Environmental Project No. 835 2003
Miljøprojekt

Use of natural refridgerants i supermarkets

Preben Bertelsen and Kim Christensen
Danish Technological Institute

Tom Gøttsch
Super Køl A/S

Danish Environmental Protection Agency
Danish Ministry of the Environment

Contents

Foreword

As the refrigeration industry also desires to supply products having the least adverse environmental impact possible, the Danish Environmental Protection Agency, Super Køl A/S, Fakta and the Danish Technological Institute entered into an agreement in the spring of 2001 to fully develop and commercialise the technology of natural refrigerants in supermarkets.

The project follows from the success experienced with a demonstration system in Odense, which proved, however, to be too costly and technology-intensive.
To make the most of the positive experience gained in operating this system, the concept had to be repeated, this time bearing market conditions in mind. Thus, the price of components becomes a factor to be considered on a par with functionality and stability, which will serve to strengthen an improve market penetration of cleaner and more environment-friendly products also in the refrigeration industry.

The success of such a project hinges on all involved parties being positive and committed. Everyone involved in this project was extremely positive, particularly Fakta Beder, Danfoss, Grundfos, Bitzer, Arneg, SWEP, Tempcold and AGA.

Project participants:
The project group consisting of the Danish Technological Institute, Super Køl and Fakta.

Danish Technological Institute
(project manager)
Energy/Refrigeration and Heat Pump Technology
Teknologiparken
8000 Århus C

Contact person: Kim Christensen, MSc (Eng.)
Tel.: +45 7220 1265

Super Køl A/S (applicant)
Holkebjergvej 73
5250 Odense SV
Contact person: Tom Gøttsch
Tlf.: +45 6617 2810

FAKTA
Hjulmagervej 12
7100 Vejle
Contact person: Jørn Hüniche
Tel.: +45 7641 4300

The reference group consisting of:

Arneg SPA
Contact person: Gian Paolo Di Marco

Danfoss A/S
Contact person: Christian Bendtsen

Grundfos A/S
Contact person: Gunnar Langgård

Tempcold A/S
Contact person: Christian Heerup

SWEP A/S
Contact person: Ejnar Pedersen

1 Summary and conclusions

1.1 Introduction

On the basis of projects previously completed under the auspices of the Danish Energy Agency's CO_2 programme (journals nos. 731327/97-0164 and 731327/99-0199) and the Danish Environmental Protection Agency (file no. M 128-0428), a project was run at Fakta Beder, supporting and fully developing the use of propane and CO_2 as refrigerants in supermarkets.

The previous projects document the excellent thermo-physical and thermo-dynamic properties of CO_2 and propane.

This project (Use of natural refrigerants in supermarkets) focuses on the energy consumption and installation costs of using propane and CO_2 in supermarkets.

To optimise installation costs, we have to use the components familiar to fitters. The project was therefore run using copper pipes and other components known from the commercial refrigeration industry. The individual parts were combined into a unit and sold as a unit to Fakta.

The unit is a product with the same energy consumption as a traditional R404A (90 kg) system, but which reduces the direct equivalent CO_2 emission contribution by 342 tonnes.

Fakta is a chain of supermarkets with about 250 outlets. The chain has expanded and developed over the past 25 years. The energy consumption usually reflects the age of an outlet.

The outlets can be grouped according to type of refrigeration system and energy consumption with sufficient numbers in each group to establish a well-defined basis for a comparison between the propane/ CO_2 system and conventional systems.

To be energy neutral, the propane/CO_2 refrigeration system must have the same level of energy consumption as that of the latest systems.

1.2 Objective

The objective of this project is to fully develop and commercialise the technology underlying the use of natural refrigerants, thus making it more accessible to a greater part of the industry. Moreover, the technology will be demonstrated on a full scale (Fakta outlet), where the previous system stood in a less commercial outlet (local outlet in Odense, file no. 731327/99-0199). The technology needs to be demonstrated in an outlet of a size with which the industry can identify.

1.3 Results

The project shows that:

- the energy consumption is within the consumption of an optimised traditional Fakta outlet;
- the installation costs are 10-20% above the cost of an optimised Scroll solution with R404A in a standard Fakta outlet;
- the installation costs of the brine circuit are significantly lowered when hoses are used, and that string control valves are not required on systems of this size;
- the injection function of the cascade heat exchanger must have a time-limited start-up function followed by traditional PID control to provide stable, uniform operation;
- the propane circuit safety requirements are operational and manageable; and
- the choice of an adjusting strategy for secondary cooling circuits is a condition for energy-optimised operation of refrigeration compressors.

1.4 Conclusion

The conclusion is that the propane/CO_2 solution can be implemented in many installations in the Danish commercial refrigeration industry. Energy-wise, the technology is neutral at present, with potential optimisation.

Installation costs will rise by 10-20% initially, but costs may also be optimised. Fitters must adjust their ability to handle CO_2/propane and brine.

Hoses can considerably enhance the installation of the brine circuit, and string-adjusting valves are not required for systems of this size. The brine circuit flow should be constant.

The injection valve on the cascade heat exchanger must be fitted with a controller with time- limited start-up function followed by traditional PID control.

Applying the Pressure Equipment Directive (Order no. 743) and later the ATEX Directive as the design basis will achieve the optimum safety, an issue that is sure to be pivotal also in future.

The project reveals that the refrigeration industry is able to offer refrigeration units using propane/CO_2 as refrigerants, thereby eliminating the direct equivalent CO_2 emission contribution.

1.5 Background

The restrictions and bans of the Montreal Protocol (1987) on the use of CFCs and HCFCs, the hardened line of the Kyoto Protocol on greenhouse gases (HFCs) and the Danish EPA's proposal for taxes on industrial greenhouse gases will lead to the extensive use of natural refrigerants in the future and attempts to reduce the energy consumption of refrigeration systems.

Today, many outlets use R404A (HFC), which is a mixture of R143a, R125 and R134a with a direct greenhouse potential of 3,800 at a time horizon of 100 years. Because outlet refrigeration systems normally have a lifespan of 10-15 years, and yearly leakage represents 10-20% of the charge, the leakage from a large number of R404A systems will continue contributing to global warming for many years to come.

Denmark has about 2,200 supermarkets and department stores selling refrigerated and frozen foods. The refrigeration systems are primarily made up of remote systems where the refrigerated display cases (refrigerated and freezer islands) are connected to a central refrigeration system located in an engine room far away from the display cases. The remote system in retail trade is characterised by long pipe stretches and large amounts of refrigerants. Typically, the systems have only been minimally optimised, because focus is on operating safety, function and appearance, all aspects that can lift sales in the outlet. Hence, energy consumption is typically relatively high, as are refrigerant leakage rates.

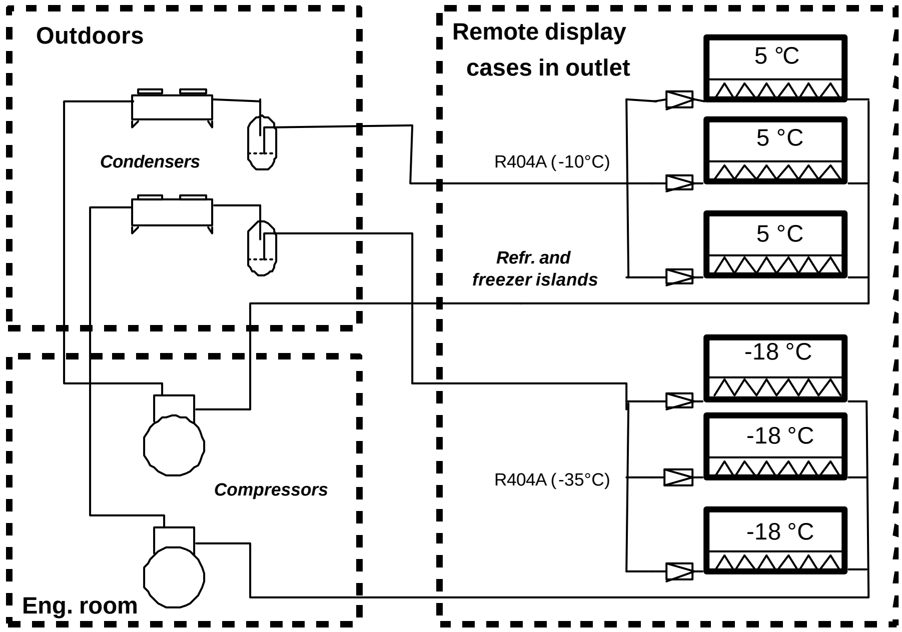


Figure 1: Schematic diagram of remote system design

When leakage occurs, the refrigerant gradually seeps from the system onto the cellar floor, shop floor and surroundings, but major leakages from burst pipes in transport lines also occur in certain cases. Leakages are discovered when system function becomes critical, which is often not the case until more than half the refrigerant has seeped out of the system.

On average, the charge of refrigerant is about 50 kg in each supermarket, corresponding to a total of 118,000 kg. New systems using HFC are estimated to have annual leakage rates of 10% (11,800 kg), equivalent to 44,840 tonnes of CO_2 emission a year when using R404A refrigerant, whose equivalent CO_2 emission is 3,800 kg of CO_2 per kg.

Supermarkets' refrigeration and freezing systems account for about 1.5% of the total energy consumption in Denmark (600 GWh per year). Given 0.78 kg of CO_2/kWh, the annual CO_2 load is 468,000 tonnes per year. Consequently, electricity consumption must be weighed heavily in the endeavours to phase out unwanted gasses from the commercial market.

1.6 The system

Several of the natural refrigerants cannot be used directly in the supermarket due to their undesirable properties as regards flammability and toxicity. For this reason, indirect systems need to be designed where these refrigerants exchange heat with a secondary refrigerant (brine), which is then pumped from the engine room to the refrigerated and freezer display cases.

Measurements and analyses made so far of this type of refrigeration system for supermarkets have proved, however, that the "price" of replacing unwanted gases will be an increase in energy consumption of 5-10%.

Using a gas like CO_2 directly in the freezer display cases and an indirect system in the refrigerated display cases will leave energy consumption unchanged compared with today's optimised systems using R404A.

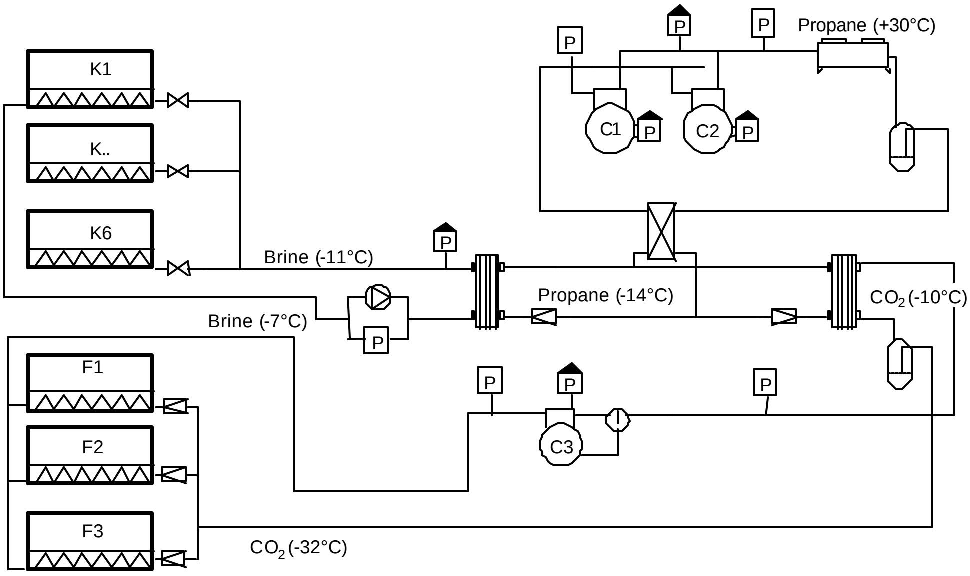


Figure 2: Schematic diagram of the design of a refrigeration system using propane and CO_2.

The refrigerated and freezer display cases shown on the left are mounted in the supermarket itself, while other system components (compressors, pumps, heat exchangers, vessels, etc.) are installed in a compressor rack located in a separate engine room.

The combination of propane and CO_2 is an optimum solution because refrigeration companies are versed in the technology of soldering copper pipes and therefore have no difficulty in building systems using the new refrigerants. Moreover, using CO_2 on the low-temperature part sharply reduces the amount of propane added. It should be possible to get below 10 kg even in major supermarkets, where today's charges of HFC stand at 60-120 kg.

2 Natural refrigerants in Fakta Beder

2.1 System principle

The system found in Fakta Beder was designed as a cascade system. Propane is used at high temperatures (-14/25°C), while CO_2 is used at low temperatures (-32/-10°C). The two refrigerants exchange heat in the cascade heat exchanger, where propane evaporates through dry expansion and CO_2 condenses. The CO_2 is used directly in the supermarket's freezer display cases and freezer rooms, while the propane exchanges heat with glycol in an indirect system.

The glycol is pumped in a closed system to the refrigerated display cases and the refrigerated rooms.

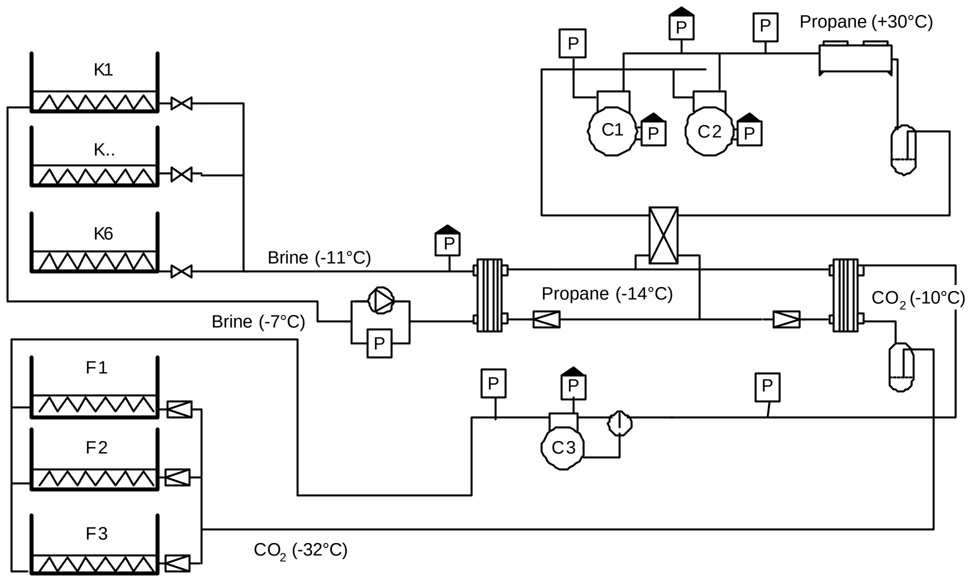


Figure 3: Schematic diagram of CO_2/propane system in Fakta Beder.

Suction gas-cooled, semi-hermetic compressors are used for both propane and CO_2. Propane compressors have an oil pump, while CO_2 compressors are splash-lubricated.

The refrigeration system itself is installed in a compressor rack, containing compressors, cascade heat exchangers, brine cooler, brine pumps, valves and vessels. The system is located in a separate engine room from which pipes and hoses connect the display cases to the system. The components containing propane are built into a ventilated enclosure.

2.2 Propane system

Propane as primary refrigerant:

- Flammable
- Properties comparable with those of HFCs, although
  – heat transfer properties are better
  – pressure drops are lower
- Copper pipes and soldering can be used

The propane system is designed as a compact indirect system, although the propane condenses directly in an air-cooled condenser. The condenser stands on the supermarket's roof.

