PROMOTION OF ENERGY EFFICIENT DISPLAY CABINETS

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ABSTRACT

To promote energy efficient commercial refrigeration, NUTEK of Sweden has staged a competition for indirectly cooled vertical display cabinets. The primary target was to decrease the use of electricity while retaining sales performance and fulfilling requirements on product temperature.
Annual electric input was stipulated to be lower than 2600 kWh/m cabinet (25 % less than the best result of a market screening test). The winner achieved 1745 kWh/m, 50 % less than the best screening result. The direct electric input to this cabinet, i.e. to fans, lighting and frame heating, was down to less than half the screening level. Nevertheless, it still had the highest value of illumination. The new designs have much improved night coverage, reducing problems with air infiltration. Furthermore, attention to coils and air curtains permit operation with a warmer brine. This reduces temperature gradients as well as defrosting and total energy input.

INTRODUCTION

NUTEK, from 1998 reorganized as SE (the Swedish National Energy Administration), has used technical procurement competitions successfully to promote energy efficiency in products such as heat pumps, refrigerators, water heaters, air handling units and control systems. Traditional promotion of efficient equipment may have draw-backs by increasing public expenditure and conserving high equipment costs. Competitions, on the other hand, do not introduce subsidies and address the issue by stimulating market interest through publicity and improved technology and/or economy. Also, an important part of NUTEK's philosophy has been to co-operate closely with companies having a market influence. These companies promote the winning equipment and will endeavour to install a minimum number of units. A contract for these installations also forms the first prize. Hence, the number of units go up, prices go down and energy will be saved at little extra cost for society.

Since refrigeration is responsible for approximately half the use of electricity in the commercial sector, this is also an area suitable for such competitions. In particular, multi-deck vertical cabinets are common and use a lot of energy and hence this type of equipment has been in the focus for a long time. Furthermore, for reasons of flexibility, indirect refrigeration systems tend to dominate in new installations. Thus it was decided to stage a competition for five-deck, indirectly cooled vertical display cabinets. The initial planning started already in 1992.

1 COMPETITION

As a first step, a screening test was carried out to assess the present state of the art by testing 6 cabinets according to prEN 441. This test was extremely important in that it provided experience in using the EN-standard, which was being developed at that time, as well as input regarding thermal quality and energy use of current cabinets. Axell and Fahlén (1995) have presented the results and back-ground of this stage, which concerned 5 indirectly cooled 5-deck cabinets and one DX-unit.

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1.1 Scope

The scope of the competition was to find the equipment with the best balance between energy efficiency, life-cycle cost, thermal storage quality, environmental aspects, sales performance and ease of maintenance. Focus was obviously on energy efficiency and it was decided to strive for a reduction by at least 25 % compared to the best result of the screening test. The same cabinet should be able to function with different types of products in terms of temperature classes between +8 and +5 °C maximum temperature and it should have a load capacity exceeding a minimum value. For the sales performance, visual impression was also considered important.

1.2 Requirements

Backström and Westman (1997) have described the conditions of the competition. The following rules and requirements applied:

- *Type of display cabinet*
  Indirectly cooled, 5 deck, vertical display cabinet with a length of 2.5 meters and a loading volume of at least 400 dm^3 per meter.
- *Thermal range of product*
  For reasons of flexibility, the cabinet should be able to operate with acceptable efficiency during ambient conditions according to climate class 2 (see ambient climate below) and:
  -Temperature class S1 with a maximum of +8°C and a minimum temperature of -1°C (Sweden)
  -Temperature class M2 with a maximum of +7°C and a minimum temperature of -1°C (EN 441)
  -Temperature class M1 with a maximum of +5°C and a minimum temperature of -1°C (EN 441)
- *Range of ambient climate*
  -Winter conditions (climate class "special"): dry bulb temperature 20°C, relative humidity 51 %.
  - Summer conditions (climate class 2): dry bulb temperature 22°C, relative humidity 65 %.
- *Refrigerating equipment*
  For the purpose of calculations, the necessary chiller was assumed to operate with an evaporation temperature 5 K below the outlet brine temperature. The cooling coefficient of performance then related to the brine temperature according to: $COP_c = 0.1 \cdot t_{b,out} + 2.4$.
- *Energy efficiency*
  The annual electric input required to comply with the requirements of temperature class S1 must be less than 2600 kWh per meter cabinet and the aim was to come below 2000 kWh. The input was calculated using data from laboratory tests made by SP (Swedish National Testing and Research Institute) according to EN 441-1994 and the already stated standardized efficiency for the refrigerating equipment. A reference year was used consisting of 40 days with climate class 2 (summer) and 325 days with climate class "special" (winter).
  Electric energy is split between indirect and direct input to the cabinet. The indirect input relates to components outside the cabinet such as the chiller and a pump to circulate the secondary coolant through the cabinet. Pumps and fans in the chiller are included in the value of COP_c. The direct input pertains to fans, lighting, defrosting and frame-heating in the cabinet itself.
- *Environmental aspects and safety*
Recycling must be possible of at least 75 % of the materials in the cabinet. The cabinet must comply with the CE requirements.
- *Lighting*
  The cabinet should be equipped with lighting that provides an illumination of at least 750 lux.
- *Operating instructions*
  The competitors should supply the following operating instructions:
  -Method of defrost, the number of defrosts and criteria for starting and stopping defrosts.

