

New Generation of Professional Kitchen Appliances with Natural Refrigerants and Reduced Energy Consumption

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1. Abstract

A new generation of professional kitchen refrigerators and freezers has been developed, tested and marketed in co-operation with the manufacturer Gram Commercial A/S and Danish Technological Institute.

The new appliances use propane (R290) as refrigerant and considerable electricity savings have been achieved by:

- a) using new and more efficient compressors
- b) using more efficient fans and introducing a new control strategy for the evaporator fan
- c) using hot compressed gas for evaporating defrost water
- d) changing the design in order to reduce the heat flow around the cabinet gasket region.

The project was supported by funds from the Danish Energy Agency.

The development project focused on 600 litre cabinets, and the "old" models (one refrigerator and one freezer) were tested in the lab at DTI. Static and dynamic simulation models were developed and used for the design of prototypes. Prototypes were built at Gram Commercial A/S and tested at DTI. 10 new freezers and 10 new refrigerators were built and installed in professional kitchens. DTI installed them and 5 + 5 "old" models with meters. This field-test was carried out in the course of one year, measuring electricity consumption, temperature inside and outside the cabinet, the number of door openings and the accumulated time of door openings.

The results of the field-tests were quite good. The electricity consumption of the freezers was reduced by 47% (from 8.53 kWh/day to 4.54 kWh/day). The energy consumption of the refrigerators was reduced by 74% (from 6.26 kWh/day to 1.62 kWh/day). The technology developed in this project has also been implemented in other appliances and they are now in production.

2. Introduction

The project has been conducted in a co-operation between a producer of professional kitchen appliances and the Danish Technological Institute (DTI). There are many different products for professional kitchens, but single-door upright refrigerators and freezers are the most popular and therefore formed the basis of this development project. These units have an integrated refrigeration system and a solid door.

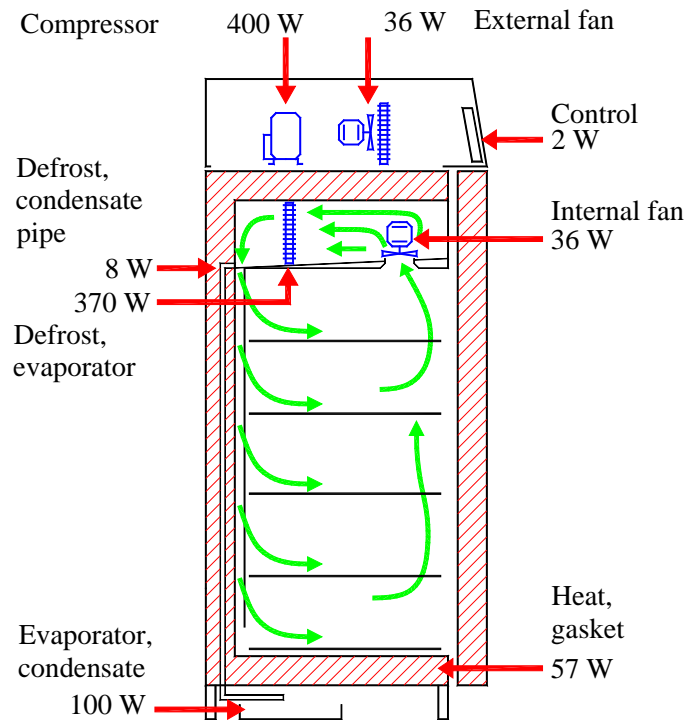


Figure 1: This figure shows the principle behind the “old” cabinets. The effect (in Watt) is also shown and the figures are valid for the relevant component when it is active.

The project was supported by funds from the Danish Energy Agency and the main objectives were to:

- reduce electricity consumption by at least 35% compared to "old" models
- change refrigerant to hydrocarbons
- maintain (or increase) the cooling capacity
- develop an up-to-date and competitive product.

The outer dimensions were to be maintained and therefore the insulation thickness is the same in the old and in the new units. The old cabinets were blown with R134a, and with the installation of new foaming machines at the Gram company cyclopentane is used in the new cabinets.