The propane system has two evaporators: one cascade heat exchanger and one brine cooler. Both are plate heat exchangers. Both heat exchangers use electronic expansion valves to inject the refrigerant. Also, the system has no oil separator. The system uses a mineral oil fully miscible with propane, so that the oil from the system returns to the compressors. Fitted balancing pipes ensure a uniform oil level in the compressors.

The internal heat exchanger (plate heat exchanger) ensures subcooling of the propane liquid before the expansion valves and superheating of the suction gas for the compressor. Compression with propane results in very low high-pressure gas temperatures, which allows the compressor to become relatively cold without an internal heat exchanger, thus making the refrigerant in the oil highly soluble. This may reduce the lubricating properties of the oil and increase the amount of oil transported from the compressor to the system.

Moreover, the compressor comes with a relatively big electrical heating element for the oil pan during standstill.

Finally, the system has a drying filter and a dirt filter in the fluid pipes, but no receiver.

2.3 CO_2 system

Carbon dioxide as primary low-temperature refrigerant:

- Neither toxic nor flammable
- High COP (high isentropic efficiency for compressor, small pressure losses and good heat transfer properties)
- Good miscibility with ester oils like HFC refrigerants
- Acceptable high-pressure gas temperatures
- High-volumetric refrigeration capacity, generating small displacements for the compressor, and small suction and liquid lines
- Drying filter, sight glass and stop valves identical to equipment used for HFC refrigerants
- Copper pipes and soldering can be used

The system is designed as a conventional refrigeration system, although it has no internal heat exchanger.

The cascade heat exchanger functions as the CO_2 system's condenser, where CO_2 condenses against evaporating propane. The condensate is not supercooled further. Next, the liquid circulates to the evaporators located in the outlet's freezer display cases and rooms. Pulse-width modulating valves are used as injection valves, and 8K overheating is maintained. The gas is then sucked back into the compressor. The system has no oil separator.

The amount of oil entering the system will, due to high solubility with the refrigerant (ester oil/CO_2) and relatively high gas velocities, be transported back into the compressor along with the refrigerant.

The compressor comes with an electrical heating element for the oil pan during standstill. Finally, the system is fitted with drying and dirt filters in the fluid pipe.

2.4 Display cases and heat exchangers

All the display cases used are standard models with evaporators adapted to the refrigerant (brine/CO_2). Brine heat exchangers are already available in the market. In this case, ECO has supplied the air coolers for Arneg's milk front and refrigerated room, where propylene glycol is used as brine. Arneg has supplied the brine heat exchangers contained in the islands. In terms of freezer islands, there are no immediate suppliers of evaporators in the market, and in this case, the Danish Technological Institute designed evaporators, which were subsequently manufactured by ECO. This goes for both the freezer room evaporators and the two evaporators for the freezer islands. All CO_2 evaporators have been manufactured as conventional fine coils with 3/8" copper pipes and aluminium fins.

Position		*Load [W]*		*Comment*
		Refrigeration (-10°C)	Freezing (-32°C)	LxBxH [mm^3]
1	Refrigerated room	4500	-	5100x3300x2360
2	Freezer room	-	4200	3600x3300x2450
3	Freezer room (ice)		2800	2100x3300x2450
4	Vertical cooling cabinet	14400	-	10 meter
4	Freezer island, big		2200	3750x1000x960
5	Freezer island, small		800	1985x1000x960
6	Refrigerated island, big	1400		3750x1000x960
7	Refrigerated island, small	700		1985x1000x960
Total		*21000*	*10000*	

Table 1: List of display cases and rooms

Refrigerated and freezer rooms have separate heat exchangers. Danfoss pulse-width modulating valves control the injection of refrigerant in all heat exchangers. The CO_2 injection valve has a period time of six seconds, while injection through the brine valve takes six minutes.

2.5 Compressor dimensioning

The above table shows that the refrigeration and freezing capacities are 21 and 10 kW, respectively. The system is dimensioned at about 21 kW (refrigeration) and 10 kW (freezing).

The dimensioning of refrigeration systems is based on information or calculations regarding refrigeration capacity. Moreover, the temperature level must be known. An outlet selling fresh (refrigerated) and frozen food operates with two different temperature levels. The temperature is between +1 and +3°C for refrigeration purposes, while it is between –25 and –18°C for freezing purposes.

These air temperatures can only be achieved if the refrigeration system for the refrigerated area operates at a temperature of about –14°C and the system for the freezing area operates at a temperature of about –32°C.

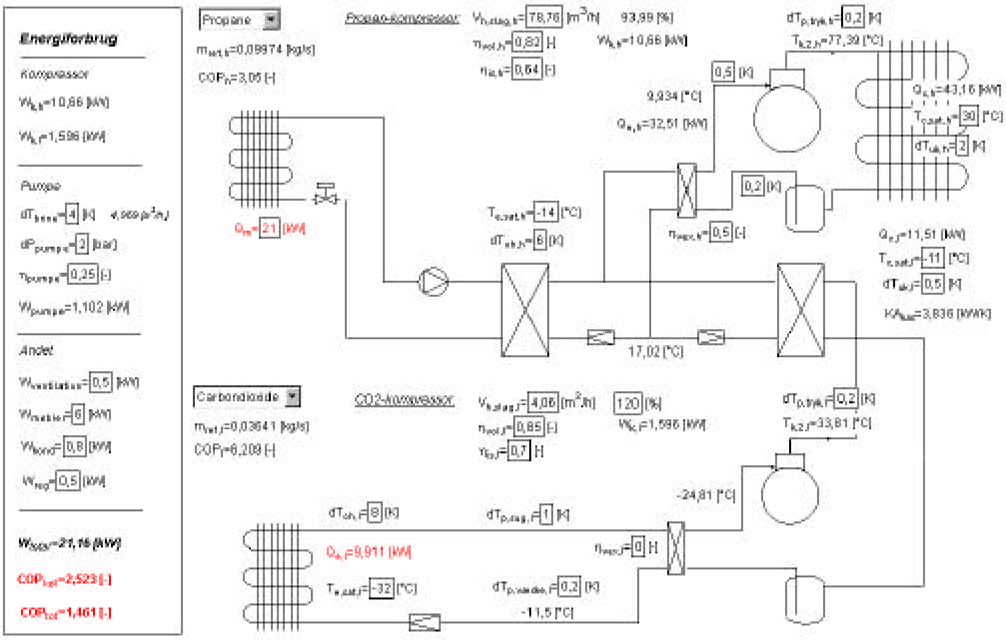


Figure 4: Calculation of total system with current CO_2 compressor

In total, the propane compressors must be able to generate 32 kW. Bitzer's catalogue only provides information about the compressor with various synthetic refrigerants. R22 comes closest to propane, so the R22 information is useful, and a recalculation will show capacity and energy consumption.

R22 *(+30/-15, T_{suc}=25°C, dT_{uk}=0K)*			***Propane*** *(+30/-14, T_{suc}=0°C, dT_{uk}=2K)*		
Type	**Displacement**	**Efficiency**	**Type**	**Displacement**	**Efficiency**[1]
4T-8.2	39.36 m^3/h	η_{ice} = 63.8% η_{vol} = 82.7%	4T-8.2	39.36 m^3/h	η_{ice} = 63.8% η_{vol} = 82.7%
Q_e	W_e	P_2/P_1	Q_e	W_e	P_2/P_1
18.56 kW	6.37 kW	4.03	16.8 kW	5.7 kW	3.56

[1] *As the pressures of R22 and propane are almost identical, the efficiencies are estimated to be the same.*

Two Bitzers 4T – 8.2 are chosen.
Combined, they will generate refrigeration effect of about 33.6 kW. The system will have an internal heat exchanger, boosting capacity to about 34.6 kW. The freezing compressor has been selected, and the model available is a Bitzer X2KC of about 10 kW.

2.5.1 Summary of information

The following table contains a summary of information.

Specifications	***Data***	***Comments***
Temperatures		
Condensation temperature R290	25°C (8.7 bar)	System currently operating at 27°C
Evaporator temperature R290	-14°C (3.0 bar)	
Condensation temperature R744	-10°C (26.5 bar)	
Evaporator temperature R744	-32°C (13.4 bar)	
Brine temperature (inlet) PG	-10°C	
Brine temperature (return) PG	-7°C	
Refrigeration effect (dimensioning)		
Refrigeration load (brine)	21 kW	Brine system with six heat exchangers
Freezing load (CO_2)	10 kW	Direct system with R744, 4 freezing sites
Propane system	34.6 kW	
Compressors (current)		
R290: 2 Bitzers	78.72 m^3/h	4T-8.2 mineral oil
R744: 1 Bitzer	4.06 m^3/h / 8.3 kW	X2KC-05.2 (Y), ester oil
Part load operation		
R290: 2 Bitzers (4 cyl.)	2/4 cyl.	Capacity: 25% - 100% at four levels
R744: 1 Bitzer (2 cyl.)	1: VLT (30-60 Hz)	Capacity: 60% - 120% (continuously)
Charge		
Propane system	10 kg	
CO_2 system	6 kg	
Propylene glycol	140 kg	

Table 2: System dimensioning details

2.6 Refrigerants

The outlet's refrigeration system uses the following refrigerants:

- *Propane (R290)*
- *CO_2 (R744)*
- *Technical propylene glycol (Dowcal N/ 40% wt.) – inhibited and approved for foods.*

2.6.1 Propane and CO_2

Propane is an odourless and non-toxic gas. However, propane is an explosive gas with lower and upper explosive limits of 2.1-9.5 % v/v (0.038-0.171 kg/m^3). The automatic flashpoint is 470°C. The gas is heavier than air and will therefore be at the lower level.

CO_2 is also odourless and non-toxic, but the gas can be hazardous to humans at concentrations higher than 0.5% v/v (5,000 ppm). The gas is heavier than air, and it should be noted that liquid expanding at pressures lower than 5.18 bar (-56.6°C – triple point) forms solid phase (dry ice). CO_2 is also characterised by its very high saturation pressure. At 25°C, the saturation pressure is 64.4 bar. Finally, it should be noted that CO_2's low critical temperature and pressure (31°C and 73.8 bar) mean that a CO_2 cycle becomes transcritical at high temperatures.

2.6.2 Brine

Technical propylene glycol Dowcal N is used. The concentration is 40% wt., ensuring a freezing point of –21°C.

The glycol is inhibited and approved for foods (by the FDA).

- Non-toxic, but should not be ingested
- Non-flammable

Dowcal N is compatible with generally used metals (copper, steel and brass) as well as plastic and elastomers (PE, PP, ABS, PVC, IIR, PTFE, EPDM, NBR and NR).

3 Component dimensioning

Reference is made to appendices 3-6 for a list of the components used (parts lists).

3.1 Pressure Equipment Directive

The design of the propane system is based on Council Directive 97/23/EC, also known as the Pressure Equipment Directive (PED). The directive was implemented in Danish law by Order no. 743/99. However, the use of pressure equipment is a national matter, currently governed by Order no. 746.

The design can either be based on a calculation method such as AD-Merkblätter or on an experimental design method. In this case, the calculation method is used to support the important safety requirements, and thus to meet the provisions of the directive.

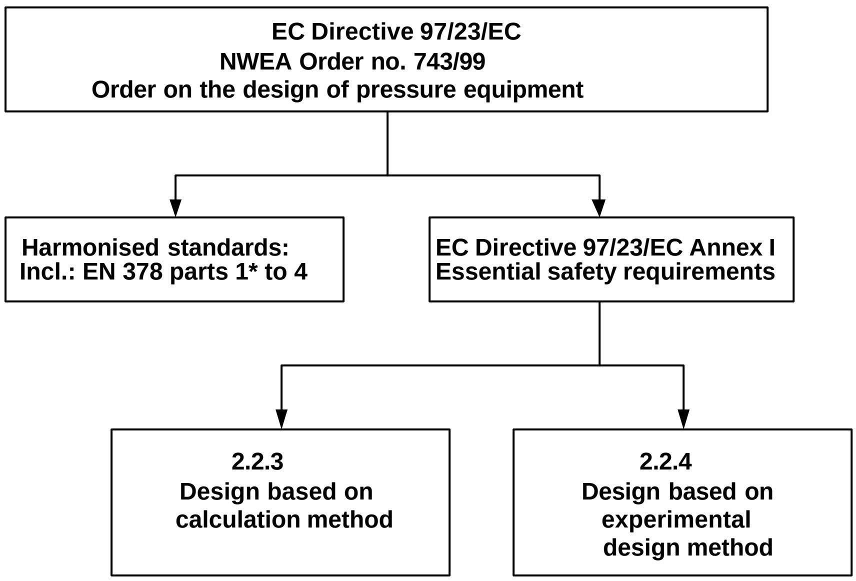


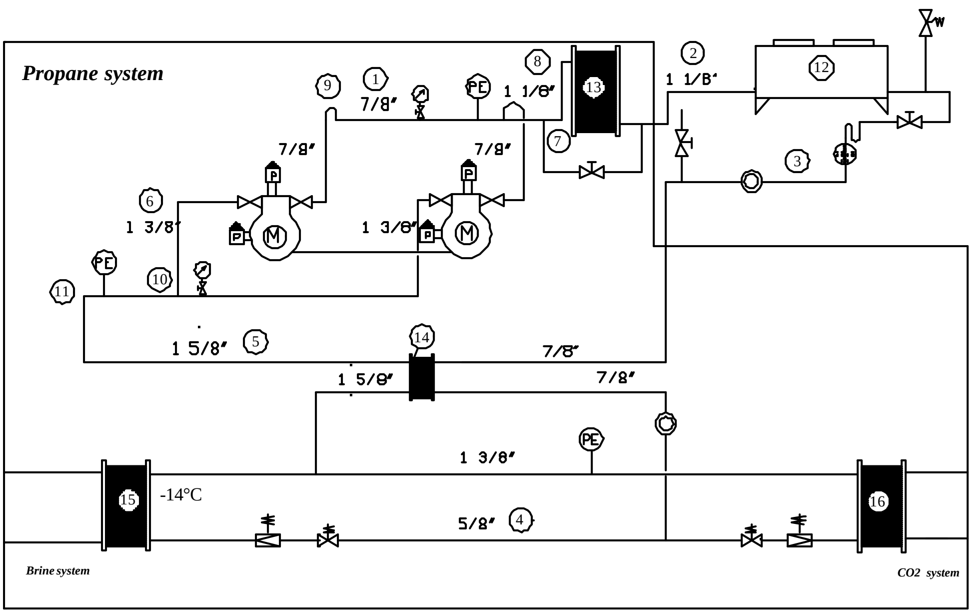
Figure 5: Principle for order compliance

3.2 Design of pressure system

1. Classification of refrigerant
2. Determination of type of refrigeration system
3. Design of pipe system
4. Determination of maximum allowable temperature/pressure
5. Determination of design pressure P_d
6. Determination of pipe dimensions
7. Determination of method for calculating strength
8. Categorisation of pipe system
9. Categorisation of pressure vessels
10. Determination of extent of documentation
11. Determination of manufacture and material standards
12. Requirements for fittings
13. Requirements for components and valves
14. Requirements for safety equipment, pressure switches and safety valves
15. Requirements for assembling methods
16. Determination of material documentation
17. Conformity assessment
18. Technical documentation
19. Determination of control and quality management extent
20. Final testing and verification
21. Approval procedure

(Reference is made to the Danish EPA's guide "Hydrocarbons in medium-sized systems"/1/)

Re 1. Propane is flammable and thus classified as Group 1.
Re 2. The system is located in a separate engine room with the door locked. This space is classified as person category C, which is permitted with propane.
Re 3. Pipe cross-section chosen on the basis of general requirements for pressure losses and then to ensure sufficient speed for the oil return.