-Volume flow and inlet temperature of the brine (secondary coolant).
-How to load the cabinet in order to efficiently use the space while still complying with EN 441.
-Set-values of thermostats.

1.3 Deviations between the competition and the screening test

One of the lessons learned during the screening test was that most cabinets were sold without defrosting or control equipment. Therefore the brine temperature and method of defrosting were prescribed. However, for new designs these parameters are major factors affecting the energy efficiency. Therefore the choice was left open in these matters for the actual competition. Furthermore, the temperature class M1 was not included in the screening test. Finally, the test standard changed from prEN 441-1993 to EN 441-1994 but this change did not influence the tests.

2 TEST PROGRAM

Axell and Fahlén (1995) have described the test program in some detail. SP tested all cabinets according to EN 441-1994 using chemically pure propylene glycol and water as the secondary coolant. The concentration was 38 % by weight, yielding a freezing point of around -20°C. Figure 1 shows the lay-out of the test installation.
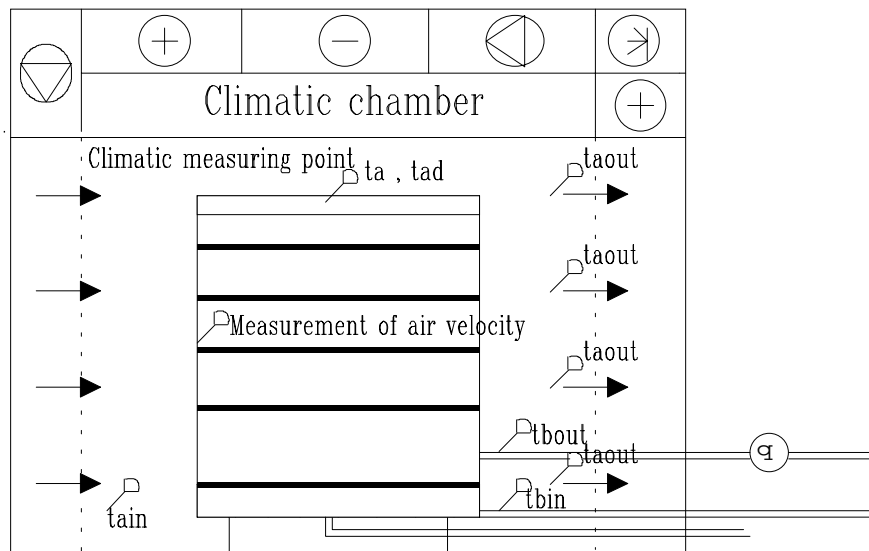

Figure 1. Lay-out of the test installation with the positions of sensors defining the test condition.

