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Development of energy efficient sales freezers by using state-of-the-art compressors, natural refrigerants and low emissivity glass cover

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ABSTRACT

The introduction of Ecodesign criteria and energy labeling schemes in the EU has started a race for increasing the energy efficiency of commercial sales cabinets.
DTI has investigated the role of the refrigeration system and the cover glass for plug-in sales cabinets. Tests were conducted for cabinets with curved glass lids and for cabinets with horizontal flat glass lids.
By optimizing the refrigeration system and using a new compressor for R600a, the energy consumption was reduced by 24.5 %.
By installing a new glass cover with super low emissivity at the lower surface, the energy consumption was reduced by an additional 15,8 % compared to the prototype with new compressor. For horizontal glass, this creates a still layer of air under the glass which helps to reduce the heat transfer through the lids even more.
Static air freezers with horizontal lids with one layer of glass with super low emissivity coating insulate the cabinet like a solid lid or a night cover.
Keywords: Ice cream freezer, hydrocarbon, low emissivity coating, energy efficiency.

1. INTRODUCTION

The EU Ecodesign directive was adopted in 2009 with the aim of setting the criteria for the minimum energy efficiency for energy related products.
For refrigeration products, the life cycle analysis often concludes that the energy consumption during the lifetime of a given product is the most important environmental impact, in some cases followed by the emission of refrigerant with significant GWP value.
This is the reason why the draft regulation, which follows the study, mostly concentrates on improving energy efficiency. Recently, criteria for supporting repairability and circular economy are included in the regulations.
The energy labelling regulation and the ecodesign regulation for commercial sales cabinets (Ref 2 and Ref 3) were adopted in 2019 and vent into force in March 2021. It regulates supermarket sales cabinets, bottle coolers, refrigerated vending machines, and ice cream cabinets.
The ecodesign regulation will ban the most inefficient products and make it mandatory to inform about the energy efficiency of the products available on various webpages. This information must be based on testing of the products.
The energy labelling scheme (from A to G) is supposed to inspire to increase the energy efficiency of the products. When implementing the new energy labelling scheme, it is the strategy that the most energy efficient products are placed in energy class C, and no products are in class A and B in the beginning.
A new project with funding from the Danish organization ELFORSK and approved by the Danish Energy Agency was started in 2020 with the aim of investigating the effect of horizontal glass lids and an improved refrigeration system. The aim was to increase the energy efficiency by 15 %.

2. IMPROVED COMPRESSOR TECHNOLOGY

An existing ice cream freezer with glass lids was tested in the lab at DTI (Danish Technological Institute) in July 2020. The freezer has a net volume of 343 liters according to EN22043:2020 (Ref 1). The glass lids have a low emissivity surface at the underside with emissivity ε_{glass} = 0.11 according to datasheet from the manufacturer. This is representative for most top end cabinets at the market so far.
The basic model is equipped with a piston type compressor 14.65 cm3, and the system is charged with 80 g R600a.
An accredited test was done in the lab at DTI, and the energy consumption was measured to 2.483 kWh/day according to EN22043:2020. This corresponds to an Energy Efficiency Index (EEI) of 48.8 % according to Ref 2 and therefore energy class D (see Figure 1).
Analysis of the refrigeration system resulted in finding another compressor with better performance: a 14.77 cm3. A new freezer was built and again with 80 g of R600a.
Now the energy consumption decreased to 1.874 kWh/day. This is a reduction of 24.5 % and an EEI of 36.8 %.

Energy efficiency classes of refrigerating appliances with a direct sales function

Energy Efficiency Class	EEI
A	EEI < 10
B	10 ≤ EEI < 20
C	20 ≤ EEI < 35
D	35 ≤ EEI < 50
E	50 ≤ EEI < 65
F	65 ≤ EEI < 80
G	EEI ≥ 80

Figure 1: Tabel defining the energy classes for sales cabinets.

3. IMPROVED GLASS LIDS

During the last 15 years, there has been a tendency to use curved lids because they are supposed to improve the sale. However, curved lids create convection in the air below the glass and in some cases droplets on the upper surface.

In a previous project, tests were conducted with ice cream freezers with curved lids. When test is conducted after EN22043:2020, the temperature and humidity in the climate chamber is 30 °C and 55 % RH (climate class 4).