Re 4. The maximum allowable pressure (PS) is fixed at 18 bar. A safety valve (SFV 15) ensures that the maximum pressure is not exceeded. The maximum temperature (TS) is fixed at 55°C.

Ambient state	£ **32 °C**	£ **43 °C**
High-pressure side with air-cooled condenser	55 °C (18 bar)	63 °C
High-pressure side with water-cooled condenser	43 °C	43 °C
Low-pressure side	32 °C (10.3 bar)	43 °C

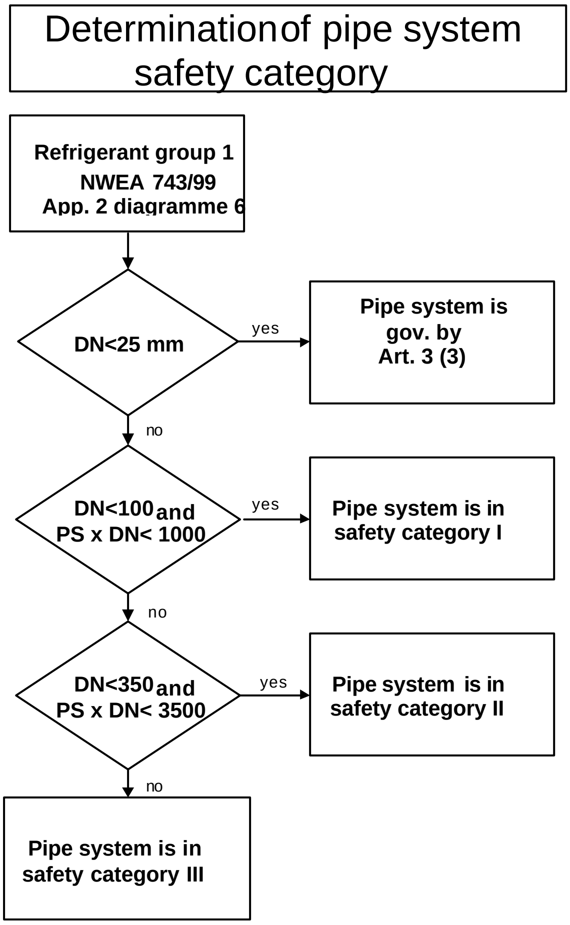
Re 5. The design pressure is determined on the basis of EN 378-2: 2000, chp. 5 – ambient temperature <32°C
High-pressure side: 18 bar (55°C)
Low-pressure side: 10.3 bar (32°C)

Re 6. The propane system is a compact system with very short pipe lengths.
The gas and liquid pipes (to and from the condenser) are the two longest pipes (about 10 metres). The suction pipe is very short (about 2 metres). Single losses (valves and elbows) chiefly account for the pressure loss in this system. Pressure losses are about 0.01 bar (0.03K), 0.035 bar (0.8K) and 0.1 bar for the fluid, suction and pressure pipes, respectively.

Re 7. The calculations of pipe strength focus on the selection of material and wall thickness, with the aim of meeting the essential safety requirements in the Pressure Equipment Directive. Deoxidised copper pipes are used, with the copper content exceeding 99.9% and the phosphorous content amounting to 0.015-0.04%. Phosphorous counteracts copper oxidation, which makes the material brittle. The composition of material complies with DIN 1787 SF-Cu 2.0090. The minimum wall thickness is determined on the basis of AD-Merkblätter B1. The calculation pressure is the maximum allowable pressure (PS). The value of annealed copper is used as 0.2% stress; the value is given by the pipe supplier (the copper must be regarded as annealed after having been heated through soldering). Fittings are put on an equal footing with pipes, but the strength factor is based on AD-Merkblätter B9 diagram Bild 7d. The condenser is also put on an equal footing with pipes (heat exchangers in the form of pipes for cooling or heating air are put on an equal footing with pipe systems – PED, article 1 (2.1.2)). Current pipes appear from appendix 2. The pipe design as regards wall thickness is based on control calculations to meet the essential safety requirements of the Pressure Equipment Directive (article 1 (2.12) and article 3 (1.3-1.4)).

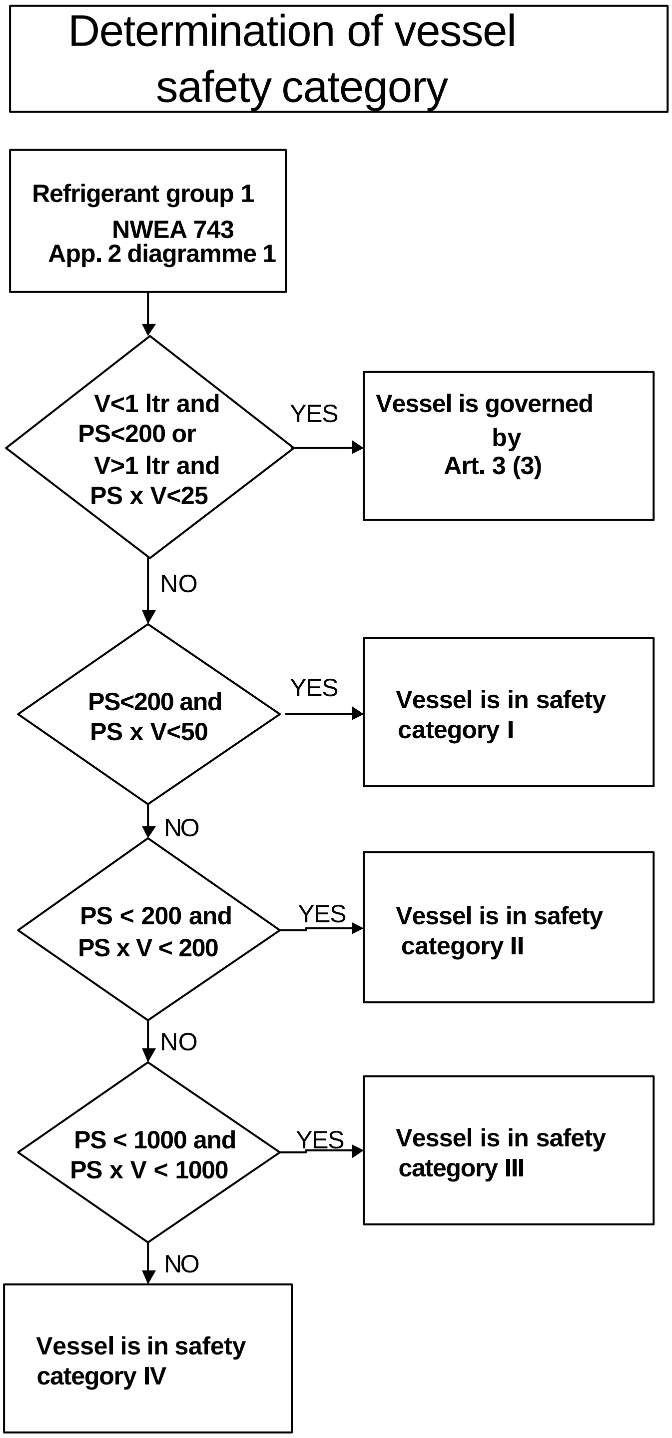
$s = \dfrac{D_a \times p}{20 \times \dfrac{K}{S} \times v + p} + c_1 + c_2$	s: nom. wall thickness [mm]
	D_a : Outside diameter [mm]
	p : Calc. pressure [bar]
	K : 0.2% stress [N/mm ^{2}]
	S : Safety factor B0 table 2 (1.5)
	v : Strength factor for joints
	c_1: Addition for neg. tolerance
	c_2: Corrosion addition (0 for non-metals)

Re 8. Determination of pipe system safety category complies with the National Working Environment Authority's Order no. 743/99, article 3.



The pipe system safety category appears from appendix 2.

Re 9. Determination of pressure vessel safety category complies with the PED, NWEA Order no. 743/99, article 3 (1.1) – plate heat exchanges are regarded as vessels. The plate heat exchanger safety category appears from appendix 3.



Re 10. The extent of documentation is exclusively determined by the safety category to which the unit belongs. In this design, no components belong to a category higher than I. The documentation requirements of module A (Annex III to the PED) must be met to regard the design as being in compliance with Order no. 743.

Module A	Internal production control
Description:	This type of control means that the manufacturer is responsible for checking that the equipment meets the PED and that the product has been designed and produced as described in the technical documentation.
Approval procedure:	No approval.
Extent of control:	The technical documentation is made available to national authorities for inspection purposes ten years after the date at which the production of pressure equipment stopped. It should be noted that the technical documentation also includes test reports.
CE marking:	The manufacturer affixes the CE marking on each piece of pressure equipment and issues a written declaration of conformity.
Identification number:	No identification number is issued by the notified body.

Re 11. The technical documentation contains material certificates and calculations supporting wall thickness and material conformity for copper pipes and heat exchangers.

Re 12. Category I fittings must have been produced from the same material as the pipes. The pipe supplier states the material's conformity and coincidence in writing. The pipes' conformity is confirmed by a material certificate - EN10204, type 3.1B. There are no fittings with a 3.1B certificate. The minimum wall thickness is determined on the basis of AD-Merkblätter. ANSI 16.22-89 (normal standard in Denmark) is the manufacturing standard for the fittings used.

Re 13. It is not yet possible to obtain PED declarations of conformity for valves. In this case, the supplier has declared in writing that the valves are suitable and usable in connection with propane.

Re 14. As regards safety category I components, sample pressure tests suffice. A pressure test certificate accompanies the plate heat exchangers. The safety valve (SFV) has been tested and sealed by TÜV NORD. The safety valve prevents the pressure from rising above 18 bar.

Re 15. Joints have been manufactured through hard-soldering – carried out by an experienced fitter. Visual inspection and test of soldering sample. Solder material: AGOP 15 with 15% Ag, 80% Cu and 5% P. The melting point is 600-800°C.

Re 16. The technical documentation made available by the supplier serves to document conformity The documentation contains information about the name of the manufacturer, allowable pressure and temperature, usability with propane, component materials, order number, pressure testing and, in some cases, the notified body.

Re 17. In order to assess the design's conformity according to module A, the technical documentation must be available for assessing the design's conformity with the relevant requirements ten years ahead. The documentation is contained in a ring binder.

Re 18. Furthermore, the technical documentation must provide diagrams, drawings and functional description – also contained in a ring binder.

Re 19. As the design belongs to safety category 1, the manufacturer does not need quality management approval. Internal production control suffices.

Re 20. Finally, the design is subjected to a leakage test at the maximum pressure possible during normal operation.

3.2.1 Comments

Declaration of conformity is a key phrase often associated with PED Order no. 743. The declaration confirms that the component meets the requirements of a specific safety category of the PED. Components carrying declarations of conformity are always difficult to find. The situation will change in time since products must carry the CE marking as at 29 May 2002. Until then, the documentation of conformity will be assessed on a component-by-component basis.

In this design of a propane/CO_2 unit, the propane pipe design is what is interesting and assessed thoroughly. The CO_2 pipe design is not subject to approval. CO_2 belongs to gas group 2 and the threshold values for the product figure PxV are greater. The cross sections of CO_2 pipes (½" and 3/8") are small, meaning that the wall thickness of standard pipes is adequate even at very high pressures.

3.3 Main component summary - propane

Number	**Description**	**Supplier**
2	Compressors	Bitzer, 4T-8.2P
1	Air-cooled condenser	ECO FCE 071C63
1	Plate heat exchanger	Propane/glycol: 21 kW, Swep, B25x70
1	Plate heat exchanger	Propane/CO_2: 10 kW, Swep V27x80 HP
1	Plate heat exchanger	Propane/propane: 2 kW, Swep, B12x70
1	Plate heat exchanger	Propane/glycol 3 kW, Swep B27x50
1	Electric expansion valve	Danfoss ETRE – 30 kW
1	Electric expansion valve	Siemens Staefa – 14 kW

Table 3: Important/main components for propane system

3.4 Use of propane system

As appears from the above, the use of pressure equipment is a national matter governed by Order no. 746. As a result, the unit must be registered with the National Working Environment Authority, which must also receive a copy of the design basis. Moreover, the following information must be provided with the system.

The system must come with an appropriate number of operational and maintenance manuals stating how to service the system.

Furthermore, the manuals must provide information about the measures to be taken in the event of breakdown or leakage. All manuals must be prepared in Danish by the manufacturer or the fitter. As a minimum, the manuals must provide the following information, if deemed relevant:

a) System purpose
b) Description of system and its equipment
c) Description and operational details of the entire system, including components, with a diagram of the refrigeration circuit and the electric circuit
d) Instructions for system start, stop and standstill, or parts thereof
e) Instructions for how to dispose of refrigerants and equipment
f) Causes of most common defects and measures to take, e.g. instructions regarding leakages discovered by authorised staff and the need to send for competent maintenance staff in the event of leakage or breakdown
g) Measures to be taken to prevent water from freezing in the condenser, evaporators, etc., at low ambient temperatures or if system pressure is reduced
h) Measures to be taken when lifting or transporting the system, or parts thereof
i) Information as it appears on summary machine cards or full machine cards, if need be

j) Preventive measures for first aid and procedures to be followed in the event of leakage, fire, explosion, etc.
k) Maintenance instructions for the entire system with scheduled maintenance to prevent leakages
l) Instructions for adding, tapping and replacing refrigerants
m) Instructions on refrigerant handling and associated risks
n) Need for periodic inspection of emergency lighting, including movable lighting
o) Instructions on function and maintenance of safety equipment, protective and first aid equipment, alarms and pilot light
p) Instructions for keeping a log
q) Required certificates

3.4.1 Machine card

The machine card must contain the following information:

a) Name, address and telephone number of fitter, service department, or other service partner or person responsible for the refrigeration system, and telephone numbers for the fire service, police, hospitals and burns centres
b) Indication of refrigerant, including its chemical name and number as indicated in the standards
c) Instructions for how to shut down the system in the event of emergency
d) Maximum pressures
e) Details about the flammability of the refrigerant

3.5 CO_2 system

The standstill pressure (saturation pressure) at, for instance, 25°C will be about 64 bar, which is very high in terms of system dimensioning. The system can be dimensioned in different ways to achieve a lower design pressure. In this case, a system has been chosen where the refrigerant is merely blown off into the surroundings if pressures exceed allowed threshold values. The system is expected to be in constant operation to keep the pressure in the CO_2 system below these values at all times.

	Operation	Standstill
Low-pressure end	19 bar	25 bar
High-pressure end	32 bar	40 bar

The maximum pressure at the suction side is 19 bar during operation. A starting pressure control (KVD) placed at the compressor's suction end keeps the pressure below 19 bar when the compressor is started. Safety valves also protect the compressor against too high pressures (19/32 bar).

The maximum pressure at the high-pressure side is 32 bar. A high-pressure switch protects the compressor against too high outlet pressure. Safety valves also protect the compressor against too high pressures (19/32 bar).

- Selection of components for CO_2 system
  - Semi-hermetic compressors from Bitzer (frequency transformer from Danfoss)
  - Expansion valves from Danfoss, AKV
  - Standard receiver/drying filter/sight glass

- Safety equipment (safety valves, pressure switches, pressure transmitters, gas sensors, etc.)

- Selection of materials
  - CO_2 system made of soldered copper pipes
  - Evaporators are made as conventional copper/aluminium heat exchangers (pipes/fins), but with 3/8” pipes

Number	**Description**	**Supplier**
1	CO_2 compressor	Bitzer, X2KC-3.2, BSE 55

Other components appear from appendix 6.

