A THERMIE PROGRAMME ACTION

THERMIE

Review of Energy Efficient Technologies in the Refrigeration Systems of the Agrofood Industry

European Commission
Directorate-General for Energy

RUE

THE THERMIE (1990-1994)

This is an important European Community programme designed to promote the greater use of European energy technology. Its aim is to assist the European Union in achieving its fundamental objectives of:

- improving the energy supply prospects of the European Union;
- reducing environmental pollution by decreasing emissions, particularly those of CO_2, SO_2 and NO_X;
- strengthening the competitive position of European industry, above all small and medium-sized enterprises (SMEs);
- promoting the transfer of technology to Third Countries;
- strengthening economic and social cohesion within the European Union.

The majority of the funds of the THERMIE Programme are devoted to financial support of projects which aim to apply new and innovative energy technologies for the production, conversion and use of energy in the following areas:

- rational use of energy in buildings, industry, energy industry and transport;
- renewable energy sources such as solar energy, energy from biomass and waste, as well as geothermal, hydroelectric and wind energy;
- solid fuels, in the areas of combustion, conversion (liquefaction and gasification), use of wastes and gasification integrated in a combined cycle;
- hydrocarbons, their exploration, production, transport and storage.

The THERMIE Programme (1990-1994) includes a provision for the enhanced dissemination of information to encourage a wider application and use of successful energy technologies. This information is brought together, for example, in publications such as this maxibrochure. Maxibrochures provide an invaluable source of information for those who wish to discover the state of the art of a particular technology or within a particular sector. The information they contain is drawn from all Member States and therefore provides a pan-European assessment.

To guarantee the maximum effectiveness of the funds available, the THERMIE Programme (1990-1994) includes an element for the co-ordination of promotional activities with those of similar programmes carried out in Member States and with other European Community instruments such as ALTENER, SAVE, SYNERGY, JOULE, PHARE and TACIS.

JOULE-THERMIE (1995-1998)

The first THERMIE Programme for the demonstration and promotion of new, clean and efficient technologies in the fields of rational use of energy, renewable energies, solid fuels and hydrocarbons, came to an end in December 1994. In January 1995, the programme was renewed as part of the new Non-Nuclear Energy Programme, better known as JOULE-THERMIE, within the European Community's Fourth Framework Programme for Research, Tehnological Development and Demonstration. As prescribed in the Treaty on European Union, this programme brings together for the first time the research and development aspects of JOULE (managed by the Directorate-General for Science, Research and Development, DG XII), with the demonstration and promotion activities of THERMIE (managed by the Directotate-General for Energy, DG XVII). A budget of 532 MECU has been allocated to the THERMIE component for the period 1995-1998.

Colour Coding

To enable readers to quickly identify those Maxibrochures relating to specific parts of the THERMIE Programmes each Maxibrochure is colour coded with a stripe in the lower right hand corner of the front cover, i.e.:

RATIONAL USE OF ENERGY

RENEWABLE ENERGY SOURCES

SOLID FUELS

HYDROCARBONS

This maxibrochure was produced in the framework of the former THERMIE Programme (1990-1994).

Further infomation on the material contained in this publication, or on other THERMIE activities, may be obtained from one of the organisations

Review of Energy Efficient Technologies in the Refrigeration Systems of the Agrofood Industry

THERMIE PROGRAMME ACTION Nº I 185

Generalitat de Catalunya
Departament d'Indústria i Energia
Institut Català d'Energia

For the European Commission
Directorate-General for Energy

Institut Català d'Energia
Member of the OPET NETWORK
Av. Diagonal, 453 Bis, Àtic.
Tel.: +34-3-439.28.00
Fax: +34-3-419.72.53
08036 BARCELONA
CATALUNYA-SPAIN

Written by:
Antonio López Gómez

Coordinated by:
Conrad Meseguer
Antoni Hernández

Design and Printing:
DRIBBLING

September 1995

Acknowledgements

Thanks are due to the following for their contribution to this publication and to those whose material was not finally selected:

ADEME PICARDIE, France, for information on French examples of energy efficiency.

ANEFRYC, Madrid, Spain, for their useful comments.

Dansk Energi Analyse A/S, Denmark, for additional information on the MD Foods case study.

ECD, Copenhagen, Denmark, for information on Danish examples of energy efficiency.

FORBAIRT, Dublin, Ireland, for information on Irish examples of energy efficiency.

Ind Coope Burton, Burton-on-Trent, UK, for information on its own case study.

Institut International du Froid, Paris, France, for their useful comments.

LDK Consultants, Athens, Greece, for information on Greek examples of energy efficiency.

March Consulting Group, Windsor, UK, for information on UK examples of energy efficiency.

UNICOPA, Guincamp, France, for information on its own case study.

SICA POM'ALPES, Manosque, France, for information on its own case study.