The diurnal test sequence consisted of 12 hours of day-time operation with night covers removed and the lighting in the cabinet switched on. Then followed a period of night-time operation with the night-covers on and lighting switched off (paragraph 3.8, EN 441-5:1994, 2nd test). Using this sequence, three tests were made on those cabinets left in the final round.
The two first tests comprised the temperature class and climates prescribed for calculating the energy used during a reference year, i.e. temperature class "special" for the product (+8°C) and climate classes 2 (+22°C/RH 65 %) and "special" (+20°C/RH 51 %). The third test condition consisted of temperature class M1 (+5°C to - 1°C) and climate class 2 (+22°C/RH 65 %). The product load was simulated by means of commercially available test-packages in accordance with EN 441:4. Some packages were also equipped with T-type thermocouples to measure temperature (M-packages). Figure 2 indicates the position of these packages.
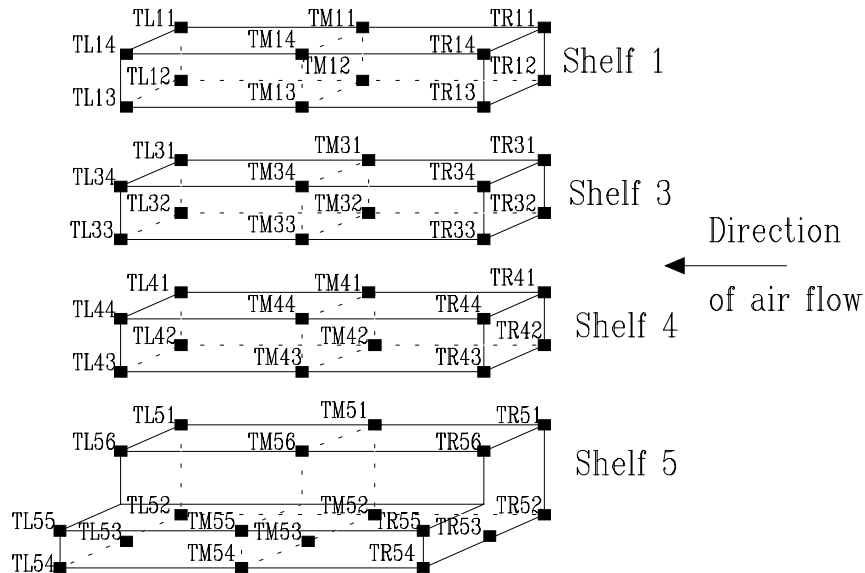
Figure 2. Designations used to locate the measuring packages (M-packages).

3 RESULTS

All competitors used different designs, air distribution techniques, defrost methods and control strategies. The winner, from Electrolux CR AB, had the highest brine temperature, which implies a low cooling requirement, a high total COP_c, and little frosting of the cooling-coil.

3.1 Results with winter conditions

Table 1 provides mean values of capacities and temperatures from tests with winter conditions.

Table 1. Winter conditions (20°C/51 %RH), temperature class S1.

Quantity	Unit	Present state of the art				Winner
		A	B	C	D	E
P_c	(kW)	1.86	2.13	2.13	1.39	0.91
P_e	(W)	258	251	202	139	64
P_{defr}	(kW)	**	**	**	**	*
$t_{b,in}$	(°C)	-8.1	-8.1	-7.8	-8.1	-1.5
t_{max}	(°C)	7.8	10.4	10.2	8.3	7.9
Position	-	TL55	TL14	TL34	TM55	TM54
t_{min}	(°C)	2.1	1.1	2.2	2.4	3.1
Position	-	TL31	TM52	TM32	TR52	TL11
t_1	(°C)	3.6	5.1	5.5	4.4	5.8
t_3	(°C)	4.5	4.8	5.9	4.1	6.2
t_4	(°C)	5.0	4.6	5.9	4.0	6.3
t_5	(°C)	5.4	5.0	5.7	4.4	6.2
t_{vis}	(°C)	4.8	5.5	6.2	4.7	6.4

* Defrosting was not necessary.