The pressure losses are relatively significant, but small in terms of temperature. Pressure losses are about 0.11 bar (0.15K), 0.35 bar (0.8K) and 0.01 bar for the liquid, suction and pressure pipes, respectively. As can be seen, the pressure loss is small even when small pipe dimensions are used. However, the penetration of heat from the surroundings causes the biggest problems for the CO_2 system.

The receiver and the liquid pipes function at about –10°C, which may cause problems regarding heat penetration and failing subcooling. In such systems with long pipe sections (e.g. 20 metres), pressure loss must be kept below 0.1K, and with 30 mm insulation, the heating of the CO_2 liquid can be maintained at about 0.7K. This may be sufficient to avoid flash gas before the valves. Alternatively, an internal heat exchanger can be fitted into each case.

3.6 Brine system

The brine circuit is regulated by a pump currently operating at a constant flow. The total length of the main circuit is 30 metres. The inlet and return pressure losses are about 0.7 bar, while the pressure loss in the brine heat exchangers is 0.2-0.4 bar. The pressure loss in the part strings (pipes, valves and heat exchangers) is 0.3-0.5 bar.

The brine circuit has been fitted with string control valves – ASV-PV and ASV-I from Danfoss. The purpose of the valves is to secure uniform pressure loss in each part circuit. The problem with ”distorted” load on part strings becomes more pronounced in large brine systems. The connection between the brine heat exchanger in the engine room and the heat exchangers in the display cases is made up of hoses drawn through pipes in the floor. The cold hoses inside the cases have caused condensation problems on the underside of the cases during the warm summer months, resulting in water on the floor. The problem can be solved by increasing ventilation underneath the cases.

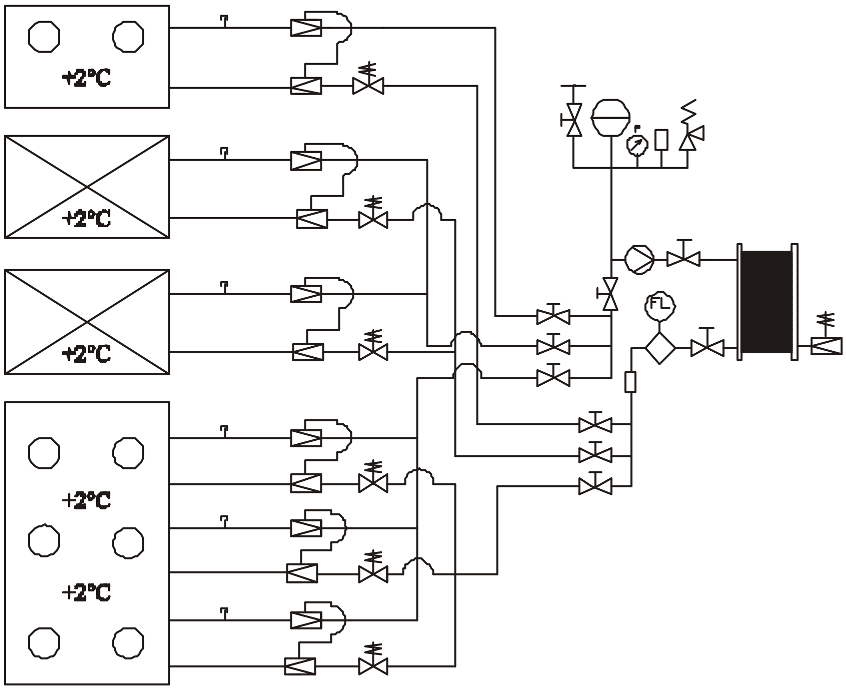


Figure 6: Brine circuit with ASV-PV and ASV-I string control valves in each heat exchanger circuit

3.7 Safety

3.7.1 Safety – engine room

The propane system stands in an engine room in a tight and ventilated enclosure. The enclosure's constant mechanical ventilation ensures a constant negative pressure in the enclosure (compared with the surrounding engine room) of 10 Pa and a ventilated volume flow of 230 m^3/h.

Hence, the enclosure can be regarded as a zone 2, where the degree of protection must correspond to IP 54. The engine room surrounding the enclosure is specified as an unclassified area.

A pressure monitor (differential pressure transducer) constantly registers whether the negative pressure stated is maintained. If it is not, the power for all non-EEx equipment in the engine room will be cut off (all equipment, excluding emergency lighting, mechanical ventilation and pressure monitor). Pressure gas and liquid pipes have been connected to the condenser on the roof of the building through the ventilation channel from the enclosure to the surroundings.

The CO_2 system stands in the actual engine room from which fluid and suction pipes have been connected to the freezer display cases. The engine room has natural ventilation (grating next to the door). In the event of CO_2 emission into the engine room, the gas will stand above the floor and be ventilated away automatically. The engine room also has a CO_2 detector registering CO_2 gas at 4,000 ppm.

CO_2 below 5,000 ppm (0.1 kg/m^3) does not affect humans – not even when they are exposed to this atmosphere for a long time. A load of 6 kg thus means that the volume must be higher than 60 m^3 to be below this figure. The only rooms with a volume less than 60 m^3 involving a risk of CO_2 emission are the engine and freezer rooms. CO_2 detectors and alarms have therefore been installed in these rooms.

Refrigerant: R290 and CO_2	
Load (mass):	10 kg/6 kg
Room volume (HxWxD) Engine room: ((3x1.6)+(3x1.7x0.5))x3 = 22.0 m^3 Enclosure: 1.4x2x1 = 2.8 m^3	
According to EN 378 and annex to IEC 335-2-40 Ventilation requirements: V = 50x(m)$^{2/3}$ (m^3/h)	230 m^3/h
Danish Emergency Management Agency Ventilation requirements: Emptying of room for gas in 10 minutes	2.8 m^3/10 min x 60 = 16.8 m^3/h
Room classification	
Enclosure	Zone 2 – IP44
Engine room	Unclassified area
Ventilation equipment and channel	Zone 1 – i.e. Ex

Table 4: Ventilation requirements

3.7.2 Safety – operation

All compressors (propane and CO_2) have high and low-pressure switches. The propane compressors also have an internal oil pump and therefore also oil differential switches. The propane system pressure switches are KP 17W with double bellows. The pressure switch bank has an inherently safe circuit as such circuits cannot produce sparks or heat capable of igniting a given explosive atmosphere.

Barriers and contactors are placed outside the propane enclosure (zone 2) in the electrical switchboard (unclassified area).

During operation, the propane system must maintain the pressure in the CO_2 system below 32 bar. The CO_2 compressor cannot run unless the propane system is running

3.7.3 Safety – standstill (CO_2)

Refrigeration systems in supermarkets virtually never stand still – only in the event of failure (power failure). During standstill, the pressure in the CO_2 system will rise slowly. The expansion valves for the CO_2 evaporators will be shut, and the high-pressure side will therefore be blocked between the compressor's pressure valve and the expansion valve. The pressure will rise slowly on account of the heat penetration.

The pressure will rise from the normal condensation pressure of 26.5 baro (-10°C) to 32 baro (-2°C) (safety valve setting) in three or four hours. The current system only has safety valves, meaning that CO_2 will be blown off into the surroundings after three or four hours' standstill of the propane system.

The blow-off occurs slowly and steadily, with the CO_2 oozing from the safety valve at about 0.4 kg/h. Blow-off into the surroundings is the cheapest and most profitable method of reducing pressure in CO_2 systems in supermarkets. Another solution is to use an expansion vessel, but the investment is simply too big.

3.7.4 Safety – service

When servicing the propane system, the fitter can disconnect the pressure monitor so that the enclosure can be opened without cutting off power to the engine room. The fitter does this at the main board in the storage room by using a key switch. Now he can service the propane system without stopping it. Since the fitter is now at risk in the event of a gas leakage (propane), he must bring a *propane detector*, which will warn him of any leakages (concentrations above 4,000 ppm) by producing sound and light signals. During servicing, the door into the engine room must be open. In the event that a leakage occurs while the system is being serviced, and the detector warns the fitter, he must leave the room immediately and cut off power to the engine room.

3.8 Servicing the system

The fitter must be aware of the special properties of propane and CO_2 when servicing the refrigeration system:

Propane	***CO_2***
– **Flammable** refrigerant. Open fire and smoking are prohibited in the engine room in all circumstances!! – The **gas detector** must always be used in the engine room when the vacuum to the propane enclosure is broken. – **Refrigerant** must be added and emptied outside at the filter!!! – Any **propane leakage** in the engine room must be avoided. – In the event that propane **leaks** into the engine room, all power to non-Ex equipment must be cut off!!!	– Use a **CO_2 detector** during work in the room. – **Refrigerant** is added and emptied at the receiver in the engine room. The hose must be placed in the ventilation during emptying. – **Warning** – CO_2 liquid may form dry ice if the pressure drops quickly (<5.18 bar). – **Warning** – CO_2 works at very high pressures, which the propane system must maintain below 30 bar. – **Warning** – very high pressure in all pipes, including suction pipes.

Table 5: Rules for servicing propane and CO_2 systems – posted on the propane enclosure

Extensive servicing of the propane system requires that the CO_2 system be stopped and emptied before the propane system is stopped. When the propane system has been stopped, the pressure will rise above allowable values in two or three hours!

3.8.1 Propane

Propane is added and emptied outdoors on the roof at the drying filter. The system is sucked empty by pump-down and emptied at the filling valve. Propane can be emptied directly into the atmosphere, but at a price of DKK 250/kg.

Propane is added at the filling valve. The outlet end of the drying filter is shut by closing the stop valve. About 10 kg of propane is added to the system. During operation, the sight glass can be used to add the correct charge.

3.8.2 CO_2

The CO_2 system is stopped and emptied by slow blow-off into the atmosphere through a hose to the surroundings (outside the room). CO_2 costs about DKK 15/kg and can be added again. The system must be emptied slowly to prevent the pressure from falling below 5.18 bar while there is still fluid. Otherwise, dry ice will form.

CO_2 can and may only be added to the system if the propane system is running properly (otherwise the pressure cannot be maintained below the threshold value). CO_2 is added at the receiver in the engine room (the pressure here is lower than the saturation pressure of CO_2 at room temperature). The refrigerant can be added during compressor standstill, but the compressor must be running to determine the correct amount to add. The sight glass at the receiver is also used in this case. If the refrigerant is added during operation, it must be added slowly to avoid too high pressures after the compressor.

Use a device with a pressure reducing valve and manometers from e.g. Hydro Gas.

Before starting the system, one must make sure that each refrigerant circuit is operational. The brine circuit is started first. Flushing and degassing are essential to system operation. Moreover, the pump and pump pressure must be checked (engine room).

The propane system can now be started. Evacuation of the system is important as is checking the oil level in the compressor. Once the propane compressor has been started, the system can be filled up. When the propane system has been started and is running properly, the CO_2 system can be started. If the system has been without pressure, it must be evacuated and refrigerant added.

3.8.3 Propane system

- Service
  - Use at least 97.5% pure propane.
  - Use rear gas for welding/soldering and keep the system clean (vacuum must be maintained at 1.5 mbar).
  - Less than 50 ppm moisture in the system (drying filter and moisture indicator).
  - Ventilate room during service.

3.8.4 CO_2 system

- Service
  - At least 99.9% pure CO_2.
  - Use rear gas for soldering and keep the system clean (vacuum must be maintained at 1.5 mbar).
  - Less than 50 ppm moisture in the system (drying filter and moisture indicator).
  - Ventilate room during service.

3.9 Control

System control is based on separate control of compressors and display cases. Danfoss controls are used for both display cases and compressors. The compressors are controlled according to a constant suction pressure. The propane system operates at –14°C, generating an inlet brine temperature of about –10°C and a condensation temperature for the CO_2 system of also –10°C.

Adap-Kool controllers control the display cases independently of the refrigeration system. Blowers, rim heat and defrosting can be controlled. Moreover, condenser blowers and the pump are controlled independently of the compressors.

The expansion valves for the two propane evaporators (brine cooler and cascade heat exchanger) use their own controller, controlling taking place exclusively after superheating.

3.9.1 Propane compressors

- The compressors are controlled by a Danfoss AKC 25H1 control.
- The compressors are exclusively controlled according to the evaporator pressure (initially set to 3 bar abs. ~ -14°C).

- The propane system may not be started unless the brine pump is running.
- Safety in the form of oil differential pressure and high-pressure switches connected to AKC 25H1.
- Expansion valves (propane) are shut during compressor standstill.

3.9.2 Propane condenser

- ECO type FCE 071C63
- Three condenser blowers controlled by AKC 25H1 through pressure transmitter and neutral zone controller, with the set point being 25°C.

3.9.3 Propane expansion valves

- A Danfoss AKC with ETRE expansion valve controls the brine heat exchanger.
- A Siemens Steafa valve controls the cascade heat exchanger.

3.9.4 Brine pumps

The system has been equipped with a Grundfos CRE 5-4 brine pump. The pump comes with Grundfos' own control. The pump can receive a control signal from the differential pressure transmitter mounted in the rack or above the brine heat exchanger.

3.9.5 CO_2 compressor

- Controlled by AKC 25H5 with frequency transformer VLT 2800, with the set point for suction pressure set initially to 14 bar abs. (~ -32°C).
- The compressor may not be started unless the propane system is running.
- High and low-pressure switches connected (the compressor has no oil pump).

The CO_2 compressor starts by force a propane compressor at half capacity. The AKC 25H5 determines the number of revolutions of the compressor.

An internal PI controller adjusts the number of revolutions, with the amplification and integration constant being set to achieve a moderate, bordering on small, adjustment in the number of revolutions. Slowly adjusting of the number of revolutions of the CO_2 compressor slowly raises the condensation pressure, thus making it more possible for the injection valve to adjust superheating at the propane side of the cascade heat exchanger.

3.9.6 Cascade heat exchanger adjustment

In this case, the injection valve on the cascade heat exchanger is a Siemens Staefa valve – controlled by a Siemens PolyCool controller. The controller is a "pure" PID controller with overheating signal as process variable.

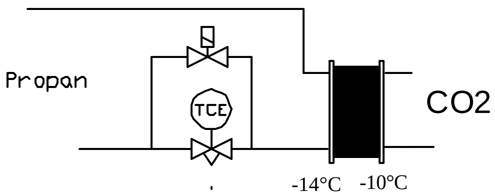


Figure 7: Bypass on cascade heat exchanger

During start-up, pressure at the CO_2 side increases quickly. The overheating signal at the propane side rises more slowly because of a large P-band, and the CO_2 compressor stops at high pressure.

The broad P-band is required because the CO_2 gas is +45°C on inlet and -10°C on outlet.

The differential element is set high to compensate for a broad P-band, meaning that relatively small changes in the process variable (superheat) cause a reaction in the valve. Unfortunately, the valve also reacts quickly and shuts when small amounts of liquid are primed.

The conclusion on this inaccurate start-up sequence is that the controller must control the valve with a start-up routine maintaining the opening of the valve during start-up for a pre-set period; the PID controller is subsequently released to control the valve. During normal operation, the controller is only to use proportional control.

In this case, the start-up routine has been fixed with a bypass as shown in figure 7; this will not be the only solution to the problem in future. Several suppliers are implementing a start-up routine in their software.