CONTENTS

1. INTRODUCTION.

The European agrofood industry is huge both in terms of size and importance and as regards energy costs, which stand at around 3,000 MECU per year. Some studies and reports estimate that it would be possible to obtain savings of up to 15% on this figure (some 450 MECU per year) through the implementation of existing energy technologies [15]. Electricity makes up approximately 30% of the total energy consumption in the agrofood industry and of this, refrigeration accounts for 16% of the total electricity consumption. Thus, possible energy savings in the refrigeration systems of the sector using existing technologies would be 0.72%, or 21 MECU per year. The conclusion is clear: a great deal of money is at stake and, therefore, all agrofood factories should be interested in making such energy savings. But saving money is not the only benefit from making the industry more energy efficient. Improving energy efficiency requires investment in new technologies and such improvements are essential, not only to obtain economic benefits, but also to minimise the environmental impact of the sector.

This is very much the direction the agrofood industry is expected to take over the short and medium term, and small, medium and large agrofood industries alike are studying investments aimed at adapting their activity to market conditions through cost saving measures (automation, energy and labour saving measures, and so on). The construction of new plants is seen to be less important than the modernisation and optimisation of existing plants [7]. Therefore, the phasing-out of CFCs (Montreal protocol) which, in many cases will require modification to plant and equipment, can serve as a catalyst for the introduction of energy improvements to refrigeration systems.

The aim of this brochure is to describe energy saving technologies which can be applied to refrigeration systems in the agrofood industry.

Firstly, energy efficient technologies for condensers and evaporators are considered, then compressors and insulation techniques are analysed (including thermographic analysis). Aspects such as computer control of refrigeration consumption and production, cold accumulation technologies, electronic ultrasonic humidifiers, energy recovery from condensers and heat pumps and refrigeration using absorption systems are studied.

Finally, a number of case studies of different agrofood factories are given.

2. ENERGY CONSUMPTION IN THE AGROFOOD INDUSTRY.

Based on information obtained from EUROSTAT, Table 1 shows overall and electrical energy consumption over the 1986-91 period in the EC agrofood industry.

Over the period considered, total energy consumption increased by around 5.6%, whilst electrical energy consumption rose by some 31.8%, showing the importance of energy savings in refrigeration systems. It will be noted from the table that whilst electrical energy consumption in 1986 was 23.5% of total energy consumption, in 1991 it represented 29.3%.

	EUR 12		EUR 10	
	Total (1000 Toe)	Electrical (1000 Toe)	Total (1000 Toe)	Electrical (1000 Toe)
1986	18,099	4,252	16,362	3,807
1987	18,443	4,413	16,610	3,939
1988	18,503	4,645	16,508	4,141
1989	18,839	4,917	16,924	4,387
1990	19,382	5,259	17,379	4,659
1991	19,111	5,606	17,028	4,993

Table 1. Overall and electrical energy consumption in the EC agrofood industry (1986-91).

Based on the figures for 1991, if the energy consumption of refrigeration systems accounts for 16% of total electrical energy consumption in the sector, and savings of up to 15% can be made by improving existing technologies, then potential savings are some 135,000 Toe per year.

3. ENERGY CONSUMPTION IN THE REFRIGERATION SYSTEMS OF FOOD PROCESSING PLANTS

Figure 1 shows the distribution of energy consumption by energy type in a developed country, together with the estimated distribution of electrical energy applications.

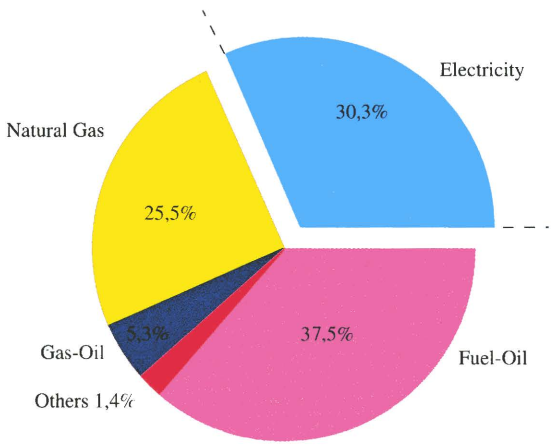
Analysis of Singh's data [16], enables us to determine the specific consumption of each of the processing systems in food plants, given in Table 2. This data, however, should be taken only as an estimate, as precise determination is complex and figures vary widely from one factory to another.

Table 2 shows that the highest specific energy consumption corresponds to meat processing and frozen food processing systems. On the other hand, beer and wine making have higher specific energy consumption than refrigeration storage.

	kWh/Kg or kWh/l
Slaughterhouses and cutting rooms (pork and beef)	0.1971
Poultry slaughterhouses	0.3742
Meat industry	0.4606
Ice-cream and frozen desserts	0.6012
Milk processing and fresh cheese production	0.0390
Frozen juices	0.1625
Frozen foods (vegetables, pre-cooked foods, fish)	0.2164
Refrigerated conservation (0°C)	0.0200
Refrigerated conservation (-20°C)	0.0500
Production of beer from malt	0.0541
Malt production	0.0081
Wine production	0.0372

Table 2. Specific consumption of each of the food processing systems in the food plants.