Due to convection under the lids, condensation took place in the front of the lids (see Figure 2).

Figure 2: Test of ice cream freezer with curved glass lids in climate chamber at DTI in 2019. Due to convection under the lids, condensation takes place upon the front part of the lids since the temperature is below the dew point. In this situation the condensation test has failed, and it would be necessary to heat the front frame to increase the glass temperature.

This freezer with curved glass lids has another size and is not directly comparable to the freezer with horizontal lids. The net volume was 256 liters, energy consumption 2.252 kWh/day and EEI = 52.3 % which corresponds to energy class E. The emissivity of the lower glass surface is $\varepsilon_{glass} = 0.11$.

To prevent condensation on the curved glass, it is necessary to heat the front frame with an electricity heater or a part of the condenser. Both methods will increase the energy consumption of the cabinet.

When the glass lids are horizontal it is much easier to prevent condensation. The reason behind this is that no convection takes place, and a still layer of air is placed just below the lids. This also helps to decrease the heat flux through the glass lids and thus helps to insulate the cabinet.

The introduction of super low emissivity surface enhances this effect.

First the basis model was equipped with a heavy insulation panel upon the glass lids with the aim of seeing the effect of using a “solid lid” or night cover (100 mm insulation foam).

Figure 3: The basis cabinet with a "night cover".

The result with the night cover was reducing the energy consumption from 2.483 kWh/day to 2.023 kWh/day, - a decrease of 18.5 % in the energy consumption.

In late 2021, it succeeded to archive samples of a quite new glass with "super low emissivity", declared to be ε_{glass} = 0.03 by the manufacturer. Samples were cut in the right dimensions by the glass manufacturer and send to the Danish manufacturer of cabinets, placed in the right frames, and send to DTI to be placed in the prototype (with the new compressor).

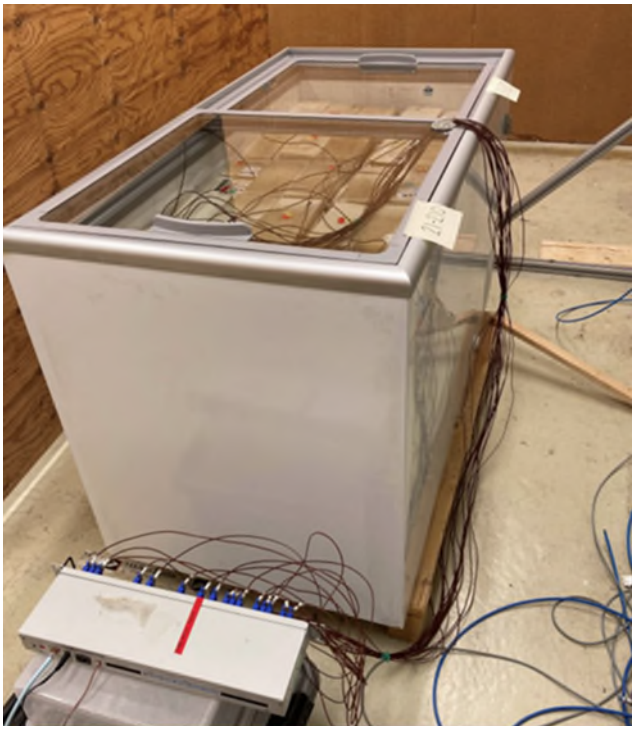


Figure 4: Prototype with the new glass lids during test at DTI.

When changing the glass lids, a sudden change in temperatures inside the cabinet was registered (see Figure 5).