3.9.7 KA value

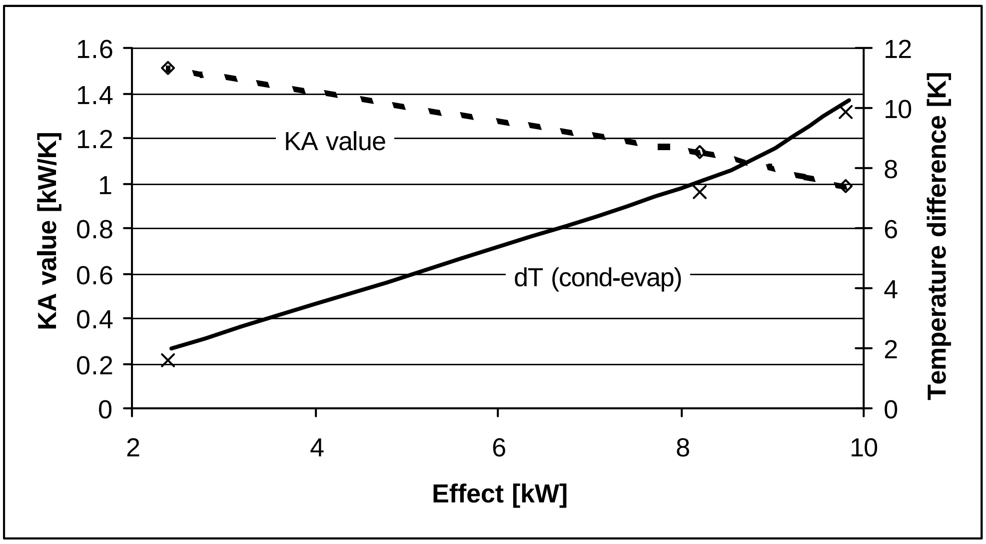


Figure 8: Cascade heat exchanger's temperature difference and KA value depending on effect

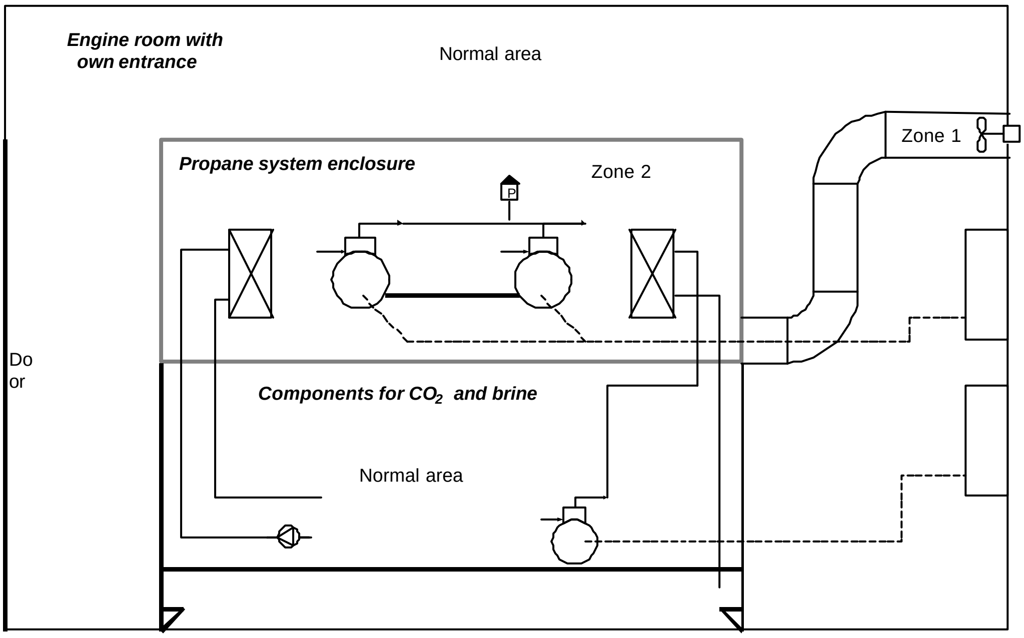
As can been seen from the figure, the temperature difference depends greatly on the effect. The relationship is even enhanced when the heat exchanger's KA value falls as the effect increases.

3.10 Daily operation

Reference is made to file no. 731327/99-0199 for system operation: demonstration of natural refrigerants in supermarkets.

3.11 Zone division and electrical installations

Zone classification:



The Danish Emergency Management Agency exclusively determines zone classification in Denmark. The agency has found that the ventilation of the enclosure is sufficient to maintain any gases at or below 25% of the lower explosion band, and that special safe ventilation ensures that all non-EEx equipment is disconnected in the event of ventilation failure. This means that the enclosure has been classified as zone 2 during normal operation and as zone 1 in the event of failure. The area outside the propane enclosure but inside the engine room is unclassified. The ventilation channel is zone 1, so the ventilator must comply with EEx (fire technology instructions no. 19).

In the event of ventilation failure, the main switch to the entire refrigeration installation will be switched off, i.e. display case controls, display case lights, etc. However, alarms can still be sent from the system.

A safety valve protects the system against too high design pressure at the high-pressure end. The area around the blow-off from the safety valve has also been classified as zone 2; the valve is located on the roof. The blow-off opening from the brine system air-escape valve has also been classified as zone 2.

3.11.1 Zone 2

Zone 2 areas are areas where an explosive atmosphere exists only in exceptional cases and then only for a short period of time. The 60079-10 harmonised standard defines short periods as no more than ten hours per year.

3.11.2 Electrical installations

The electrical installations comply with the Danish Electricity Council's Danish Heavy Current Executive Order, chapter 704 – Potentially explosive areas. According to the order, the material used in zone 2 must be at least IP 44, the surface temperature must not exceed 100°C, and sockets must have covers. General rules also apply to dangerous sparks and inherent safety requirements for the use of material in connection with gas groups IIA, IIB and IIC.

The requirements contained in the order regarding installations in potentially explosive areas resemble those contained in EN 60079-14.

3.11.3 Propane

Propane belongs to the IIA gas group and T1 temperature class – identical to $NH_{3.}$

3.11.4 Inherent safety

Inherent safety is understood as: a circuit that both during normal operation and during failure cannot produce any sparks or heat of such a nature that a given potentially explosive atmosphere can be ignited.

3.11.5 Electrical components in Fakta Beder

The propane system in Fakta Beder contains pressure switches for high and low-pressure monitoring, pressure transmitters for controlling compressors and oil-pressure monitoring. All these components are in direct contact with propane. The components are fitted in a zone 2 area (the propane enclosure). The common provisions on potentially explosive areas comprise these components. Therefore, the requirements include inherent safety for pressure transmitters and protection against dangerous sparks between banks in pressure switches. PLC replaces the timer function of the oil differential pressure monitor.

The pressure switches have double bellows, gold switches and IP 54 encapsulation (KP17W). Where the voltage to the bank does not exceed 8 v, EEx-approved impulse isolators (from PR) offer protection against sparks.

The oil differential pressure monitor on the compressors is undertaken by conventional MP54s, where the heating element has been replaced by a small PLC located outside zone 2 in an electric cabinet.

Pressure transmitters for compressor control have an inherently safe circuit with an EEx-approved Zener barrier (from PR).

The compressor terminal box complies with IP54 and has a special terminal block. An anchor pipe separates the coils for solenoid valves from the gas. The coils meet IP67 and the voltage is 24 v AC.

Whether chapter 704 of the Danish Heavy Current Executive Order requires the use of an inherently safe circuit in connection with pressure transmitters is debatable.

3.12 ATEX directive

The implementation of the ATEX Directive by Orders nos. 696 and 697 with effect as from 30 June 2003 means that chapter 704 of the Danish Heavy Current Executive Order can no longer be used as a foundation. The directive covers electrical and mechanical equipment used in potentially explosive atmospheres. The implementation of the directive means that the harmonised standards will provide the foundation for meeting the ATEX Directive.

The harmonised standards for electrical equipment are EN 60079-10 - 17 and EN 50014-50021.

All electrical and mechanical equipment to be used in an EEx area must be approved and certificated according to EN 500014 - 20.

The following applies to zone 2 equipment: equipment suitable for zone 0 or 1 or equipment particularly suited for zone 2 may be used. For instance, ”n” protection or equipment encapsulated according to IP54 and that does not produce sparks. Equipment potentially producing sparks must meet the requirements set out in IEC 79-11.

Implementation of the ATEX Directive ensures uniform safety and health conditions through joint European rules and guidelines.

3.12.1 ATEX and Fakta Beder

However, the implementation of the ATEX Directive will not tighten electrical installations requirements. The rules may be less ambiguous and clearer.

Manufacturers of components for EEx installations must document compliance with the directive and the harmonised standards. The product must be CE-marked according to ATEX.

After 30 June 2003, pressure transmitters must comply with EEx and bear the CE marking and the “EEx” stamp showing compliance with “ia” or “ib” standards, which indicates IIA protection, the gas group for propane, etc., and T1 for the temperature class. The marking will be ”better” in practice. In general, components are classified for higher gas groups and temperature classes than the ones mentioned here.

The pressure switches must also bear the CE marking and be protected by Zener barriers. Chapter 704 of the Danish Heavy Current Executive Order often relies on the harmonised standards applicable from 30 June 2003. Therefore, the fitter will find no significant differences.

3.12.2 Comments

The implementation of the ATEX Directive means that the “new” method of approving installations will also cover the electric part , i.e. the manufacturer must document compliance with the directive and put the CE marking on the unit in keeping with the PED. The unit supplied (the refrigeration system) must also bear the CE marking as regards ATEX.

4 Energy

The Fakta chain of supermarkets consists of about 250 outlets between 0 and 25 years old. This means that the outlets' refrigerated installations vary and reflect developments in refrigeration technology over the past 25 years. Hence, the outlets cannot be regarded as a homogeneous quantity, but must be grouped according to age and type of installation. In recent years, new outlets have been established on the basis of a specific concept. So today a large number of outlets only vary slightly in terms of square metres, number of lights, ventilation and refrigerated installations.

4.1 Reference outlets

The outlets constituting Fakta Beder's basis of comparison are all relatively new and more or less of the same size. They have around 32-39 metres of refrigerated equipment, comprising islands, refrigerated cabinets, refrigerated and freezer rooms, displaying foods to customers.

The outlets' total power consumption is registered monthly through the refrigeration system's monitor and control system. The power consumption reflects the outlets' homogeneity. The power consumption of the individual outlet depends of course on staff behaviour, geographical location of the outlet, turnover and opening hours, but variations are limited.

In other words: although the power consumption is influenced by many parameters and these vary significantly, a pattern can still be seen in the breakdown of power consumption of the various outlets.

The power consumption indicates when something is "normal" and when something is not normal in the individual outlet.

This homogeneity results in a distribution scale for the power consumption of the Fakta chain of supermarkets.

The scale is in keeping with "Industry energy analysis (supermarkets)", category 1/2/:

Refrigeration/freezing system:	64%
Lighting:	33%
Other:	3%

The accordance between the distribution scale and the breakdown of energy consumption at Fakta has been tested and established by an internal survey among thirty Fakta outlets. The scale's accordance has also been confirmed by a new internal Fakta report, with COWI /3/ looking at ten different outlets (appendix 7)

4.1.1 Inaccuracy

Using the energy consumption registered in many outlets as a reference transfers the inaccuracy of each measurement from inaccuracy relating to measuring equipment, correction factors, running hours, etc., to inaccuracy of key figures. Having many measurements for many homogeneous outlets means that the inaccuracy of key figures is reflected in the variation in consumption.

4.1.2 Random testing

Fakta Solbjerg is identical to Fakta Beder in many ways and also matches the reference group. The outlets are relatively new, have 32 metres of refrigerated equipment, three cash registers and electric doors. They differ in terms of ventilation, outdoor lighting and number of square metres.

Fakta Solbjerg's energy consumption for July 2001 totalled 12,932 kWh. The outlet is open Monday to Friday from 9 am to 7 pm and Saturday to Sunday from 9 am to 5 pm.

The outlet's power consumption is generated by refrigeration/freezing systems and lighting, depending on the number of opening hours plus one hour before and after opening hours (staff behaviour of Fakta Beder). Fakta Solbjerg has 192 fluorescent 58 kW lamps.

4.1.2.1 Breakdown by lighting

As regards Fakta Solbjerg, we only know the total energy consumption and the number of fluorescent lamps. Energy consumption of lighting is found by multiplying the number of lamps by the power consumption per lamp and number of running hours. The energy consumption of refrigeration/freezing is found by subtracting the energy consumption for lighting from total consumption. Consumption for other purposes is estimated at 3%.

Energy key figure breakdown at Solbjerg in July	Breakdown by lighting in July:
64% of 12,932 for refrigeration/freezing: 8,276kWh	8,214 kWh (12,932–3,942–776) kWh
33% of 12,932 for lighting: 3,880 kWh	3,942 kWh
3% of 12,932 for other : 776 kWh	776 kWh

It appears that the key figure breakdown only deviates by 1-2% from the breakdown by the number of opening hours and lighting power consumption, indicating that the use of key figures to compare the energy consumption of refrigeration/freezing systems does not increase inaccuracy.

4.1.3 Outlets

The following table lists selected reference outlets and individual measurements from year 2000 (see appendix 1 for full table).

Outlet	Sunday	Metres of cases	July kWh	July kWh/rfg-frz	August KWh	August kWh/rfg-frz
Hals	Yes	32	15441	9882	15088	9656
Skibhusvej	No	36	10445	6685	10810	6918
Kolding	Yes	39	13936	8919	13964	8937
Grenå	No	33	11171	7149	12976	8305
Farsø	Yes	32	14342	9179	14251	9121
Børkop	Yes	32	14528	9298	14510	9286
Hjallerup	Yes	32	12256	7844	12464	7977
Struer	Yes	32	13887	8888	14334	9174
Middelfart	No	38	12750	8160	13192	8443
Viborg	No	37	13106	8388	13106	8388
TOTAL eight outlets			105977	67825	108798	69630
Average			13247	8478	13600	8704
Lower quartile			-15.7%	-15.7%	-8.4%	-8.4%
Upper quartile			9.7%	9.7%	6.7%	6.7%

Table 6: Summary of table of reference outlets' energy consumption (see also appendix 1)

Outlets nos. 31 and 158 (the top two) are not included in the average calculation as they are outside the normal range.

The other outlets are comparable. For outlets with more than 32 metres of refrigerated equipment, energy consumption has been equated to 32 metres. Allowance has also been made for outlets not usually open on Sundays.

In the event that the consumption of an outlet of this group is within these limits, the situation is normal (i.e. deviations can be explained by staff behaviour, climate, different installations, etc.).