Total energy consumption in the agrofood sector.



Distribution of the electricity energy consumption.

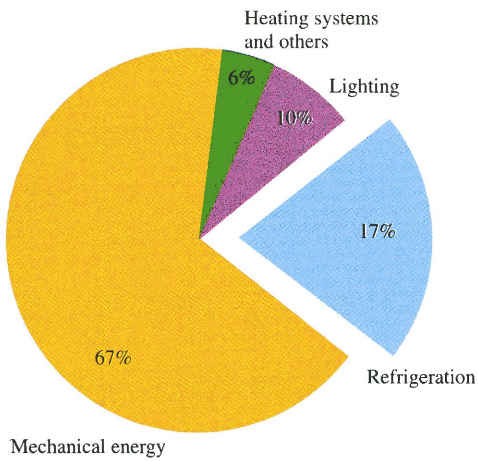


Figure 1. Distribution of the energy consumption by energy type in an industrialised country.

4. ENERGY EFFICIENT TECHNOLOGIES FOR REFRIGERATION PLANTS IN THE AGROFOOD INDUSTRY

4.1 Energy efficient technologies for condensers and evaporators

A refrigeration system works most efficiently when evaporation temperature is as high as possible and condensation temperature as low as possible. This statement is based on the theoretical performance of a thermodynamic cycle:

$$\text{Theoretical coefficient of performance} = \frac{Te}{Tc - Te}$$

where Tc is condensation temperature and Te evaporation temperature in degrees Kelvin. In practice, real cycles tend to have 60% efficiency compared to theoretical performance, and thus the scope is great for increasing the efficiency of refrigeration systems. In order to minimise energy use in the refrigeration cycle it is therefore necessary to decrease as much as possible the difference between evaporation temperature and condensation temperature. Floating head pressure control should allow condensation temperature to be as low as possible.

4.1.1 Evaporating condensers

Both the initial investment required and the running or energy costs of condensers depend on the condensation system adopted. Condensation temperature (Tc) is determined principally by the type of condenser, as follows:

a) Evaporating condenser,

$$Tc = t_{BH} + 12°C$$

where t_{BH} is the most unfavourable wet-bulb temperature in the region where the condenser is to be installed. For continental areas, a wet-bulb temperature of 22°C is taken, and 25°C for coastal zones in europe.

b) Horizontal multi-tube condenser using running water, from well or surface waters,

$$Tc = ta + \Delta t + (\Delta t)_C$$

where ta is the input temperature of the water in the condenser, Δt the temperature difference between output temperature of the water and condensation temperature, and (Δt)c is the increase in temperature of the water in the condenser (which tends to average around 8°C).

c) Horizontal multi-tube condenser with cooling tower,

$$Tc = (t_{BH} + 7°C) + \Delta t + (\Delta t)_C$$

d) Air-cooled condenser

In such equipment, the condensation temperature can be set at approximately 15°C above most unfavourable air temperature.

For example, taking a continental area with ambient temperature in summer of 35°C, with a t_{BH} of 22°C and well-water temperature of 18°C, the following condensation temperatures would apply, according to the condensation system in use:

- evaporative condenser: .... Tc = 34°C
- horizontal multi-tube condenser using running water: .... Tc = 31°C
- horizontal multi-tube condenser with cooling tower: .... Tc = 42°C
- air-cooled condenser: .... Tc = 50°C

In this way, evaporative condensers allow the refrigerant to be condensed at a lower temperature than other systems, with the exception of those using running water.

For each degree centigrade by which condensation temperature is reduced, energy savings of 2-4% are made, according to the compressor characteristics and required evaporation temperature. The installation of evaporating condensers in replacement of condensation systems using water and cooling tower reduces condensation temperature by an average of 3°C, with energy savings ranging from 6-12%.

Figure 2 shows how an evaporating condenser works. The system uses the cooling effect of water evaporating on the surface of the tubes in which the refrigerant circulates as superheated vapour from the compressor. As distributors apply water to these tubes so air is force-circulated in counter flow from bottom to top. As this condensation system is based on the evaporation of water, the amount of humidity in the air will have a significant effect on the functioning of this type of condenser: it will be much more efficient when the air is dry, with low relative humidity. It is important to take into account, also, that as the water evaporates the mineral salts content of the recirculated water will also increase. This means that the water used in such condensation systems has to be maintained at suitable quality.