**Defrosting continued longer than necessary but still $t_b < t_a$, so part of P_{defr} adds to P_c.

Figure 3 compares the mean values of the cooling requirement during day-time with the requirement during day-and-night operation. The diagram also includes the direct electric input.
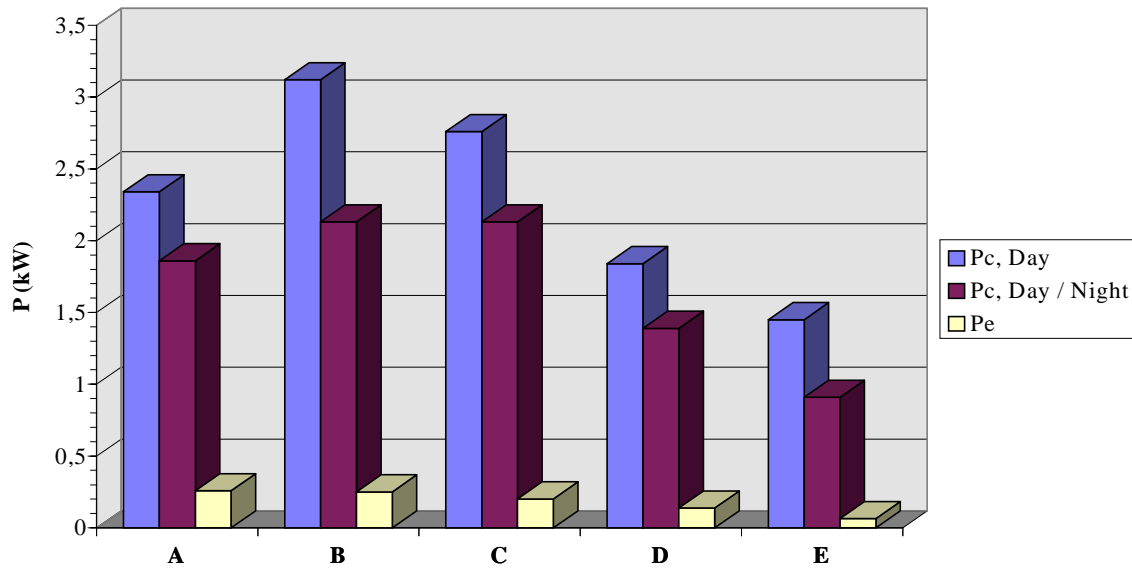

Figure 3. Winter conditions (20°C/51 %RH): Comparison of day-time cooling requirement and the diurnal (day/night) cooling requirement and direct electric input. A-D represent the screening test and E represents the winner.

3.2 Results with summer conditions

Table 2 provides mean values of capacities and temperatures from tests with summer conditions.

Table 2. Summer conditions (22°C/65 %RH) , temperature class S1.

Quantity	Unit	Present state of the art				Winner
		A	B	C	D	E
P_c	(kW)	3.31	2.72	2.97	1.88	1.50
P_e	(W)	257	252	203	139	64
P_{defr}	(kW)	1.72	**	**	**	*
$t_{b,in}$	(°C)	-8.2	-8.1	-8.0	-8.1	-1.7
t_{max} Position	(°C) -	7.6 TL55	12.0 TL13	9.9 TL34	9.2 TL14	7.5 TR54
t_{min} Position	(°C) -	-0.9 TL31	1.2 TL32	2.7 TL31	1.9 TR11	2.1 TM12
t_1	(°C)	1.4	5.8	5.8	4.4	5.0
t_3	(°C)	2.8	5.4	5.9	3.9	5.4
t_4	(°C)	3.4	5.2	6.1	3.7	5.7
t_5	(°C)	4.4	5.6	5.9	4.2	5.6
t_{vis}	(°C)	5.6	6.2	6.4	4.6	5.7

* , ** See comments to table 1.

Figure 4 compares the mean values of the cooling requirement during day-time with the requirement during day-and-night operation. The diagram also includes the direct electric input.
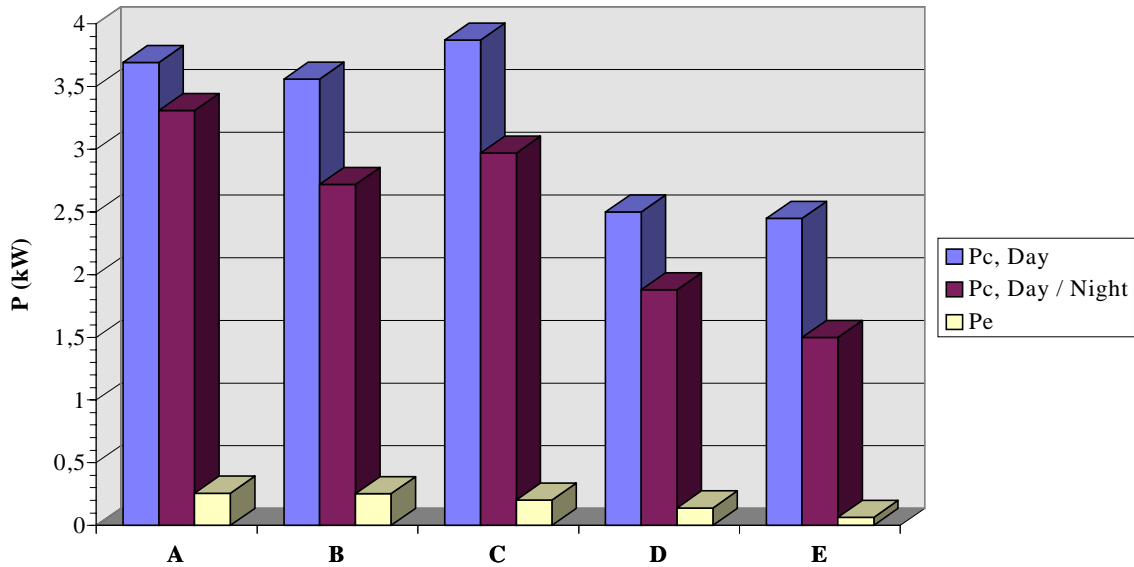
Figure 4. Summer conditions (22°C/65 %RH): Comparison of day-time cooling requirement and the diurnal (day/night) cooling requirement and direct electric input. A-D represent the screening test and E represents the winner.