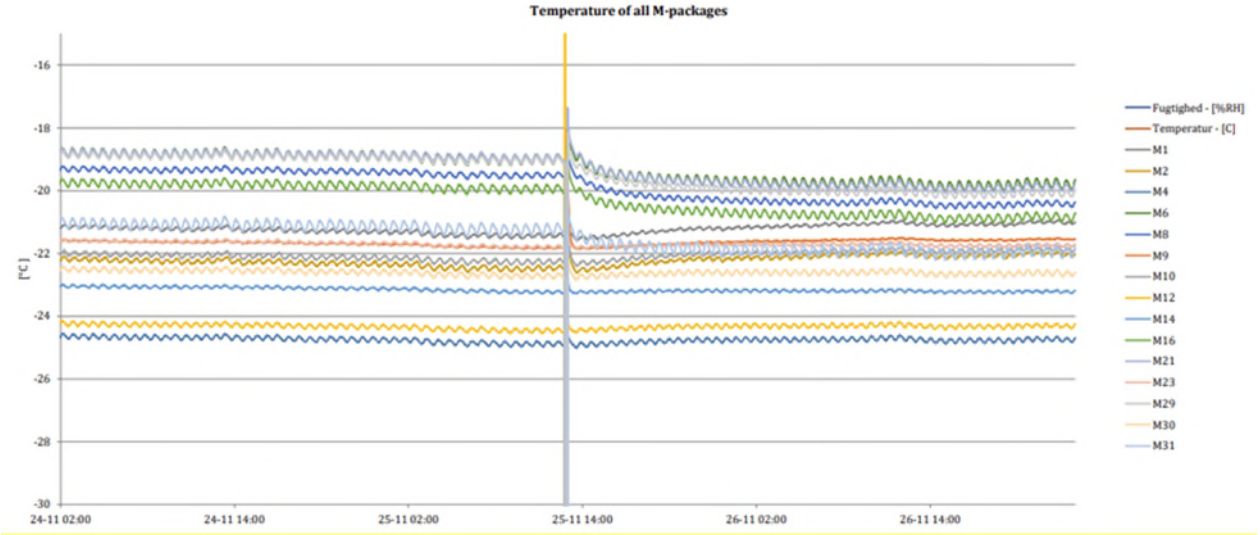


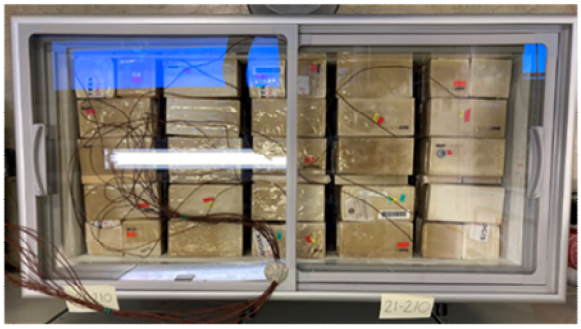
Figure 5: When changing the glass lids to the new "super low emissivity" glass it could be seen on the temperatures in the test packages inside the cabinet. Especially the packages in the upper part of the freezers became colder. A change in thermostat setting to reach the max. temperature of – 18 ^{0}C was done hereafter.

Test of the prototype with the new glass lids resulted in an energy consumption of 1.579 kWh/day, and the result is that the new glass lids reduced the energy consumption with 15.8 %.

The total energy consumption from the basic model to the prototype with new compressor and new glass was reduced from 2.483 kWh/day to 1.579 kWh/day, and this is a decrease of 36.4 %.

Now the EEI is 31.0 % (Energy Class C).

Elcold freezer



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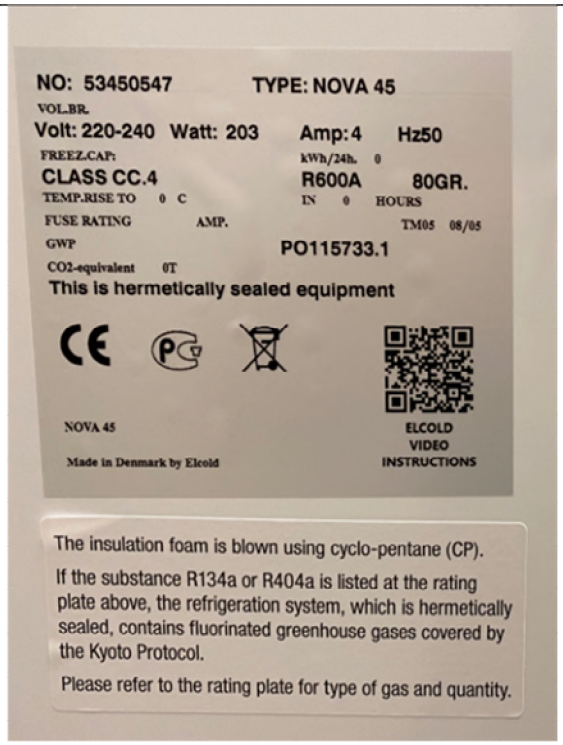

Rating plate

Compressor

Figure 6: Photos of the prototype with new glass lids and new compressor.