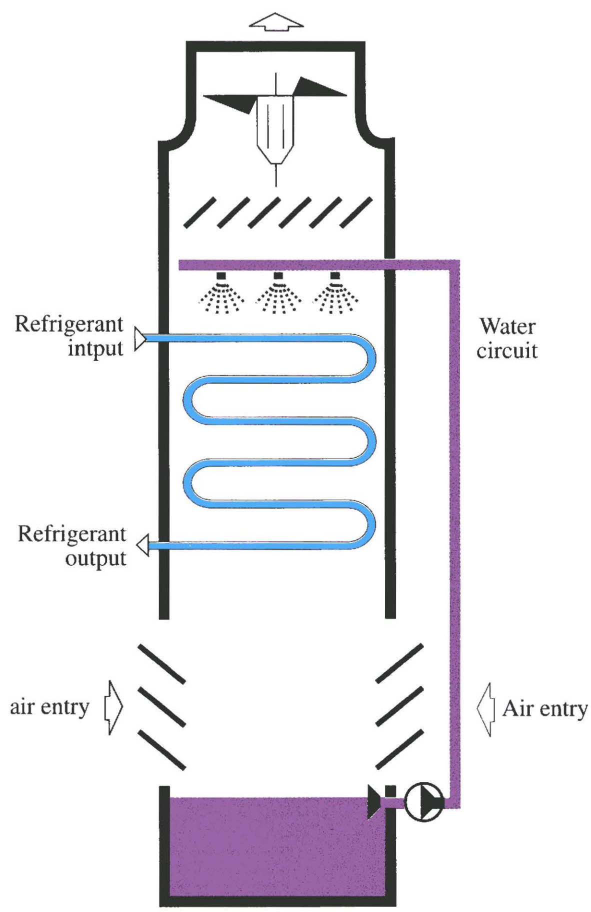


Figure 2. Diagram showing the operation of an evaporating condenser.

4.1.2 Defrosting with continuous control of the ice layer in air blast coolers.

The periodic removal of the layer of frost which forms on air blast coolers in refrigerating chambers is a necessary operation in order to maintain a good overall coefficient of heat transfer and to prevent the blocking which ice can cause even in evaporators with high blade separation -12 mm and more- restricting ventilation inside the chamber. This operation, known as defrosting, can be carried out either by circulating hot gases in the evaporator, by spraying water onto the evaporator or through the use of electrical coils on the evaporator tubes.

In order to reduce the amount of heat applied to the interior of the chamber, defrosting operations should be kept to a minimum whilst being sufficiently frequent to ensure that the evaporators work in optimum conditions.

In order to control the intervals between defrosting operations and the duration of the process, timers can be used or, more simply, the refrigeration operator can determine, after visual inspection, the correct moment and duration of defrosting. However, with both procedures there is the risk that the optimum conditions will not be maintained. If too many defrosting operations are carried out, i.e. the time interval between defrosts is too short, it will lead to an unnecessary introduction of heat into the chamber. If too few take place, then the evaporator will not be working at the optimum efficiency due to the build up of a layer of ice. Instead of these systems, automatic systems for the detection of the thickness of the ice and of the completion of the defrosting operation ensure the correct frequency and optimal duration of defrosting, minimising energy consumption.

This technology is based on the use of infrared sensors placed on the evaporator blades, capable of measuring the thickness of the ice layer (from 1-10 mm) on the exchange surface. Once the ice reaches a certain set thickness, the sensor transmits the command to begin defrosting.

The system can be easily connected to a central computer control system connecting the entire refrigeration plant so that as many defrosting operations as possible are carried out during off-peak periods, with minimal energy and economic costs.

Control of the duration of the defrosting operation allows for immediate action to prevent excessive heating. In certain cases, it was possible to reduce circulation times of hot gases previously set at 25 minutes to 15 minutes through the use of a thermostat. Such control systems also bring with them significant energy savings. Flow detectors in the defrosting wastepipes are used to monitor the efficiency of the defrosting operation.

4.1.3 Adjustment of the heat exchange surface of evaporators and condensers.

The duty of a heat exchanger, wether an evaporator or a condenser, is determined as follows:

$$Q = A.U. (\Delta t)_{ml}$$

where Q is the duty or, what is the same thing, the amount of heat displaced (in kW) through the exchange surface A (in m^2); U is the overall heat transfer coefficient (in $kW/m^2.°C$), which depends on the design of the heat exchanger, on the heat exchange fluids employed and the conditions in which they circulate; and $(\Delta t)_{ml}$ is the average logarithmic temperature difference between the refrigerant fluid and the cooled/heated fluid (water or air).

If a duty Q is required in the evaporator or in condenser, and the heat exchange surface A is insufficient, the system will supply the power demand through an increase in temperature difference $(\Delta t)_{ml}$. The consequence of this is a decrease in evaporation temperature or an increase in condensation temperature, with, as mentioned above, a negative effect on energy efficiency (the difference between condensation and evaporation temperatures is increased).

