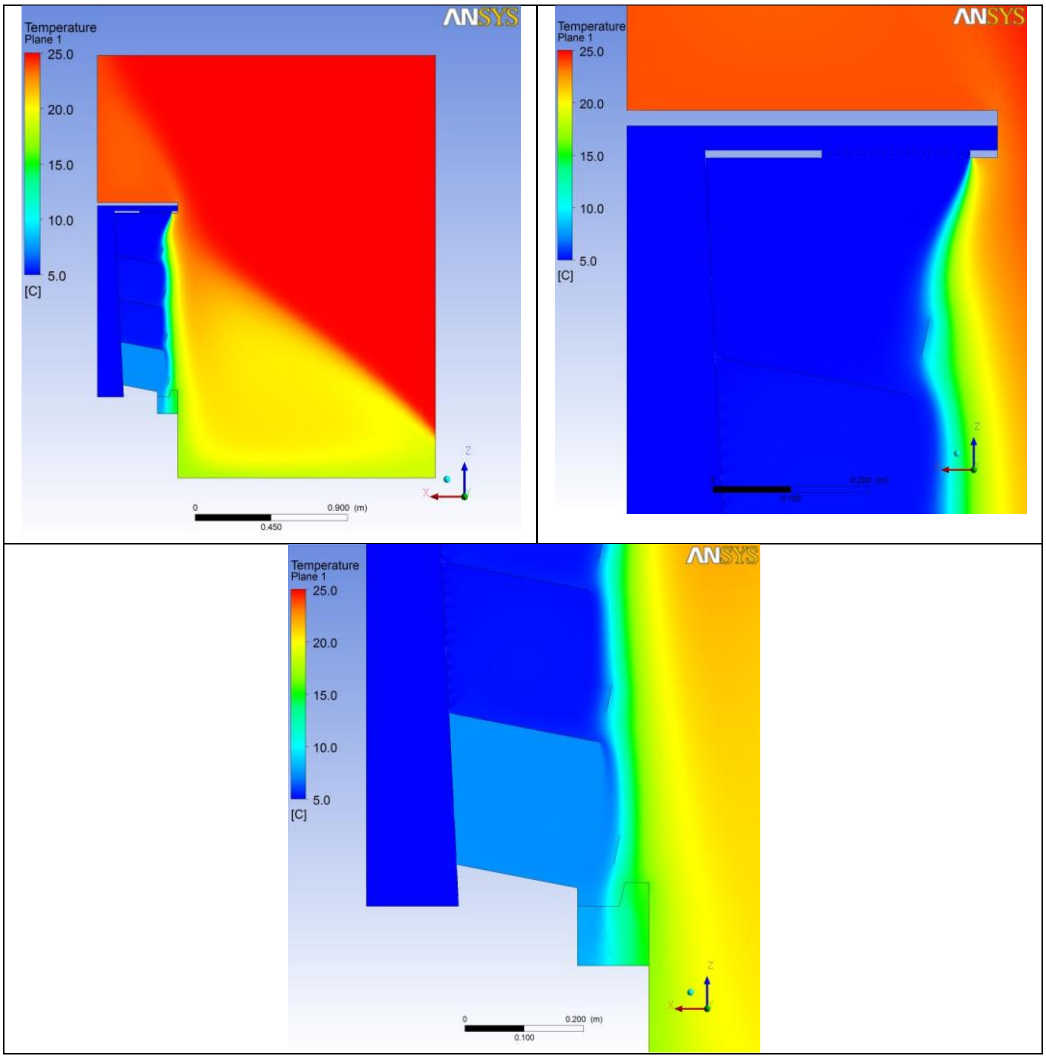


The calculation includes:

1) An empty cooler
2) A full cooler
3) Open shelf bottom
4) Closed shelf bottom
5) ¾ of the shelf bottom closed. Closed from the rear side towards the front
6) With different flow rates of air
7) With different distance from the front of the bottom shelf to the outlet of the air
8) With different distance from the front of the top shelf to the inlet of the air at the top front