3.3 Calculated annual use of energy

Figure 5 compares the calculated annual use of energy for the winning cabinet (E) with the results of the screening test. W_e is the direct electric energy used and W_c is the energy required by the refrigeration system (compressor, pumps etc.). It is apparent from the diagram that the winning cabinet is a substantial improvement. In fact, comparing this cabinet with the requirements of the European energy labelling scheme (Elefsen et al, 1995) it would most likely go straight into class A.
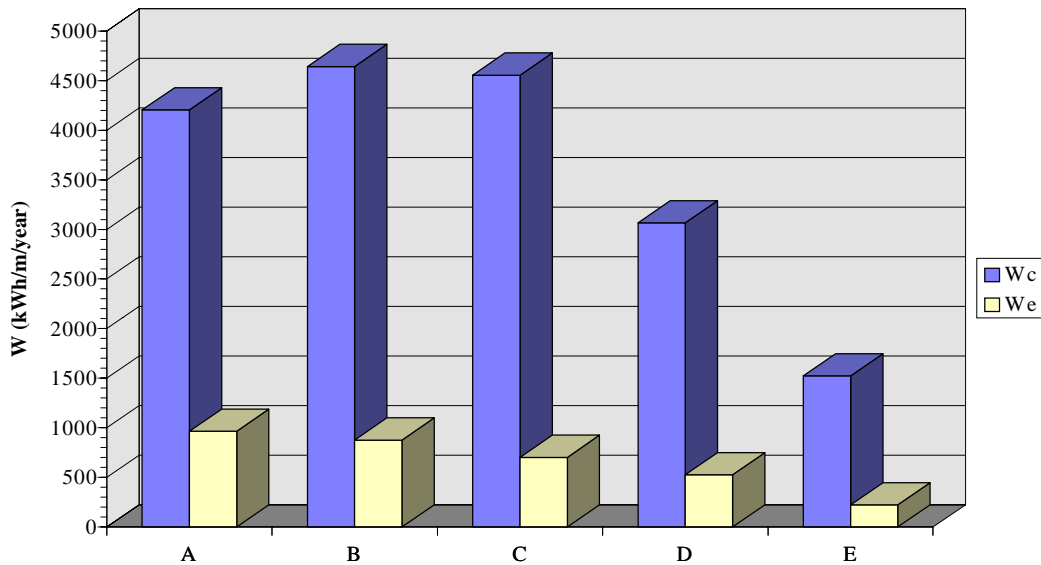

Figure 5. Annual use of energy. A-D are based on the screening test and E is the winner of the competition.

3.4 Comparison of results

The energy savings due to night covers ranged from 25 % up to 40 %. These figures derive from a comparison between a 24 h test without night covers and a test cycle using 12 h with night covers and 12 h without. Another interesting comparison concerns the difference in cooling requirement between summer and winter conditions. This difference ranged between 21 % and 39 %.

The water drained during a full test cycle (24 h) varied between 10 dm^3 and 20 dm^3 for the summer case (22/65) and temperature class S1 (+8°C). One reason for this difference is that the brine inlet temperature has varied between -1.7 °C and -3.9 °C for the different cabinets. A cold coil will induce condensation or frosting. In fact, the winning unit could operate with no defrosting at all. All cabinets were also tested with temperature class M1 (+5°C) at the ambient condition 22°C/65 % RH. During this test, one of the cabinets had problems with the minimum temperature (-1°C) in some of the M-packages.

In the screening tests, night-covers effected savings of the order of 30 %. However, several of the cabinets had problems with air infiltration at the edges of the night curtain resulting in some M-packages being unacceptably warm. On the other hand, the winning cabinet in the competition had special guides for the night curtain and this helped in minimizing infiltration.