It is generally accepted that for each degree Celsius by which evaporation temperature is increased average energy savings of 4% are obtained, and for this reason, it is necessary to achieve optimum size of both condenser and evaporator so as to maximise evaporation temperature and minimise condensation temperature. Appropriate design would take into account both restrictions on initial investment (which tend to minimise exchanger surface) and the objective of maximising the profitability of the refrigerating plant (which means that running costs -in this case, energy costs- have to be reduced). Table 3 shows the temperature differences in correctly-dimensioned evaporators for refrigeration chambers. If the temperature differences of a plant are higher than those indicated, then the possibility of increasing the exchanger surface should be studied.

The exchange surface is correctly-sized if:
• Chambers around 0°C: chamber temperature - evaporation temperature < 8°C
• Frozen chamber (frozen store): chamber temperature - evaporation temperature < 7°C
• Chamber freezers: chamber temperature - evaporation temperature < 6°C
The circulating airflow through evaporator is sufficient if: air input temperature to evaporator - air output temperature from evaporator < 3°C

Table 3. Temperature differences in correctly-sized evaporators for refrigeration and frozen chambers.

Another way of increasing evaporation temperature is by increasing -though only up to a certain point- the airflow through the evaporator. In this way, overall heat transfer coefficient U in the previous equation is increased, raising the refrigeration power the evaporator can supply. This increases evaporation temperature and, therefore, lowers $(\Delta t)_{ml}$. In fact, it could be recommendable to increase the airflow if the difference between input and output air temperatures in the evaporator is above 3°C. This has to be done, generally speaking, through the installation of large fans which turn more slowly, and not by increasing the speed of existing fans.

In the case of air cooled condensers, it is recommended to increase the condensation surface if $(\Delta t)_{ml}$ is above 12°C, and to increase airflow if the difference between the temperature of output air and condensation temperature is below 5°C.

In the case of water condensers, if the difference between the temperature of input water and that of condensation is greater than 15°C, it is recommended, firstly, to clean the calcium salts from the condenser and, if clean, to increase the heat exchange area of the condenser. If the difference between input and output temperatures of the water is over 7°C, first the circuit should be cleaned of calcium salts, algae, etc, and once clean, water flow should be increased. The latter measure increases U and the cooling power of the condenser, in this way lowering condensation temperature and increasing the energy efficiency of the refrigerating plant.

4.2 Energy efficient technologies for compressors

The compressor is the main energy consumer in refrigerating plant, and therefore has to be carefully selected during the refrigeration system design stage. For example, a cold store at set temperature of -25/-30°C can be equipped with one of the following systems:

- refrigeration equipment running with a CFC and single compression.
- centralised machine room, with dry expansion and single stage compression.
- centralised machine room, with dry expansion and double stage compression.
- centralised machine room, with ammonia and overcharged flooded regime in evaporators and double stage compression.

The energy efficiency (COP, Coefficient Of Performance) of these systems will be 1.15, 1.35, 1.60 and 2.05 respectively. In this way the energy consumption of the refrigerating system using the first solution can be 3-4 times greater than with the fourth alternative.

Double compression is generally recommended both for freezing tunnels and frozen food stores in the agrofood industry.

In refrigerating plants in the agrofood industry, practically speaking, three types of compressor are used: reciprocating, screw and centrifugal compressors. Reciprocating compressors are used for powers below 600 kW, screw compressors for powers between 160 and 2,000 kW and centrifugal compressors are applied to systems with power of 800-3,000 kW.

Control of the capacity of a multicylinder reciprocating compressor is normally carried out through the "discharge" of one or more cylinders so that these are rendered inefficient. This is done by deflecting the discharge towards the inlet pipe when the inlet pressure is lower than a pre-set level. However, this cylinder discharge method reduces the cooling effect more than the electrical energy consumed by the compressor in the drive motor, that is to say, it reduces specific cooling duty (the kW displaced by the refrigerating plant for every kW consumed by the compressor drive motor). As can be seen in Figure 3, a similar effect is observed with screw compressors.

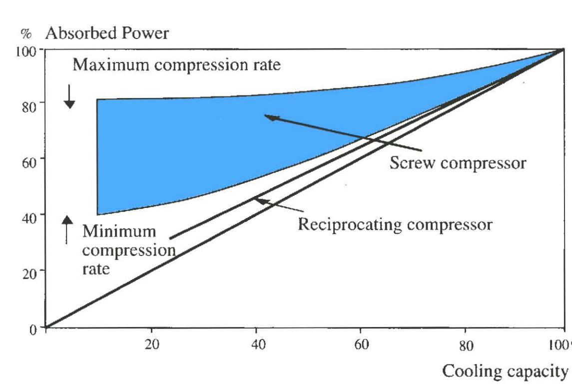


Figure 3. Absorbed power against cooling capacity depending on the compressor system used.