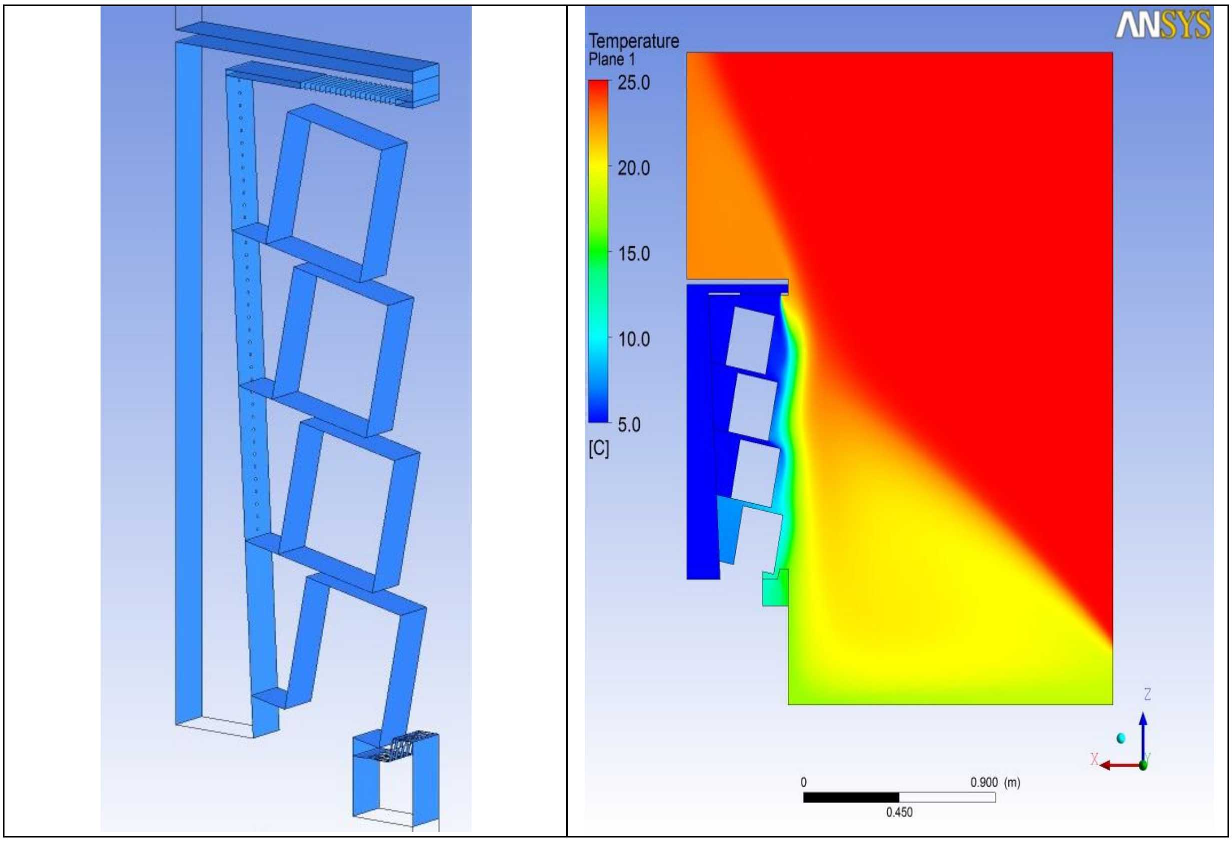
1) An empty cooler

The calculation is done with shelves with a completely closed bottom. There are no holes in the back at the lowest shelf. The air flow forms a fine air curtain. There is a flow of fairly cold air that ends outside the outlet to the evaporator and this will cost some energy and increase the intake of warm humid air. At the lowest shelf the temperature is higher because there are no holes in the back at the lowest shelf.



2) Test with a fully loaded cooler.