4.1.4 Total energy consumption (reference outlets)

Consumption of the eight outlets for the year breaks down as follows:

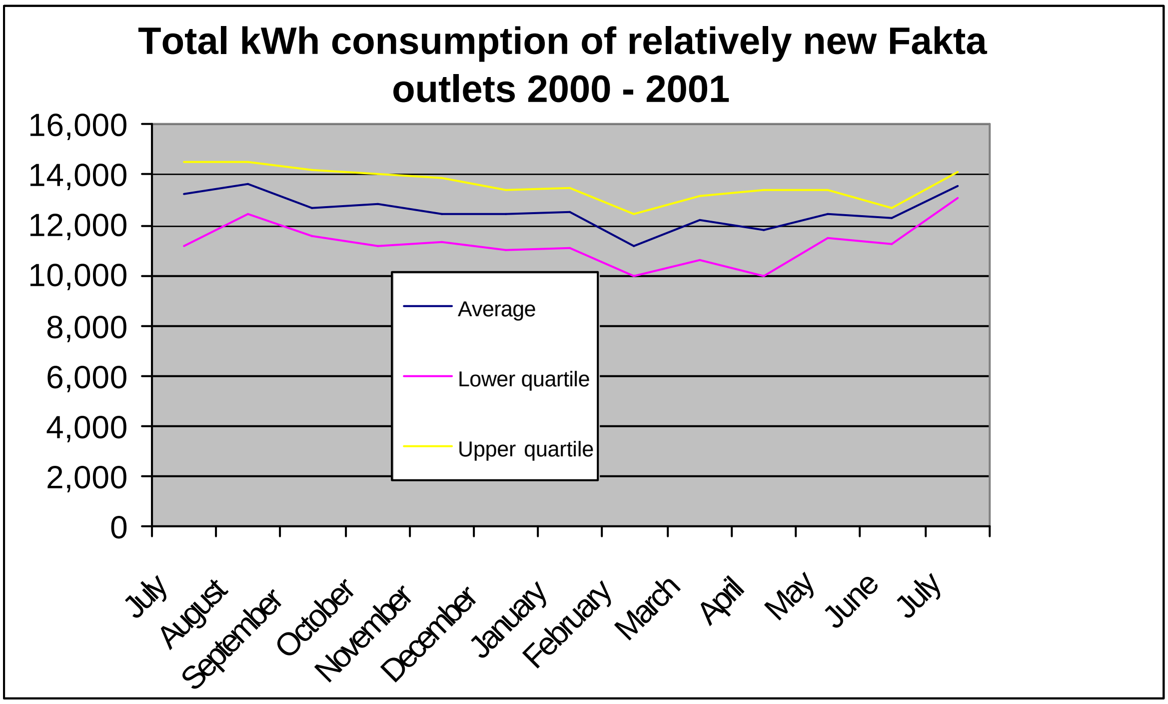


Figure 9: Energy consumption – Fakta Beder

4.2 Energy meters at Fakta Beder

Fakta Beder's power consumption is registered at three locations. In addition to the outlet's total consumption, the total consumption is registered for refrigerated installations, i.e. compressors, fans, rail heating, case lighting, pump and defrosting heating elements, and the brine pump has an electricity meter.

4.2.1 Power consumption (outlet)

Consumption breaks down as follows:

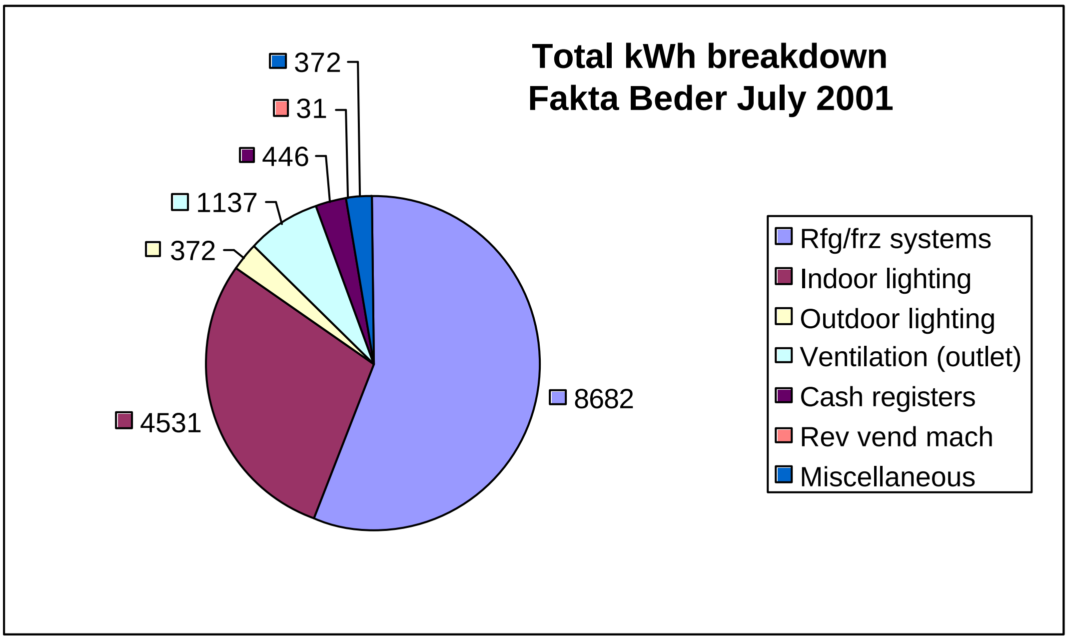
	Number	kW each	Running hours/day
Rfg/frz systems	1	8682	24
Indoor lighting	210	0.058	12
Outdoor lighting	10	0.1	12
Ventilation (outlet)	1	2.62	14
Cash registers	3	0.4	12
Reverse vending machine	1	1	1
Miscellaneous	1	2	12

Table 7: Power consumption – Fakta Beder

Unlike the reference outlets, Fakta Beder has a ventilation system.

4.2.2 Energy consumption (outlet)

The outlet's consumption of energy in July breaks down as follows:



The refrigeration/freezing system accounts for 8,682 kWh of total energy consumption.

4.2.3 Power consumption by refrigeration/freezing component

The power consumption of the individual refrigeration/freezing components breaks down as follows:

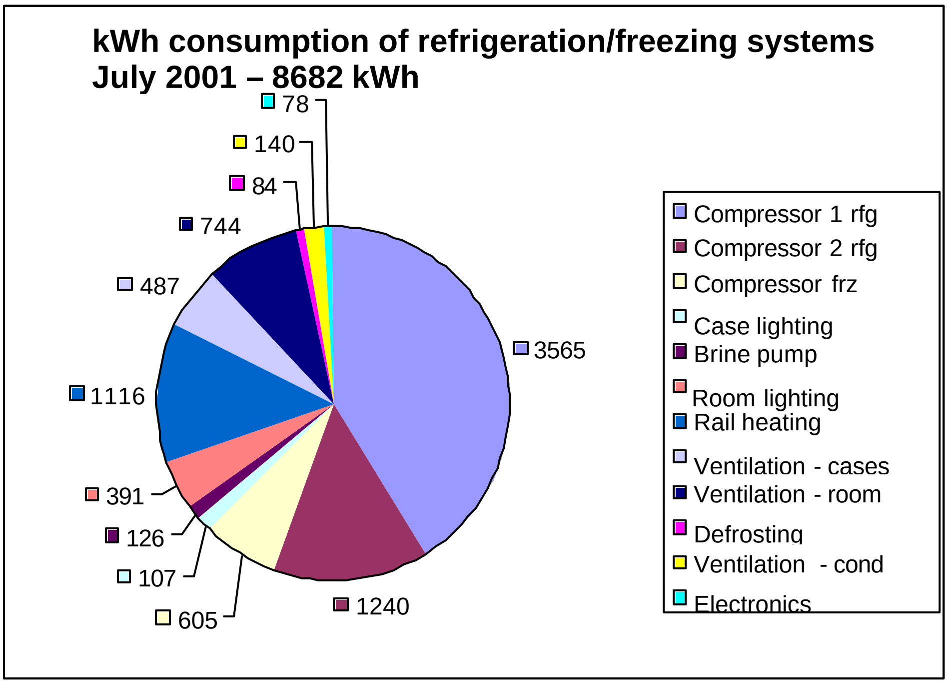
Unit name	Number	kW/each
Brine pump	1	~ 0.4
Compressor 1 (rfg)	1	~ 5.5
Compressor 2 (rfg)	1	~ 5.5
Compressor (frz)	1	~ 1
Display case lighting	8	0.072
Room lighting	15	0.07
Rail heating	10	~0.15
Fans (display cases)	23	0.038
Fans (rooms)	8	0.125
Defrosting	12	~0.9
Fans (condenser)	3	0.125
Electronics	11	0,01

Table 8: Refrigeration/freezing system (kW/unit).

Power consumption values preceded by a tilde (~) are average values. These values are the result of measuring the change in the total power consumption of each unit at repeated starts. Other values are values specified on the unit in question. Some unit running hours have been determined on the basis of logs from the Adap-Kool system. Other running hours have been determined on the basis of system setup values.

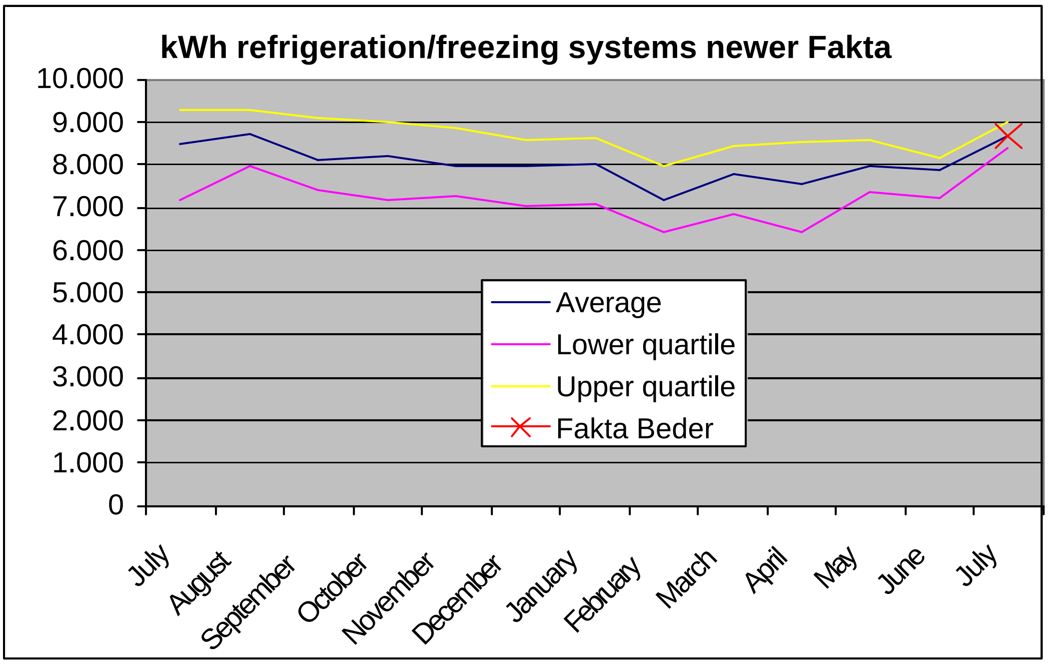
4.2.4 Power consumption (refrigeration/freezing system)

The July power consumption of the Fakta Beder refrigeration/freezing system breaks down as follows:



4.2.5 Comparison between measured consumption and consumption broken by key figures

This chart compares the measured energy consumption of the refrigeration/freezing system installed at Fakta Beder with a reference system's energy consumption broken down by key figures:



The refrigeration system installed at Fakta Beder is within normal limits.

There are no material changes in reference outlets' energy consumption in July, and their consumption varies by as little as 3-4% from average energy consumption. The measured energy consumption of the Fakta Beder refrigeration/freezing system accounts for 60.1% of total equivalent consumption.

The Fakta Beder system thus supports Fakta's energy distribution model. Yet total consumption must be adjusted for the amount of energy used for ventilation.

Fakta Beder is the result of the latest concept in the Fakta chain of supermarkets, implying more square metres, more outdoor lighting, display cases adapted to lower temperatures with more hot wires to prevent condensation, etc. The model is supported despite these variations.

4.3 Optimisation

The reference systems all have direct expansion of R404A and Scroll compressors. As in all Fakta outlets, these systems are equipped with Adap-Kool controllers.

As mentioned above, the system installed at Fakta Beder uses a brine circuit for refrigerated display cases and rooms.

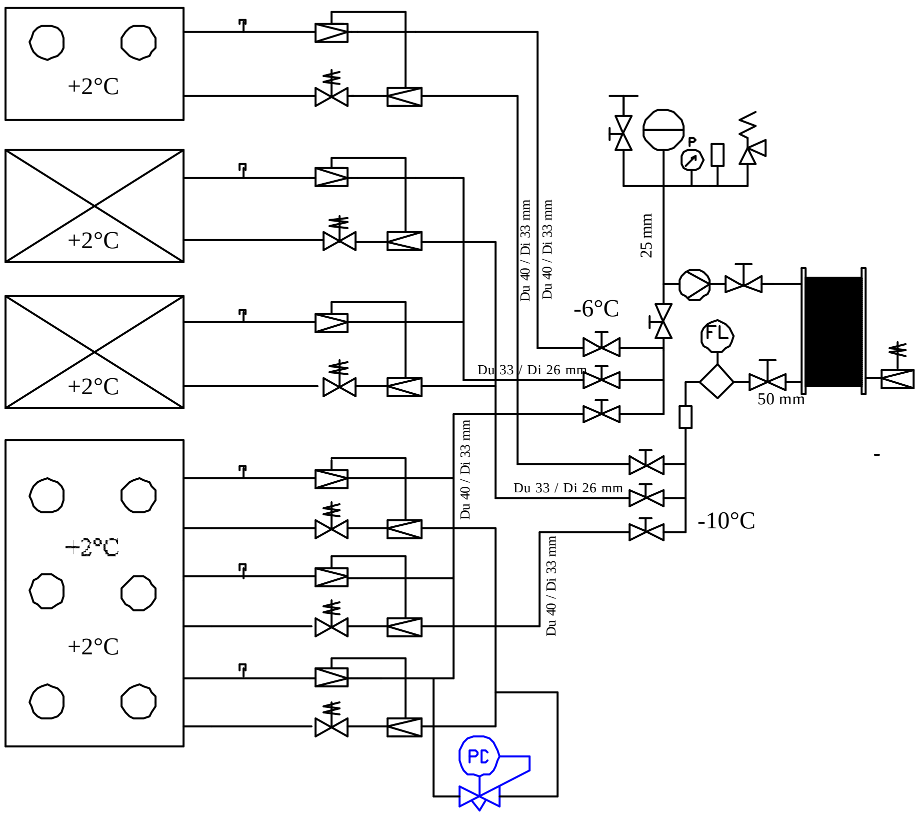


Figure 10: Schematic diagram of a brine circuit

A simple on/off function was installed in July 2001 to control refrigerated surfaces. The differential pressure valve (the “PC” valve) was not installed, so the modulating temperature control function cannot be used. A modulating temperature controller is a special Danfoss thermostat for keeping the surface temperature of refrigerated surfaces constant using on/off pulsation. The solenoid valve function cannot be used without bypass control.

Inadequate brine circuit control causes refrigeration compressor 2 to start too many times. The reason is that both the flow and the temperature change at great speed, causing the compressors, as a result of a high plate heat exchanger load, to quickly bring down suction pressure to its normal level. For this purpose, compressor 2 must be turned on and off quickly. Bypass control uses the buffer effect present in the brine circuit, thus reducing the number of times the compressor starts and thereby saving energy.

(Optimum brine circuit control is studied in (file no. 1253/00-0023) “Controlling and monitoring refrigeration systems optimally in terms of energy”.)

4.4 Conclusion (energy)

Unsurprisingly, the energy consumption is identical to that of conventional R404A systems. To put it briefly, propane and CO_2 have far better heat transfer figures than R404A, but the system using a cascade heat exchanger and a brine circuit has a loss of energy, thus causing the two systems to match each other.

Improving the propane/CO_2 design is always possible, but it is important to optimise the brine circuit to achieve a constant load on the propane compressor in order to use the brine buffer effect to save energy.

5 Project finances

Tom Gøtsch, Super Køl A/S, wrote this chapter.

5.1 Statement of project finances

The statement of project finances is based on registration of hours/costs as shown below:

Refrigeration:	System	Display cases	Installation Materials	Installation Hours
Costs	X	X	X	X
Total cost price	XX	XX	XX	XX

Power:	Adap-Kool board	Electrical switch board	Installation
Costs	X	X	X
Total cost price	XX	XX	XX

For competitive reasons, all figures have been converted proportionately as the final conclusion of the statement of project finances is based on a comparison with basic calculations made for a Fakta HFC parallel system.