At the beginning, the project was based on cabinets with net volume of 506 litres – “the 600 cabinets”, but on the request from a group of potential users the cabinet with net volume of 563 litres – “the 660 cabinet” became the basis of the project. This latter cabinet is the most popular and the best-selling cabinet in Denmark. The two types of cabinets are almost identical, the refrigeration systems are identical and the only difference is that the latter cabinet is 15 cm taller than the first cabinet.

The initial tests and the calculations were based on the “600-cabinet”, but in the end lab-tests and field-tests were based on the “660-cabinet”. The “old” cabinets were installed with an

electrical heater to evaporate defrost water, and this heater (100 W) is active synchronous with the compressor. The “old” freezer is installed with an electrical heater (57 W) around the door to prevent condensation outside the door gasket.

3. Method

The project has been divided into five parts:

- Test of the “old” cabinets
- A theoretical part (model, simulations and recommendations)
- Construction of prototypes and test in lab
- Field-test of 10 new refrigerators and 10 new freezers + a reference group
- Reports and information.

The “old” cabinets were tested in the Refrigeration Laboratory at Danish Technological Institute. A climate chamber for testing according to EN441 was used for the tests, which were conducted at climate class C (+25 °C, 60 % RH) with no door openings. This test condition was common practice at the production company.

A dynamic simulation programme was developed for both the freezer and the refrigerator with the objective of:

- developing a model that agrees with the measured results
- investigating alternative solutions related to cooling capacity and electricity consumption
- testing the new control strategy.
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Also other computer based calculation programmes were used; especially a finite element programme (FEM) was used to find a new construction with the objective of reducing the electrical heater around the door in the freezer.

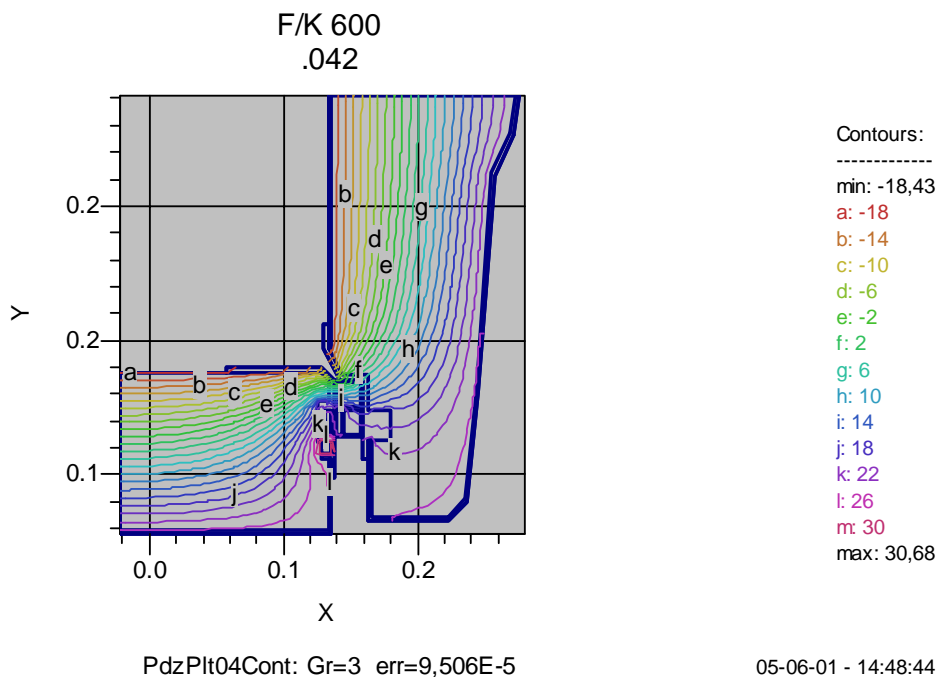


Figure 2: Example of computer simulated isotherms in the door sealing in the freezer using a new construction and a smaller heating element. Such calculations created the basis for the new construction of the sealing of the freezers. The figures to the right represent temperatures in [°C]. The main task was to prevent condensation outside the cabinet.

4. Choice of refrigerant and compressors

By using the simulation programme new concepts were chosen for the freezer and the refrigerator. The first main task was to choose the refrigerant in the new generation of cabinets. In the “old” cabinets two different refrigerants were used: R134a in the refrigerators and R404A in the freezers.