The square figure on each shelf indicates 4 x 0,5 l PE bottles. The square is completely air tight. So there is no airflow through the square. This is a little deviation compared to a shelf with more rows of real bottles.

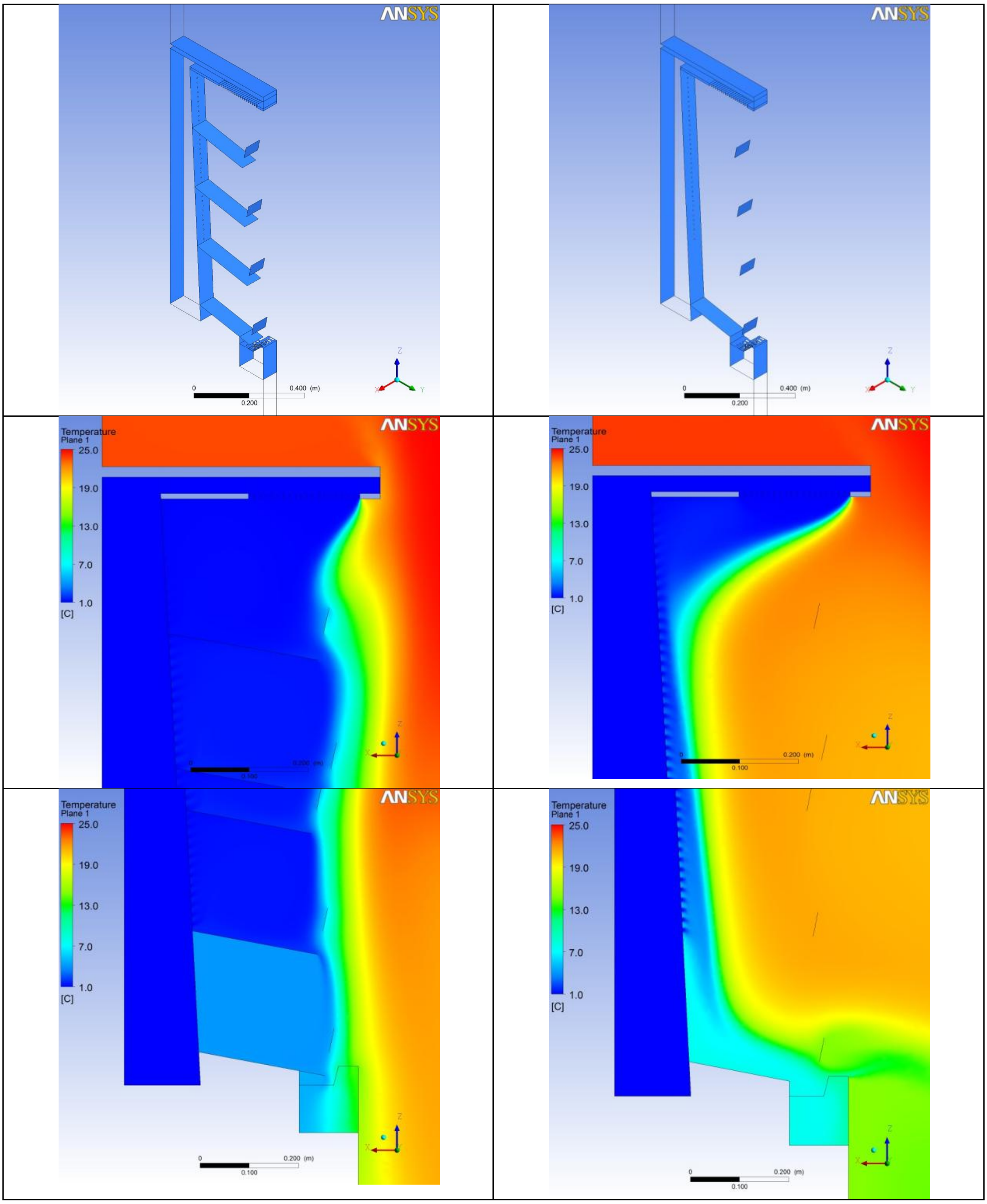


With a fully loaded open cooler the cold air passes down in front of the bottles on the top shelf so the bottles will stay cold even if the top of the bottles disturb the air curtain a little. At the bottom shelf the air that passes close to the bottles is about 5°C warmer than the inlet air.