Statement of project finances (index = construction costs = 100):

Refrigerant installation:	System	Display cases	Installation Materials	Installation Hours	Total
Total costs (refrigeration)	100	244	64	91	499
HFC concept system, including tax *	85	237	49	72	443
Extra costs CO_2/propane	15	7	15	19	56
%	18%	3%	31%	26%	13%

* after first fill

Electrical installation:	Adap-Kool board	Electrical switch board	Installation	Total
Total costs (power)	32	56	52	140
HFC concept system, including tax	30	23	38	91
Extra costs CO_2/propane	2	33	14	49

Total project:	CO_2/ propane	Convent. HFC system	Dif. Total	%
Refrigerant installation	499	443	56	13%
Electrical installation	140	91	49	54%
Total	639	534	105	20%

5.1.1 Total extra costs are mainly affected by the following three factors:

1. Electrical switch board
2. Installation (refrigeration system)
3. Design (refrigeration system)

Electrical switch board

The electrical switch board is affected particularly by:

- Frequency converter
- Special circuit breaker (AC/DC)
- Fuse circuit design
- 2 x compressor control, depending on frequency converter
- Oil control using PLC

If the solution is simplified, certain components are replaced (AC/DC relay and 1 x compressor control, in particular) and the oil control design is changed, the total project index is likely to drop from 56 to 40.

Installation (refrigeration system)

The process of installing the refrigeration system is affected by a lack of installation experience and a certain element of training the fitters involved in the project. Installation on the basis of some experience is likely to be made at index 75 rather than index 91.

Design (refrigeration system)

Increased system design experience and competition especially in regard to heat exchangers and compressors are likely to reduce the index from 100 to 90.

Assessing the Fakta Beder CO_2/propane project on the basis of the above adjustments will result in the following calculations:

			Dif.	
Adjusted total project:	**CO_2/ propane**	**Convent. project**	**Total**	**%**
Refrigerant installation	499	443		
÷ adjustments	÷26	-		
	473	443	30	7%
Electrical installation	140	91		
÷ adjustments	÷16	-		
	124	91	33	36%
Total (less adjustments)	597	534	63	12%

5.2 Conclusion (project finances)

The CO_2/propane system and the chosen installation at Fakta Beder result in total extra costs ranging from 12 to 20% (from 27 to 18% for system and installation in isolated terms).

Looking at the extra costs of the CO_2/propane system on the basis of the Fakta Beder installation, one can make the following general statement:

The extra costs of the system will decrease considerably if its total kW needs increase. An estimate shows that the extra construction costs as far as refrigeration is concerned will be neutral if the capacity requirements increase by a factor of three (about 60 kW for refrigeration and about 30 kW for freezing).

The following conclusion can thus be made: the total extra costs of building a system that is three times larger than the Fakta Beder installation will range from 6 to 11%. This conclusion allows for the fact that the alternative HFC fill volume will also increase by a factor of three, implying that tax will have a substantially larger effect on calculations.

6 Results

For the second time, the supermarket sector has seen the design, installation and run-in of a refrigeration system whose principle is different and based on natural refrigerants. Unlike the components used in the first supermarket, components well known to a standard refrigeration fitter have now been used, and they have proved their capabilities.

The project has demonstrated how to use new design rules for copper pipe installations; how to use hoses for indirect refrigeration; that string control valves are not needed in small-scale brine circuits; that CO_2 installation for low temperatures (without oil separator and suction gas cooler) is simple; that EEx installations can be made at low costs; and that cascade refrigerator control is easy.

The project shows that the system principle is neutral in terms of energy compared with a conventionally optimised R404A system. The energy consumption of the Fakta Beder refrigeration system has been measured directly and compared with that of eight representative outlets. The system has thus reduced the direct, equivalent CO_2 contribution by 357 tonnes by removing 90 kilos of R404A from the outlet.

The project shows that it is possible to reduce the consumption of energy through brine circuit optimisation. The brine circuit is not optimal in terms of control. However, this has not caused the outlet any direct problems, but has resulted in too many and frequent compressor starts. It is therefore very positive to learn that the system is neutral in terms of energy at the moment.

The project shows that component and installation costs are about 20% higher than those of a conventional R404A system; that it is possible to reduce costs; and that HFC tax will feed “more clearly” through in large-scale systems. Consequently, the increase in costs will be negligible (5 – 10%).

Since its upstart, the refrigeration system has run with no failure or problems. The system has met the conditions intended and keeps the temperature at -20°C in freezer display cases and at +2°C in refrigerated display cases. The system’s qualities have proved satisfactory especially under very hot conditions.

This report has brought about a good deal of work and a large number of descriptions as regards the design of the propane system. The main reason is that commercial refrigeration has previously not been subject to Order no. 743, so data must be processed, interpreted and understood in order to form the basis for future discussions.

There has been no particular focus on the CO_2 system. This seems slightly unfair as this system is working exceptionally well. The CO_2 system had no difficulty keeping the temperature during the summer although its dimensioned load equals the freezing system’s maximum capacity. The compressor has not run at full capacity during long periods – not even during the very hot days of July. The set point temperature is –32°C for suction pressures, and the freezer room temperature must be kept at –25°C .

List of references

/1/ Hydracarbons in mid-sized refrigeration systems. Danish Environmental Protection Agency.

/2/ Industry energy analysis (supermarkets). 1994.

/3/ COWI report (Fakta). 2001.

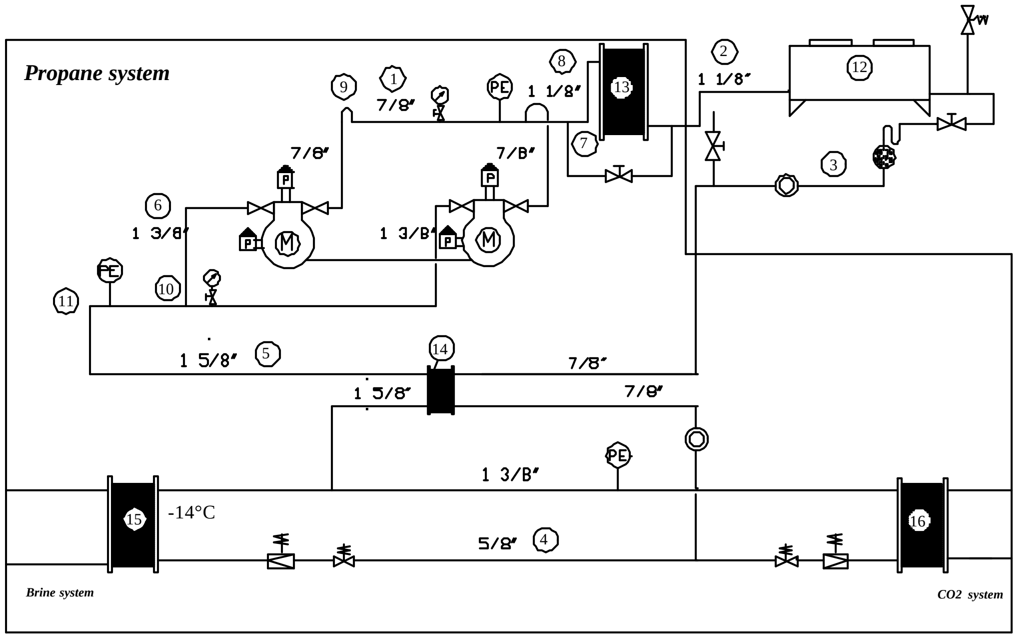
Reference outlets' energy consumption for refrigeration/freezing – July 2000 to July 2001

Outlet number	Name	Sunday	Metres	Jul 2000 kWh/ rfg/frz	Aug kWh/ rfg/frz	Sep kWh/ rfg/frz	Oct kWh/ rfg/frz	Nov kWh/ rfg/frz	Dec kWh/ rfg/frz	Jan 2001 kWh/ rfg/frz	Feb kWh/ rfg/frz	Mar kWh/ rfg/frz	Apr kWh/ rfg/frz	May kWh/ rfg/frz	Jun kWh/ rfg/frz	Jul kWh/ rfg/frz
31	Hals	Yes	32	9882	9656	8672	8868	8460	8845	8918	8389	8970	8744	9214	9424	10303
158	Skibhusvej	No	36	6685	6918	6548	7009	6490	6891	6669	5906	6669	6386	6931	6652	7354
				0	0	0	0	0	0	0	0	0	0	0	0	0
12	Kolding	Yes	39	8919	8937	8395	8754	8298	8529	8262	7480	8133	7881	8098	8169	8525
14	Grenå	No	33	7149	8305	7912	7995	7513	7685	7480	6668	7323	6907	7605	7563	8613
19	Farsø	Yes	32	9179	9121	8427	9005	8601	8587	8643	7968	8419	8303	8581	8140	8901
23	Børkop	Yes	32	9298	9286	9098	8985	8872	8448	8464	7581	7990	7939	8349	8042	9053
25	Hjallerup	Yes	32	7844	7977	7475	7581	7293	7529	7627	6637	7514	7350	7689	7985	8426
26	Struer	Yes	32	8888	9174	8358	8851	8396	8257	8612	7472	8368	8549	8691	8362	9013
69	Middelfart	No	38	8160	8443	7416	7152	7662	7030	7078	6393	6816	6410	7375	7212	8456
118	Viborg	No	37	8388	8388	7834	7281	7274	7659	7810	7142	7864	7035	7381	7382	8388
	TOTAL eight outlets			67825	69630	64914	65604	63909	63724	63974	57342	62425	60373	63770	62855	69376
	Average			8478	8704	8114	8200	7989	7965	7997	7168	7803	7547	7971	7857	8672
	Lower quartile			-15.7%	-8.4%	-8.6%	-12.8%	-8.9%	-11.7%	-11.5%	-10.8%	-12.7%	-15.1%	-7.5%	-8.2%	-3.3%
	Upper quartile			9.7%	6.7%	12.1%	9.8%	11.1%	7.8%	8.1%	11.2%	7.9%	13.3%	7.7%	3.6%	3.9%
	Lower quartile			7149	7977	7416	7152	7274	7030	7078	6393	6816	6410	7375	7212	8388
	Upper quartile			9298	9286	9098	9005	8872	8587	8643	7968	8419	8549	8581	8140	9013

Assessment of Fakta Beder's piping system according to PED, NWEA Order no. 743/99 article 3

(Copper pipes supplied by Tempcold)

Operating conditions according to EN 378-2:2000 chp. 5

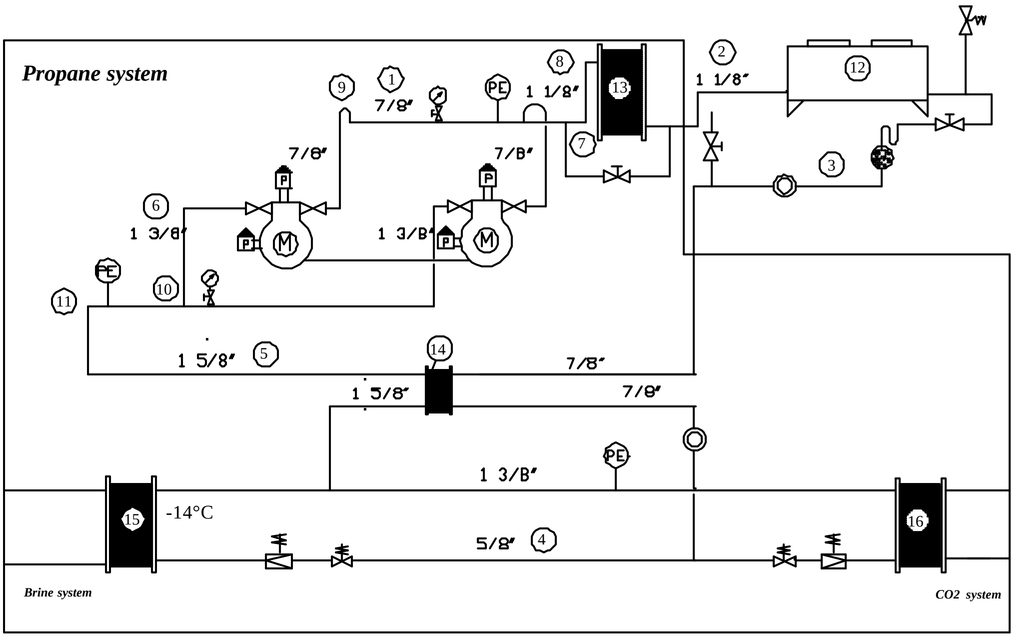


Position	Type	Basis of design	Risk assessment Operating conditions according to EN 378-2 chp.5	Copper pipes 99.9% Cu 0.03% P. alloy C12220 Standard of production: DIN 1754 Outukumpu	Maximum allowable pressure PS	PSxV PSxDN	Safety category for fluids in group 1	Certificate of material
1	Hot gas pipe	Order no. 743, art. 3	Ambient temp. < 32º high pressure 55ºC = 18 bar	7/8" DN22.3 (22.22 x 1.02)	18	403	Art. 3(3)	
2	Hot gas manifold	Order no. 743, art. 3	Ambient temp. < 32º high pressure 55ºC => 18 bar	1 1/8" DN28.6 (28.58 x 1.02)	18	517	Safety category 1	3.1B
3	Joint liquid pipe	Order no. 743, art. 3	Ambient temp. < 32º high pressure 55ºC => 18 bar	7/8" DN22.3 (22.22 x 1.02)	18	403	Art. 3(3)	
4	Liquid pipe	Order no. 743, art. 3	Ambient temp. < 32º high pressure 55ºC => 18 bar	5/8" DN15.9 (15.88 x 0.9)	18	286.2	Art. 3(3)	
5	Joint suction pipe	Order no. 743, art. 3	Ambient temp. < 32º low pressure 32ºC => 10.3 bar	1 5/8" DN41.2 (41.28 x 1.22)	18	741.6	Safety category 1	3.1B
6	Suction pipe	Order no. 743, art. 3	Ambient temp. < 32º low pressure 32ºC => 10.3 bar	1 3/8" DN34.9 (34.92 x 1.07)	18	628.2	Safety category 1	3.1B
7	T-joint (high pressure)	Order no. 743, art. 3	Ambient temp. < 32º high pressure 55ºC => 18 bar	1 1/8" DN28.6 (28.58 x 1.16)	18	517	Safety category 1	Supplier's declaration
8	90º angle (high pressure)	Order no. 743, art. 3	Ambient temp. < 32º high pressure 55ºC => 18 bar	1 1/8" DN28.6 (28.58 x 1.16)	18	517	Safety category 1	Supplier's declaration
9	90º angle (high pressure)	Order no. 743, art. 3	Ambient temp. < 32º high pressure 55ºC => 18 bar	7/8" DN22.3 (22.22 x 1.02)	18	403	Art. 3(3)	Supplier's declaration
10	T-joint (low pressure)	Order no. 743, art. 3	Ambient temp. < 32º low pressure 32ºC => 10.3 bar	1 5/8" DN41.2 (41.28 x 1.22)	18	743.04	Safety category 1	Supplier's declaration
11	90º angle (low pressure)	Order no. 743, art. 3	Ambient temp. < 32º low pressure 32ºC => 10.3 bar	1 5/8" DN41.2 (41.28 x 1.22)	18	743.04	Safety category 1	Supplier's declaration

Position	Type	Basis of design	Risk assessment Operating conditions according to EN 378-2 chp.5	Copper pipes	Maximum allowable pressure PS	PSxV PSxDN	Safety category for fluids in group 1	Certificate of material
12	Condenser	Order no. 743, art. 1 (2.1.2)	Ambient temp. < 32º high pressure 55ºC = 18 bar	35 circuits 3/8" (9.53 x 0.81)	18	171.54	Art. 3(3)	
12	Condenser (inlet)	Order no. 743, art. 1 (2.1.2)	Ambient temp. < 32º high pressure 55ºC = 18 bar	35 x 1.5	18	630	Safety category 1	3.1B
12	Condenser (outlet)	Order no. 743, art. 1 (2.1.2)	Ambient temp. < 32º high pressure 55ºC = 18 bar	28 x 1.5	18	504	Safety category 1	3.1B