A more efficient alternative from the point of view of energy consumption consists in adjusting the volumetric flow of the compressors by varying compressor speed. This can be done by using electronic systems for varying speed, such as "inverter" systems, by using twin-speed engines (4 and 8 poles) or by using internal combustion engines to drive the compressor.

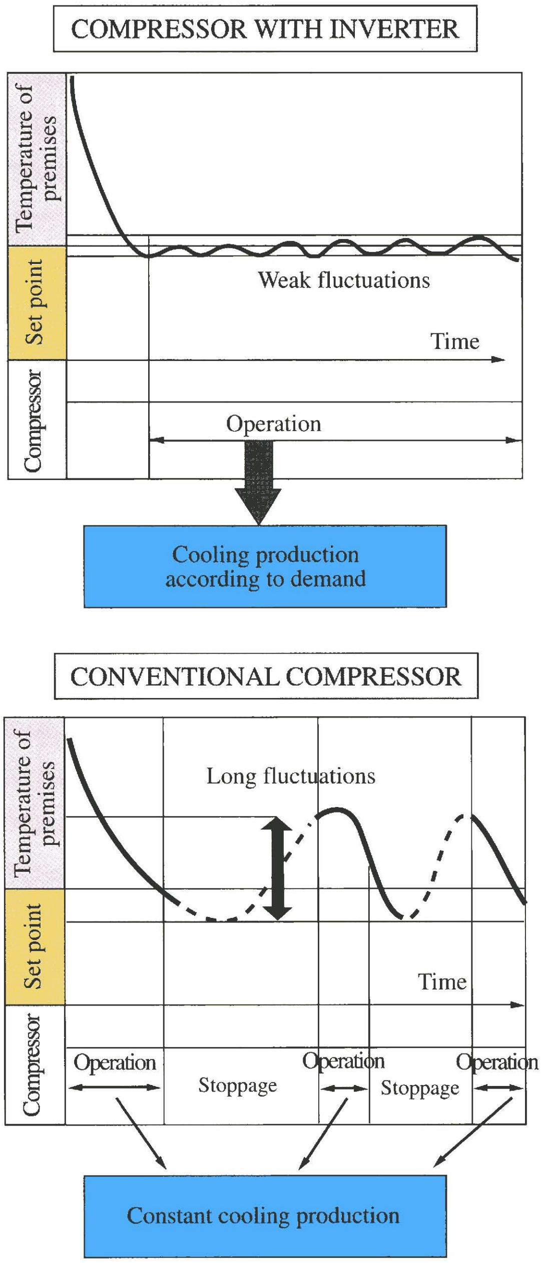


Figure 4. Evolution of the temperature inside the cold room and cold production using inverter or conventional compressor.

The most suitable method, due to the shorter pay-back period on the investment, is to use the inverter system (see Figures 4 and 5), especially in the case of high-capacity compressors. In these systems, cold production is managed and controlled by PLCs with specific programmes according to the application of the cooling. For example, at a plant for the refrigerated conservation of apples using screw compressors, energy savings of around 20% are achieved compared to conventional systems for regulating compressor power.

Twin-speed engines are best suited to cases where there are two clearly-defined load levels. Internal combustion

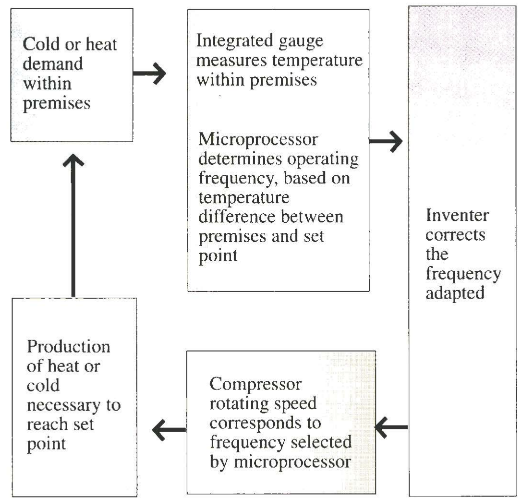


Figure 5. Diagram on how an inverter system works.

engines present three advantages over the other methods mentioned: a wide margin of speed variation can be obtained, there is the possibility of recovering the excess heat from exhaust fumes and the cost of the energy used to drive them can be lower.

As the greatest energy efficiency in compressors is achieved when they work at maximum design capacity, they should always be operated in such conditions. One way of ensuring this is by having multiple compressors working in parallel, so that cooling effect can be regulated by stopping one or more compressors and running the others at full capacity.