There is some cold air (12 to 20°C) that passes down on the outside of the air outlet to the evaporator.

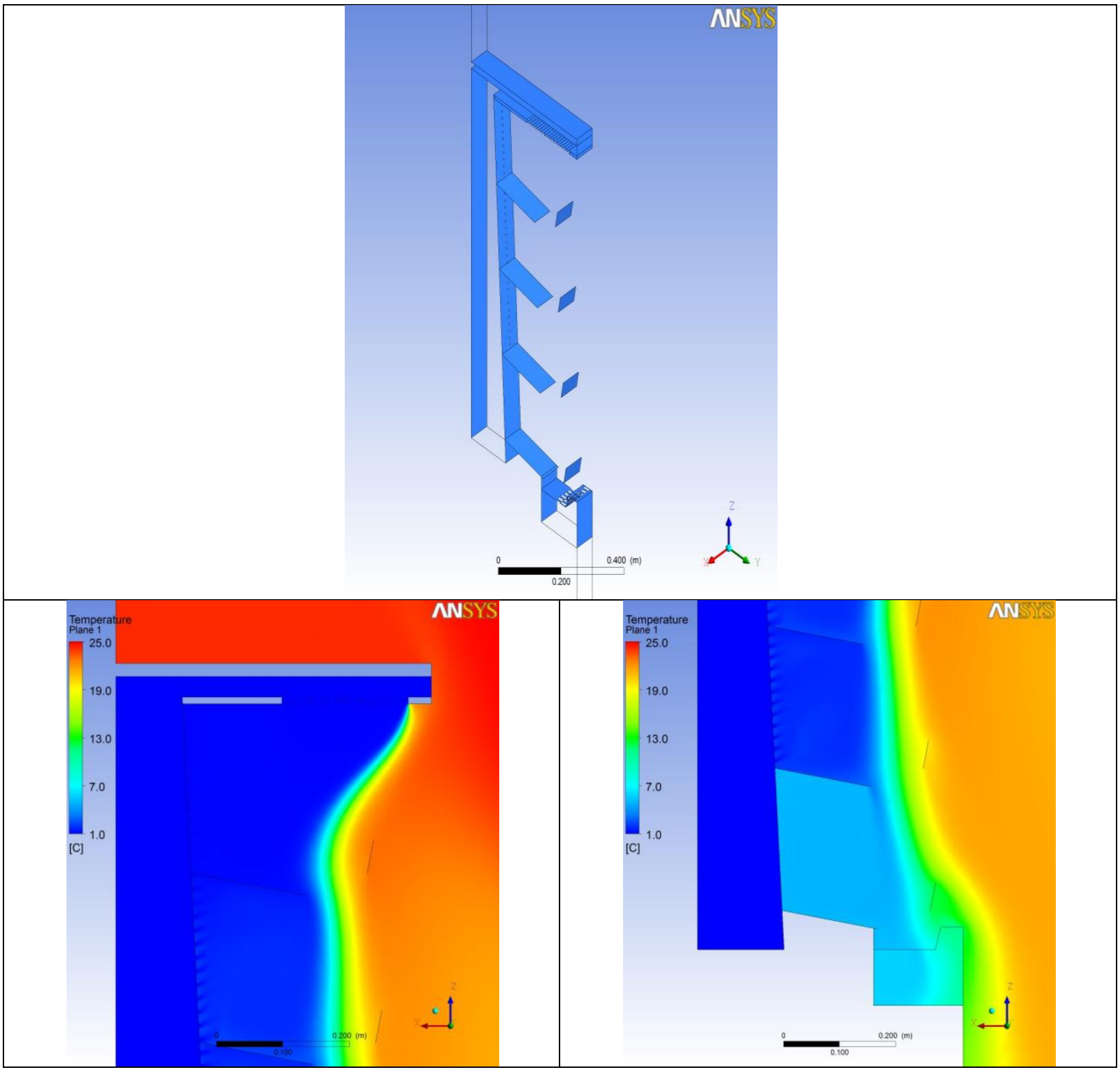
3) Closed shelf bottom

4) Open shelf bottom



On the appliance with closed bottom the empty room is still filled with cold air. On the appliance with open shelf bottom the empty room is almost filled