Appendix 2

Safety categorisation of SWEP plate ex-changers

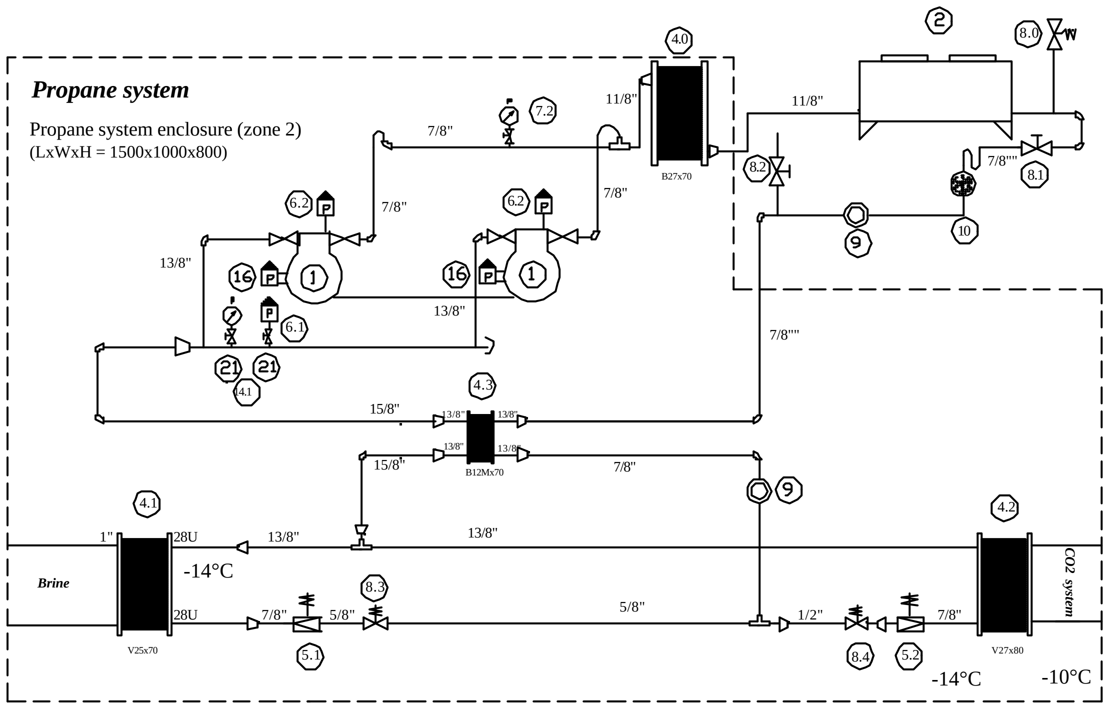


Safety assessment of plate heat exchangers, Fakta Beder:

Position	Function	Type	Volume (litres)	Design pressure according to:	Safety category	Gas group	PSxV
15	Evaporator brine/propane	SWEP V25x70	3.8 litres (propane)	EN378-2-2000 chp. 5 Ambient temperature < 32ºC (low-pressure side) i.e. 32ºC/11.2 bar (abs)	1	1	3.8*11.2 = 42.5
14	Suction gas heat exchanger	SWEP B12x70	1.9 litres (liquid side, propane)	EN378-2-2000 chp. 5 Ambient temperature < 32ºC (high-pressure side) i.e. 43ºC/14.6 bar (abs)	1	1	1.9*14.6 = 27.7
14	Suction gas heat exchanger	SWEP B12x70	2.4 litres (gas side, propane)	EN378-2-2000 chp. 5 Ambient temperature < 32ºC (low-pressure side) i.e. 32ºC/11.2 bar (abs)	1	1	2.4*11.2 = 26.9
16	Cascade propane/CO_2	SWEP V27x80	4.3 litres (propane)	EN378-2-2000 chp. 5 Ambient temperature < 32ºC (high-pressure side) i.e. 32ºC/11.2 bar (abs)	1	1	11.2*4.3 = 48.1
16	Cascade propane/CO_2	SWEP V27x80	4.4 litres (CO_2)	Safety valve SFV 15 30 bar	1	2	4.4*30 = 132
13	Heat recovery (superheat remover)	SWEP B27x50	2.8 litres (propane)	EN378-2-2000 chp. 5 Ambient temperature < 32ºC (low-pressure side) i.e. 43ºC/14.6 bar (abs)	1	1	2.8*14.6 = 40.9

Appendix 3

Propane system components

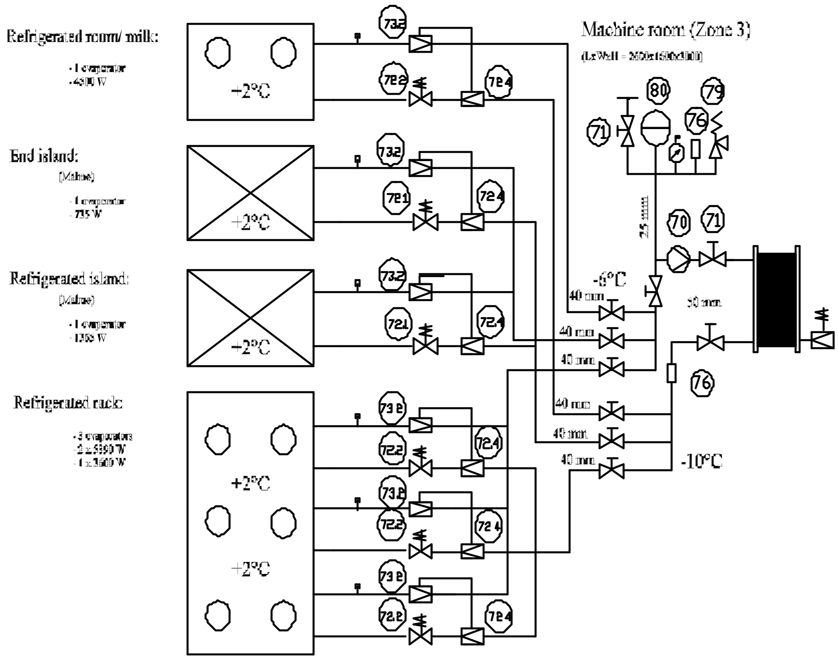


Danfoss components for propane system, Fakta Beder (special agreement with Danfoss)

Propane system

Pos. no.	Number	Description	Order no.	Approved
8	1	SFV 15 T 318 safety valve ½", weld, w/nitrile	2416+15800	OK
8.1	1	GBCs, stop valve 7/8"	009G502500	OK
10	2	DCR 0487 Filter house 3/4", weld, 1.2 litres	023U105100	OK
10	2	DN compact insert	023U408000	OK
9	2	SGN sight glass, solder, 22S u/u	014-018600	OK
8.2	1	GBCs, stop value (fill)	009G502000	OK
8.3	1	EVR 10 solenoid valve 5/8"	032F121400	OK
8.4	1	EVR 6 solenoid valve 1/2"	032F120900	OK
8.3	1	Coil IP67 24 V	018Z670700	OK
8.4	1	Coil IP67 24 V	018Z670700	OK
6.1, 6.2	2	Pressure switch KP17B double bellows 6 mm, solder, w/gold contacts	As 06-127400	OK
6.1, 6.2	2	IP 55 encapsulation for KP double	060-035000	OK
		Soldering nipple 1/4" flare for 1/4", solder	023U800200	OK
16	2	MP 55 oil differential pressure switch without time relay	060B029900	OK
8.2	3	Stop valve GBC 6s manometer	009G502000	OK
		Propane system control		
	1	AKC 25H1 compressor control	084B201800	
	1	AKS 32 pressure transmitter, 1-12 bar G 3/8" A	060G200500	
	1	AKS 32 pressure transmitter, 1-34 bar G 3/8" A	060G200700	
	2	Soldering nipple G 3/8", solder	017-436800	
	2	AKS 21 Pt 1000 temperature sensor	084N200700	
	2	AKS 32 pressure transmitter, 1-12 bar G 3/8" A	060G200500	
	1	Special AKC24W controller		
	2	AKS 11 Pt 1000 temperature sensor	084N000500	
	2	Soldering nipple G 3/8", solder	017-436800	
	2	AKS25W4 immersion pipe temperature sensor 1/2"	084N206000	
	1	ESMT outside temperature sensor	087B116400	

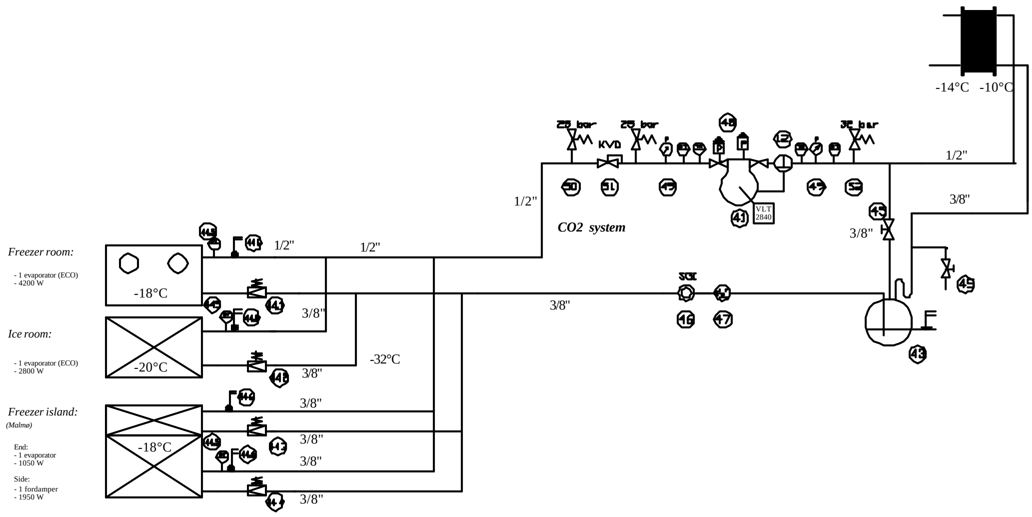
Brine system components



Brine circuit components of CO_2/propane system, Fakta Beder:

Pos. no.	Number	Description	Order no.
	4	AKC 121 B evaporator control	084B290400
	6	AKS 11 temperature sensors	084N000800
	6	AKS 21 temperature sensors	084N200300
72.1	2	EVSR 14 solenoid valve 1/2"	068F405300
72.2	4	EVSR 18 solenoid valve 3/4"	068F405400
72	6	230 V 50 Hz coils 12W	018Z680100
72.4	6	String control ASV-I 3/4"	003L805200
73.2	6	String control ASV-PV 0.5 bar difference 3/4"	003L801200
73.2	6	Special spring for ASV-PV	

CO_2 system components



Danfoss components for CO_2 system, Fakta Beder

Pos. no.	Number	Description	Order no.
50	2	SFV 15 safety valve 1/2", weld, SFV 15 DIN 325	2416+18500
51	1	KVD pressure controller 1/2", solder	034L017300
48	2	KP 5 pressure switch	060-117300
52	1	Henry 32 bar	
45	3	GBCs, stop valve 3/8"	009G502100
47	1	Drying filter DU 303 3/8", solder	023U353300
46	1	SGI 10 3/8", solder	014-003500
ADAP-KOOL components			
44.1	1	AKV 10-4	068F117000
44.2	1	AKV 10-3	068F116700
44.3	1	AKV 10-2	068F116400
44.4	1	AKV 10-2	068F116400
44	4	Coil for AKV 10	018Z678100
44.5	3	AKS 32R pressure transmitter, 1-34 bar 1/4" flare	060G009000
44.5	3	AKS 32R wiring	060G103400
44.6	16	AKS 11 Pt 1000 temperature sensors	084N0008000
49.1	1	AKS 32 pressure transmitter HP (CO_2), 1-34 bar 1/4" flare	060G207100
	1	AKS 32 pressure transmitter LP (CO_2), 1-20 bar 1/4" flare	060G207000
	5	Soldering nipple 1/4" flare for 1/4", solder	023U800200
	2	AKS 21 temperature sensors	084N200700
Controllers			
	1	AKC 115A display case control for two evaporators	084B617400
	2	AKC 114A display case control for 1 evaporator	084B617200
	1	Compressor control AKC 25H5 special 084x219200	084B202100
	1	VLT frequency converter 2840 400 V 9.1A	195N107500

Selected pages from internal Fakta report (prepared by COWI)

Key figures

Outlet no.	**Address**	Power (refrigeration) MWh/year	Power (lighting) MWh/year	Power (misc.) MWh/year	Power (total) MWh/year
201	Ejbovej 35 Bjæverskov	107 (63%)	55 (32%)	8 (5%)	170 (100%)
203	Vallekildevej 27 Hørve	121 (64%)	62 (33%)	5 (3%)	189 (100%)
204	Sct. Jørgensgade37 Kalundborg	117 (67%)	51 (30%)	5 (3%)	192 (100%)
209	Arn. Nielsens Boul. Hvidovre	102 (67%)	46 (30%)	5 (3%)	153 (100%)
217	Frederikshorgvej 18 Helsinge	87 (57%)	61 (40%)	5 (3%)	153 (100%)
223S	Amagerbrogade 29 Copenhagen S	200 (62%)	112 (35%)	10 (3%)	322 (100%)
226S	Hurnlebækcenteret Humlebæk	132 (70%)	51 (27%)	6 (3%)	187 (100%)
328	Njalsgade, 13 Copenhagen S	141 (71%)	54 (27%)	6 (3%)	201 (100%)
340	Hamletsgade 8 Copenhagen N	111 (63%)	61 (35%)	5 (3%)	177 (100%)
377S	Banevej 1 Karise	118 (57%)	F84 (40%)	5 (3%)	207 (100%)
	Average	**123 (64%)**	**64 (33%)**	**6 (3%)**	**193 (100%)**

Comparing these figures/percentages with those of the 1994 industry energy analysis for supermarkets shows the following percentage distributions for outlets with a selling space of less than 1,200 sq. metres:

	Industry energy analysis (18 outlets)	**Fakta 2001 (10 outlets)**
Refrigeration and freez-ing	64%	64%
Lighting	30%	33%
Misc.	6%	3%

As shown by this table, the Fakta percentages do not differ substantially from the industry energy analysis percentages. These percentages can be used for rough calculations. Outlet energy consumption deviates by +/- 7%.

Refrigeration figures

On the basis of the 1994 industry energy analysis for supermarkets, etc., Super Køl and COWI have developed a unit termed equivalent metre.

1 equivalent refrigeration metre equals 3,000 kWh/year.

The figures stated have been calculated on the basis of actual measurements previously made, but are in no way “scientific” and should be taken with some uncertainty.

In theory, it is now possible to compute the expected refrigeration need using the following equivalent rates:

Refrigerated display case/room	**Door/kWh/year or kWh/year/metre**	**Equivalent rates/m**
Refrigerated rack	3000:3000	1
Milk room (per door)	2450:3000	0.8
Freezer room (per door)	5100:3000	1.7
Freezer room, ice (per door)	6000:3000	2.0
Freezer island (own compressor)	3500:3000	1.2
Freezer island (parallel system)	2400:3000	0.8
Refrigerated island (own compressor)	1500:3000	0.5
Refrigerated island (parallel system)	900:3000	0.3
Island, ice	3000:3000	1.0
Coca-Cola	1500:3000	0.5

Example:

Annual theoretical energy consumption of one milk room:

0.8 equivalent metres * 6 doors * 3000 kWh/year = 14,400 kWh a year