All competitors succeeded in using a brine temperature which was higher than that used in the screening test. One contributing factor was that the manufacturers had used the experience from the screening test to optimize the control strategy, set-values, flowrates, and other technical data.

4 DISCUSSION

The competition was a success in that the winner beat the energy requirement by a wide margin. The calculated yearly use of energy was 1745 kWh per year per metre cabinet and this is 50 % lower than the best result of the screening test. This result derives from improvements in several areas. Firstly, it is important to have a control strategy that adapts to the diverse cooling demands due to changing operating conditions, e.g. changes in climate and day/night operation. Data for the operational parameters and set-values are very important to get an even temperature distribution in the M-packages irrespective of the test cycle or the ambient conditions during a year.

A general observation is that the warmest M-packages occur in the bottom front part of the cabinet (T54-56) while the lowest temperatures appear near the back. The vertical distribution differs between the different display cabinets and one factor influencing the location of minimum temperature is the cooling-coil position. A close control of the spatial and temporal variations in product temperature is essential in the optimization of display cabinets. For this purpose, all competitors had worked with the air flow patterns inside the cabinet. Compared to the units of the screening test, the air-curtains were now stronger and the supply of cold air from the rear of the cabinet was changed (the distribution is varied vertically by differently sized and shaped holes).

The coil area has been increased and it is now possible to run the cabinet with a higher brine temperature. This will also increase the COP of the refrigerating installation, as well as reduce frost growth and pressure drop. Reduction of the need to defrost is also reflected in the quantity of melting water during a test cycle. This varied between the competing units from 10 dm^3 up to 20 dm^3. The difference in brine temperature is one factor but it is not the only. Another important factor is the function of the air curtain. The temperature difference between the warmest M-packages and the inlet brine temperature is still relatively high at 9.5 K. A challenge for future designs would be to decrease this difference even further.

Finally, the major factor in reaching the winning result was the reduction of the indirect electric input. However, the direct input is still important since all energy which is dissipated inside the cabinet must be paid for twice. Firstly it has to be supplied and secondly the dissipated heat must be removed by additional cooling. The winning cabinet succeeded in halving the direct input while still

maintaining the thermal and visual quality inside the cabinet. Not only did the winning cabinet have the lowest value of the direct electric input for lighting but it also had the highest value of the illumination.

NOMENCLATURE

Symbol	Explanation	Unit	Symbol	Explanation	Unit
COP	Coefficient of Performance	-	t	Temperature	°C
P	Power (capacity)	W, kW	V	Volume	m^3
RH	Relative humidity	%	W	Work	J, kWh

Subscript	Explanation	Subscript	Explanation
a	air	max	maximum
b	brine	min	minimum
c	cooling	Mmn	middle, shelf no. m, position n
d	dew point	out	outlet
defr	defrost	Rmn	right, shelf no. m, position n
e	electric	vis	visible
in	inlet	1	mean value for shelf no. 1
Lmn	left, shelf no. m, position n	3	mean value for shelf no. 3
m	shelf no. m from the top ($1 \leq m \leq 5$)	4	mean value for shelf no. 4
		5	mean value for shelf no.5

5 REFERENCES

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PROMOTION DES PRÉSENTOIRS D'ÉNERGIE EFFICACES

RESUME: Pour favoriser une efficace réfrigeration NUTEK de Suède a mis en scène une compétition pour des présentoirs verticaux à refroidissement indirect. Le but principal était de diminuer l'utilisation d'électricité en gardant la performance de vente et en satisfaisant les exigences en ce qui concerne la température du produit.

L'utilisation d'électricité annuelle a été determinée d'être inferiéure à 2600 kWh/m présentoirs (25 % de moins que le meilleur résultat d'un test de contrôle du marché). Le gagnant a réalisé 1750 kWh/m, 50 % de moins que le meilleur résultat de contrôle.

L'utilisation d'électricité directe, c'est-à-dire pour les ventilateurs, l'éclairage, et le chauffage du châssis, a baissé jusqu'au moins que la moitié du niveau de contrôle. Néanmoins, ce présentoir avait toujours la valeur d'éclairage la plus haute.

Les nouvelles constructions ont beaucoup amelioré le couvercle de nuit en réduisant les problèmes d'infiltration d'air. De plus, l'attention aux éléments refroidsseurs et aux rideaux d'air permet une marche du frigoporteur plus chaud. Cela réduit les gradients de température aussi bien que le dégivrage et l'utilisation d'énergie totale.