R290 (propane) was chosen as refrigerant for the new cabinets as it is possible to use only one refrigerant for both freezer and refrigerator. The service car then only needs to bring one bottle of refrigerant in the future. Only about 100 grams of R290 were used in the new freezer as well as the refrigerator.

5. Heating element around freezer door

As mentioned, the “old” freezer is equipped with a 57 W heating element around the door to prevent condensation outside the cabinet. A finite element programme was used to test a number of alternative constructions and the placing of the gasket and heating element (see figure 2).

The calculation ended with a new construction and a new placing of the gasket and heating element reducing the electrical heating to 15 W and reducing the heat transfer into the freezer cabinet.

6. Evaporator and condenser

Only minor changes were made for the evaporator and condenser. The “old” condenser had “flat” (oval) pipes that were changed to round circular pipes so the requirements to pressure when changing to R290 could be fulfilled.

7. Fans and new control strategy for evaporator fan

A lot of work was carried out to find new and more efficient fans. Especially the efficiency and energy consumption of the evaporator fan is very important. The energy consumption must be “paid for twice”, since the heat has to be removed again by using the refrigeration system.

In the first prototypes, DC-fans were used because they have better efficiency, but in the end they were replaced by AC-fans because of noise problems with the DC-fans. The most efficient DC-fans were chosen, and improvements were made inside the cabinet to ensure a good air distribution. This was done by modifying the air duct at the rear end of the inside cabinet.

A new control of the evaporator fan was introduced. In the “old” cabinets the fan runs continuously - not only in the ON-period but also in the compressor OFF-period. This is to ensure that the thermostat immediately registers if warm food is placed in the cabinet. This strategy results in a high consumption of energy. The new strategy is based on the evaporator fan only running periodically in the compressor OFF-period. Every fifth minute the fan starts and runs for one minute. If necessary, the compressor starts. Otherwise, a new standstill period of five minutes arises. This strategy results in considerable energy consumption savings.

The evaporator fan in the “old” refrigerator was a 36 W type. This ended up being a 10 W fan (with better efficiency). The condenser fan was changed from a 36 W to a 20 W type fan. The evaporator fan in the “old” freezer was also the 36 W type. In the last prototype and in the field-test series a 20 W type was used. This type turned out to be unstable in some units

(for unknown reasons) and the fan has been changed to the original type until a solution arises for the 20 W type.

8. Evaporating defrost water

In the “old” cabinets a 100 W electrical heating element runs synchronous with the compressor. In the new cabinets this has been changed to a hot gas evaporation system. A small box in the rear end collects the defrost water, and the hot gas pipe leads to the box and evaporates the water. This functions well.

In the field-test it turned out that a problem occurred in extreme situations (for refrigerators with many door openings) and the energy content in the hot gas was not sufficient to evaporate the condensate. Therefore, an additional system is activated if the box is filled with water. A floater activates a heating element.

Component	Standard (600-cabinet)	0-series (660-cabinet)
Compressor	FR7.5G	TL5CNK (Danfoss)
Refrigerant	R134a	R290 (propane)
Volume (brut.)	600 litres	660 litres
Condenser	STVF14121 (665 W dT 15 K)	STV9227 (1025 W dT 15 K)
Condenser fan	1 x 36W	1 x 20W
Evaporator	7 rows	6 rows
Evaporator fan	1 x 36W	1 x 10W
Defrost	0W	0W
Pipe heater	0W	0W
Evaporating defrost water	100W	0W (hot gas)

Table 1: Specification of key components in the refrigerator. Later on, an additional heater was installed so the condensate could evaporate if the box is filled.

Component	Standard (600-cabinet)	0-series (660-cabinet)
Compressor	SC12CL	SC12CNX (Danfoss)
Refrigerant	R404A	R290 (propane)
Volume (brut.)	600 litres	660 litres
Gasket heater	57W	15W
Condenser	STVF14221 (1000W)	STV7321 (780W)
Condenser fan	1 x 36W	1 x 20W
Evaporator	7 rows	6 rows
Evaporator fan	1 x 36W	1 x 20W
Defrost	1 x 350W	1 x 350W
Pipe heater	8W	8W (during defrost)
Evaporating defrost water	100W	0W (hot gas)

Table 2: Specification of key components in the freezer. Later on, the evaporator fan was changed to the old type due to defects in the new one.