with warm air. We have tested this and found that with shelves with open bottoms and only 1 row of bottles at the front of the shelves, the temperatures of the bottles was very warm. With shelves with closed bottoms the temperature of the bottles was significant colder.

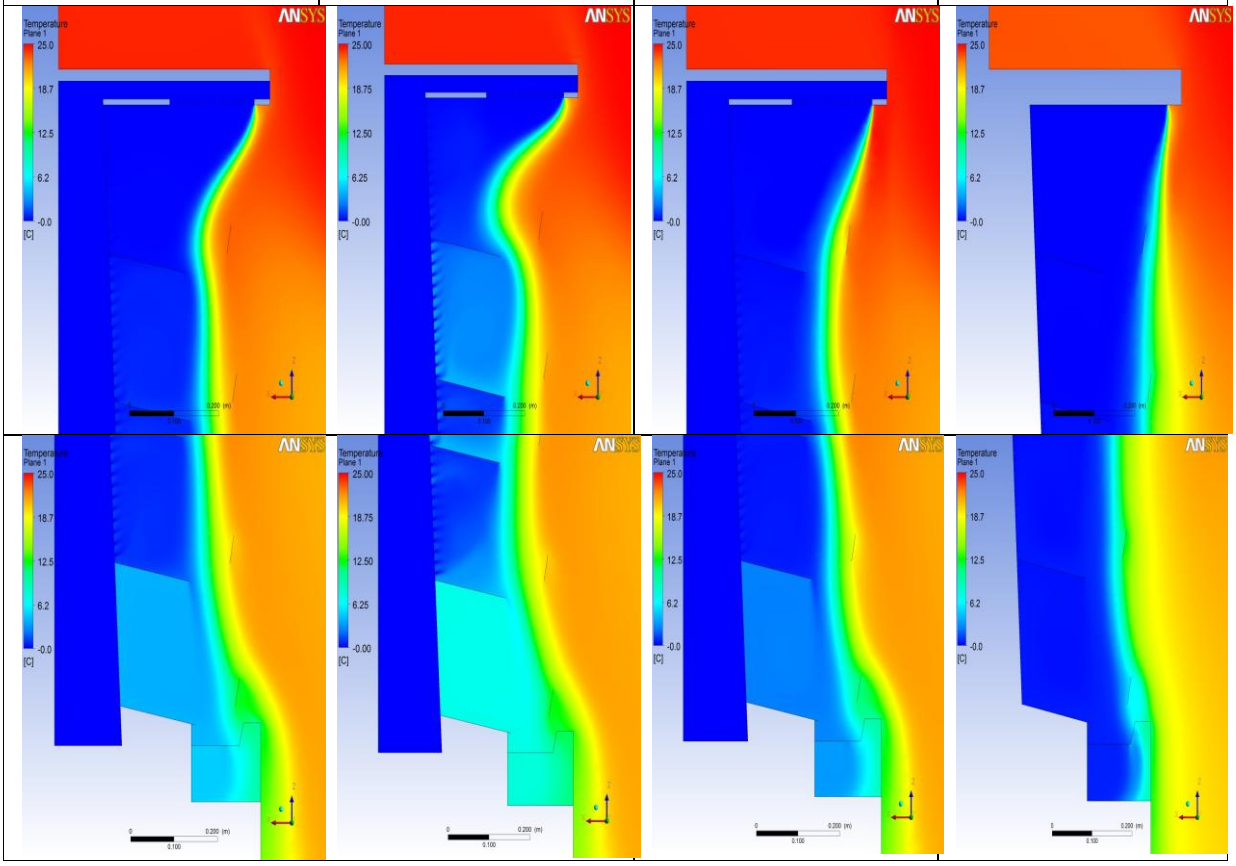
5) With shelf bottom ¾ closed:



It is seen that the warm air is limited of the closed bottom of the shelves.
Our tests have shown that with the actual construction, where the air outlet holes to the evaporator are so close to the bottles in front on the bottom shelf, it is better with ¾ closed shelves. The reason is that there is cold air that slides from the back to the front along the closed shelf bottom. This air cools the bottles at the front of the shelves without disturbing the air curtain much. With the full closed shelf bottom this air flow will disturb the air curtain.

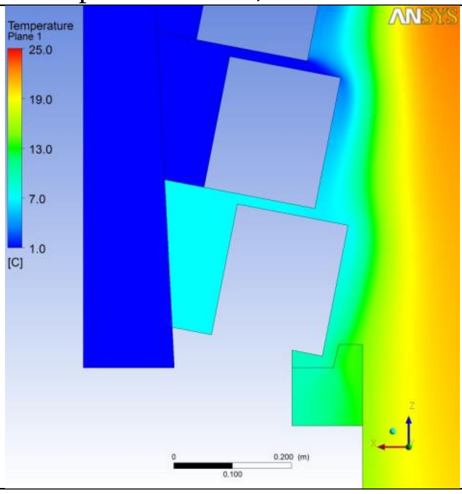
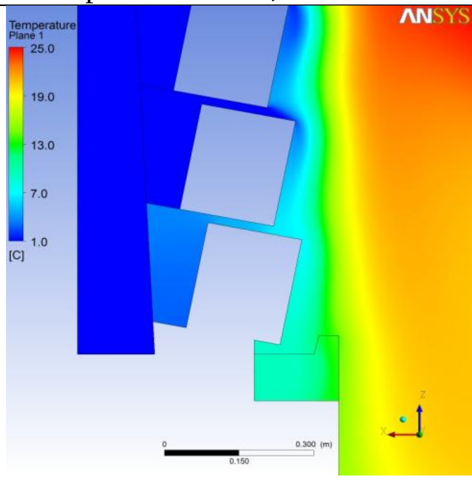
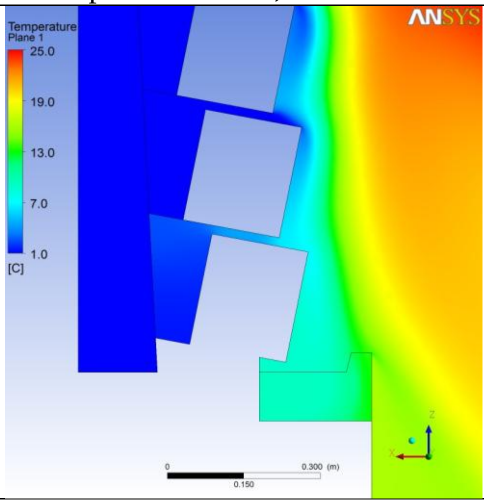
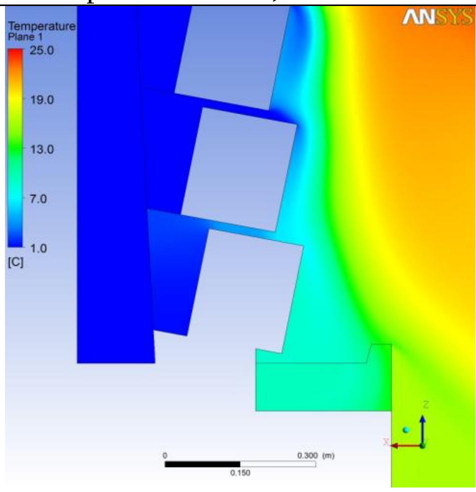
6) Test with different air flows on the cooler with ¾ closed shelves.

originally 800 l/min	600 l/min	1000 l/min	2000 l/min



Cooler. With bigger airflow the heat convection at the front rises.
Remark: The temperature at the air outlet to the evaporator did fluctuate with the higher flow rates and that could indicate that the calculations are not fully valid at 1000 l/min and 2000 l/min.