CALCULATION OF HEAT FLUX

During test after EN22043:2020, the freezer is filled with test packages up to the load line, which is defined by the manufacturer. In this case it is about 9 cm, and the experience in the lab at DTI is that this is a typical value for ice cream freezers.

Supposing that the air is still in the layer between the test packages and the glass lids, the heat flux (q) between the parallel surfaces can be calculated as, when we assume T_{glass} = 293 K, $T_{packages}$ = 255 K and $\varepsilon_{packages}$ = 0.95 (Ref 4):

$q = q_{conduction} + q_{radiation}$

δ is the distance between lids and test packages

λ_{air} is the heat conductivity of dry air (at 0 ^{0}C)

$q_{conduction} = \lambda_{air}/\delta * (T_{glass} - T_{packages})$

$= 0.0244$ W/mK/0.09m*38K = 10.30W/m^2

σ is Stefan-Boltzmann constant = $5.67*10^{-8}$ W/(m^{2}K^4)

$q_{radiation} = \sigma*(T_{glass}^4 - T_{packages}^4)/(1/\varepsilon_{glass} + 1/\varepsilon_{packages} - 1)$

In case 1, with $\varepsilon_{glass} = 0.11$:

$q_{radiation} = 19.48$ W/m^2

In case 2, with $\varepsilon_{glass} = 0.03$:

$q_{radiation} = 5.34$ W/m^2

The total heat flux between glass and test packages:

Case 1: q = 29.78 W/m^2

Case 2: q = 15.64 W/m^2

The heat flux through the lids is almost halved caused by improving the glass lids using super low emissivity coating.

4. DISCUSSION

Horizontal glass lids with super low emissivity at the lower surface can increase the energy efficiency and reduce the energy consumption of ice freezer cabinets.

After the introduction of EU Ecodesign criteria and energy labelling scheme it might be opportune for cabinet makers to “go back to” horizontal lids. Horizontal lids prevent convection under the lids, and a still layer of air is created during normal duty of the cabinet. This layer helps to insulate the cabinet.

The standard for upper end cabinets is using glass with coating with an emissivity of about 0.11.
By using single layer glass with a super low emissivity of 0.03, the effect is enhanced to almost be as good as a night cover.

This principle can also be used for other types of cabinets like supermarket cabinets. Some people would maybe feel that horizontal lids are old fashioned and might reduce the sale of food. On the other hand, there have before been similar changes in supermarket cabinets e.g., from open to closed cabinets, and now most users have accepted the closed cabinets and the effect of sale is minor.

Glass with super low emissivity coating can also be used for curved/inclined lids, but the effect will be relatively smaller because some convection will take place. The same will be the case in cabinets with forced air flow.

According to additional costs: The new energy efficient compressor costs approximately additional 20 % compared to other efficient compressors. The new super low emissivity glass is quite new, and the additional price is not yet quite clear.

5. CONCLUSION

The refrigeration system and the role of the cover glass have been investigated for plug-in ice cream freezers. Tests were conducted for cabinets with curved glass lids and for cabinets with horizontal flat glass lids.

By optimizing the refrigeration system and using a new compressor for R600a, the energy consumption was reduced by 24.5 %.

By installing a new glass cover with super low emissivity at the lower surface, the energy consumption was reduced by an additional 15,8 % compared to the prototype with new compressor. For horizontal glass, this creates a still layer of air under the glass which helps to reduce the heat transfer through the lids even more.

Static air freezers with horizontal lids with one layer of glass with super low emissivity coating insulate the cabinet similar to a solid lid or a night cover.

During the last 15 years, there has been a tendency to use curved lids because they are supposed to improve the sale. However, curved lids (or inclined lids) create natural convection in the air below the glass and in some cases dew on the upper surface and therefore a need for heating the glass. The tendency with curved glass might be rolled back (to some degree) after the implementation of the EU energy labelling scheme.

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