4.3 Insulating refrigeration and freezing chambers.

4.3.1 Inspection of thickness of insulation.

As heat is transmitted from a hot zone (at a higher temperature) to a cold zone (at a lower temperature), there will always be a flow of heat towards the refrigerated area. This heat transfer Q through the walls of the refrigerated space is expressed as follows:

$$Q = A.U.\,\Delta t, \qquad \text{(in kW)}$$

where A is the surface area of the wall (in m^2), U is the global coefficient of heat transfer (in $kW/m^2.°C$) and Δt is the temperature difference between the internal and external surfaces of the wall. In this way, Q can be decreased whilst A and Δt remain constant, by making U as low as possible. In this way, both the size, or installed refrigeration capacity, and the energy consumption of the plant will be reduced. This explains the recourse to thermal insulation in cold rooms or cold spaces in general (tanks, pipes, etc).

The relative importance of cold losses in cold stores is related to its set or used temperature. Thermal losses, particularly in cold rooms at set temperatures of -20°C or below, can be very large if not suitably insulated.

A practical and useful way of determining the state of efficiency of the wall insulation of a cold store is to analyze the following temperature differences:

a) The difference between the temperature of the internal surface of the wall of the cold store and its set temperature.
b) The temperature difference between the external surface of the cold store and the ambient temperature
(as long as this is not a surface affected by sunlight or thermal equipment).

If the insulation is in a good state of conservation these temperature differences will be small. For practical purposes, guidelines could be set for temperature differences expressed in percentages of the difference between ambient air and internal cold room temperatures:.

- Frozen chambers and freezing tunnels: 10-13%
- Cold stores around 0°C: 14-17%

If percentages are higher than these, the possibility of reinsulating chambers should be studied.

Another method of determining the efficiency of the insulation of cold stores, tanks and cold pipes is to use thermographic analysis.

Traditionally, insulation is repaired by the replacement of worn material with new material. However, this procedure has two important disadvantages: it is expensive in terms of labour costs, and there is a relatively high loss of time before the store can be used once more. An alternative solution is to install the new insulation, injected polyurethane, over the existing material.

Figure 6 shows the executed reinsulation which can be carried out both in cold stores with stone walls and those constructed with self-supporting panels. First, holes are made in the walls and small PVC pipes set into them to hold the metal profiles (omega) which will support the internal protection panels. These holes are sealed with polyurethane in order to avoid the creation of thermal bridges.

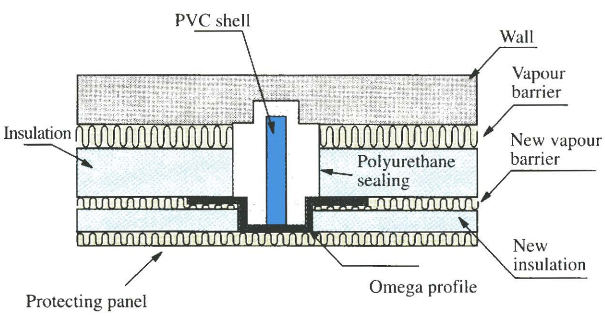


Figure 6. Technical solution for reinsulating cold stores.

The cost of reinsulation carried out in this way is as follows:

Injected polyurethane (30-40 kg/m^3)	2.18 ECU/m^2.cm
Anti-vapour screen	2.50 ECU/m^2
Protection panels	
Lacquered sheet	25 ECU/m^2
Polyester	26.25 ECU/m^2

5 cm of polyurethane and polyester protection panelling would cost 39.68 ECU/m^2.

In order to determine the saving and viability of the reinsulation operation, a distinction has to be made between frozen food stores (at -20°C) and cold stores (around 0°C).

Calculations are based on the following data:

- Annual average external ambient temperature: 15°C
- Coefficient of convection of internal air: 1.16 E-2 kW/m^2.°C
- Coefficient of conductivity of polyurethane: 2.32 E-5 kW/m.°C
- Cooling production for each kJ (1kWh=3,600 kJ) of electrical energy consumed:
  *Freezing chambers: 1.16 kJ
  *Chambers at 0°C: 1.51 kJ
- Difference between internal wall temperature and internal ambient temperature of the store, expressed as a percentage of the total difference (external and internal ambient temperature):
  *Freezing chambers: 10%
  *Chambers at 0°C: 15%

FREEZING CHAMBERS (-20°C)

PRESENT INSULATION (Heat loss through the walls per m^2 and year):

Q/A = 356.0 kWh/m^2.year
Electrical energy consumed = 306.6 kWh/m^2.year
Cost = 28.74 ECU/m^2.year

NEW INSULATION (with 5 cm of polyurethane):

Q/A = 101.71 kWh/m^2.year
Electrical energy consumed = 87.6 kWh/m^2.year
Cost = 8.21 ECU/m^2.year
COST SAVINGS = 20.53 ECU/m^2.year

PAY-BACK PERIOD = approx. 2 years
CHAMBERS AT 0°C:

PRESENT INSULATION (Heat loss through the walls per m^2 and year):