Old door/sealing	+ 42 %
Old defrost water evaporating system	+ 16 %
Old condenser fan	+ 4 %
Old evaporator fan	+ 31 %
Old pipe heater	+ 7 %
Old condenser	- 1 %

Note 1: This analysis was based on a 10 W heater for evaporating water, later on this was improved by using hot gas for evaporating the water

Note 2: In this analysis a 10 W evaporator fan was used. Later on the “old” 20 W fan was used again because of fault on the new one. Later on the new control strategy was implemented and saving electricity

Table 3: Analysis of significance of different changes. The figures show what would happen if the change did not take place. If the old door/sealing were used, the electricity consumption would increase with 42 % etc.

9. Testing prototypes

A first-generation of prototypes was built after the results from the “old” cabinets and computer simulations had been analysed. This first-generation was based on the old cabinets, the old control strategy and the old defrost water evaporation system. The cabinets were tested in the climate chamber at climate class C and the results were analysed.

The second-generation of prototypes was based on the new design around the door, the new control strategy for the evaporator fan and the new evaporation system. The cabinets were tested and the results were analysed and compared with results from the simulation programme.

10. O-series

11 new refrigerators and 11 new freezers were built, based on the second-generation of prototypes. This 0-series also had a new design on the front, created by professional designers. The 0-series is based on the “660”-cabinet. One new refrigerator and one new freezer were tested at in the climate chamber at Danish Technological Institute and the results are shown in table 4.

[kWh/day]	“Old type” (600-cabinets)	0-series (660-cabinets)
Refrigerator	2.7	0.8
Freezer	7.8	3.3

Table 5: Results from tests in climate chamber (EN441, 25 °C, 60 % RH, no door openings).

11. Field-test

A field-test was conducted with the purpose of:

- measuring the energy consumption in real use
- finding teething problems in the new cabinets
- comparing energy consumption with the “old” cabinets.

The 10 new refrigerators and 10 new freezers were placed in kitchens in Copenhagen, Odense and near Vejle. A reference group of 5 + 5 of the old cabinets were found in the same area. The “old” units were installed recently (a maximum of one year).

The old and the new appliances were placed in canteens, restaurant kitchens and schools. Two of the freezers were placed at a McDonalds restaurant and two more were placed as research freezers. 2 “old” and 2 new refrigerators were placed at Odense University Hos-

pital, and they had a considerable number of door openings (each up to 200 per day). All units in the field-test were equipped with instruments measuring energy consumption, number of door openings, temperature in the cabinet and temperature in the ambient. The test was conducted for one year and in the beginning Danish Technological Institute visited all the cabinets every month to read meters and to see if teething problems occurred. Later on visits were made every third month.

In the first three months a couple of teething problems were found, including defects on the evaporator fan in the freezer and too much condensate in the refrigerators at Odense University Hospital (units with many door openings).