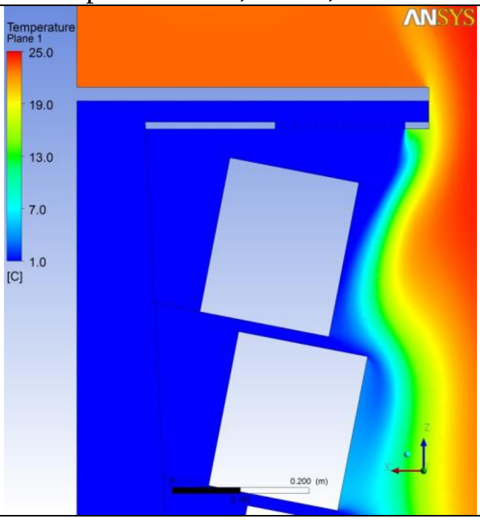
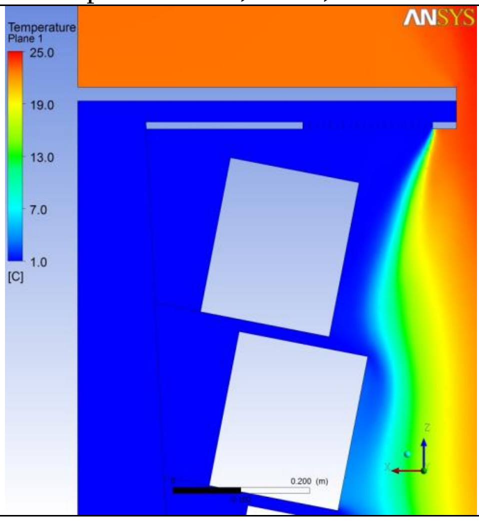
7) With different distance from the front of the bottom shelf to the outlet of the air

Original construction Outlet temperature: 11,47 °C	Outlet pushed 50 mm more out Outlet temperature: 11,19 °C
	
Outlet pushed 100 mm more out Outlet temperature: 10,91 °C	Outlet pushed 150 mm more out Outlet temperature: 10,91 °C
	

The temperature at air outlet decreases until the distance is 100 mm. From 100 mm to 150 mm the air outlet temperature is the same.

The air temperature at the bottles in the front of the two lowest shelves is about 6 °C warmer than at the inlet in the back. To lower the temperature in the front we have to increase the air flow. To maintain an undisturbed air curtain the 150 mm will be the optimized distance.

8) With different distance from the front of the top shelf to the inlet of the air at the front

<table>
<tr><td>Inlet pushed 40 mm out
Outlet temperature: 11,5 – 12,4 °C</td><td>Inlet pushed 80 mm out
Outlet temperature: 11,1 - 12,7 °C</td></tr>
<tr><td>
</td><td>
</td></tr>
</table>

The temperature in front of the bottles on the top shelf is not getting colder when the air inlet at the top is pushed out from the bottles. But the air curtain is contained inside the front of the cooler. In this way the air curtain is less influenced of air disturbances from outside the cooler.

Remark: The placing of the air inlet makes the temperature of the air outlet fluctuate more and this indicates that the calculation is not fully valid.

Enclosure: Test reports

The DTI has produced a test report for 18 tests of different impulse sales cooler (standard version + several prototypes). The test results are collected in one report: Report No I08-05, from 22nd June 2010.

The report is enclosed this report in PDF-version.