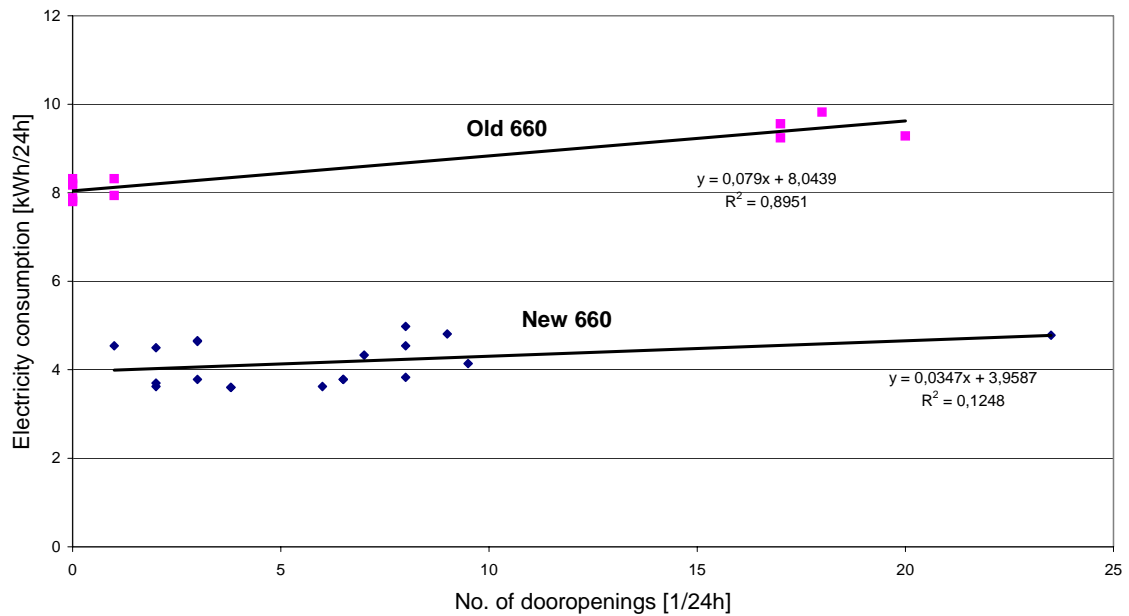
[kWh/day]	Refrigerator K660	Freezer F660	Freezer, corr.
Old model	6.26	8.53	
New model	1.62	4.17	4.54
Savings	74 %	51 %	47 %

Table 4: Results from field-test for one year of "old" and new refrigerators and freezers. The "freezer corr." is a calculated correction of the measured value, if the new evaporator fan is changed to the old fan, which took place when defects were found in the new fan.



Figure 3: Photo of the new cabinet. The compressor and condenser are placed in the top.

Electricity consumption vs. dooropenings



Electricity consumption vs. Door openings

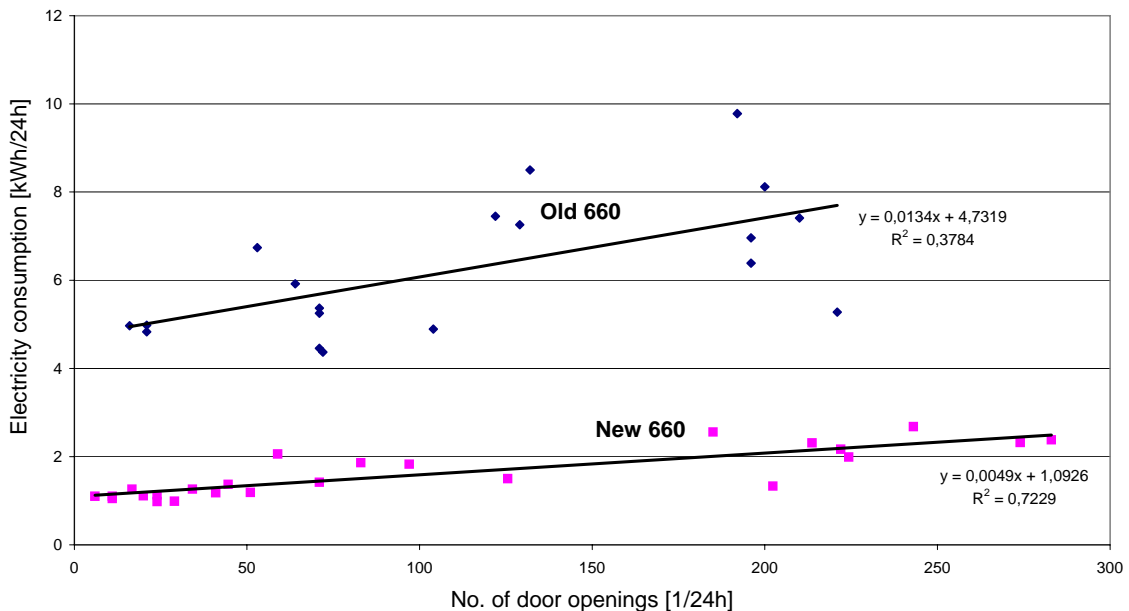


Figure 4: Electricity consumption vs. door openings for the freezers

Figure 5: Electricity consumption vs. door openings for the refrigerators

12. References

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