Q/A = 228.74 kWh/m^2.year
Electrical energy consumed = 151.0 kWh/m^2.year
Cost = 14.21 ECU/m^2.year

NEW INSULATION (With 5 cm of polyurethane):

Q/A = 38.14 kWh/m^2.year
Electrical energy consumed = 25 kWh/m^2.year
Cost = 2.36 ECU/m^2.year

COST SAVINGS: 11.85 ECU/m^2.year

PAY-BACK PERIOD: approx. 3 years

Another important aspect to bear in mind in order to reduce energy consumption in cold stores is the possibility of reducing cold loss in doors and access corridors. Sealing corridors and installing plastic curtains (which reduce the entry of air into the store by 70%) is a good idea for cold stores, whilst for freezing chambers the most suitable solution is to install double doors and, eventually, to automise doors opening and closing. Besides cold loss, infiltration of external air -which brings with it a certain degree of humidity- causes the formation of frost on the evaporators and increases energy consumption as heat transfer is lost due to the decrease in global coefficient U and the need to increase frequency of defrosting.

4.3.2 Heat loss in refrigeration systems. Thermography.

Infrared thermography is a teledetection instrumental technique which enables the visualization of electromagnetic infrared radiation within the bands of 3-5.6 and 8-12 micrometers with present commercial detectors. These infrared bands correspond exactly to those of bodies at ambient temperature (approximately 300 K or 27°C) which emit the thermal radiation. For this reason, the technique is especially suited to visualising heat flow in industry, as through thermography a distribution of thermal radiation is converted into a visible image.

The technique has the following characteristics:

(1) It gauges temperature and emissivity without "touching" the surface being monitored (it is a non-destructive technique).
(2) The measurement is carried out completely passively, that is to say, it does not require an external light source, so that measurement can be done by day or night in any location.
(3) The above characteristics make the technique ideal for detecting energy loss in industrial refrigerating plant. The losses of energy through insulation materials or due to air infiltration are detected immediately due to the temperature change produced. Thermographic measurement allows the importance of cold loss to be evaluated and the decision taken as to whether it is necessary to repair or reinsulate the cold surfaces studied.

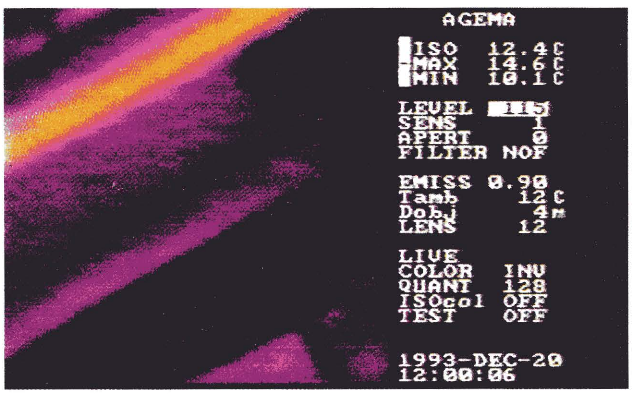


Figure 7. Thermography showing cold losses in a cold storage chamber.

Thermal imaging can be carried out using the company's own equipment and personnel, trained in the maintenance of refrigeration facilities, but it is normally a more viable solution to commission a specialised company to carry out the study.

Thermographic inspections (see Figure 7), are used to visually determine the efficiency and need for the insulation of cold surfaces, and of systems for "sealing" cold rooms (single or double doors, curtains, etc). Some of the principal applications of thermography are the following:

(1) To determine the sealings of a building where there are excessive heat losses and gains, with risk of deterioration.
(2) To determine the causes of thermal anomalies detected, and the damage which these may cause.
(3) To study to causes of defects in insulation detected by visual inspection.
(4) To inspect the defective areas detected in previous thermographic studies and to determine the evolution of deterioration over a period of time.
(5) To check whether repair or maintenance work has to be carried out effectively, comparing thermographs taken before and after the implementation of such measures.
(6) To determine the importance of air leaks in sealings in defective parts already known, and to establish correlations with other symptoms of degradation of sealings.
(7) To determine the thermal resistance of walls by methods based on weighted measurement according to the temperature of the air and the wall surface.
(8) To locate air leaks in cold room sealings, particularly ceiling/wall/floor joints.

For instance, audits carried out on cold stores have detected the presence of: perimetric thermal bridges in insulations (floor/wall joint) due to poor execution work or faulty maintenance; defective application of vapour barriers; defects in door sealings; defective or deteriorated insulation in cold room sealings or pipes carrying refrigerants. Through thermographic techniques, even leakages of refrigerants can be detected.

In cold stores, the weakest points in terms of energy are, obviously, the wall/floor joints and the floor itself. Figure 8 shows the way insulation should be arranged in order to avoid the creation of the typical thermal bridge and the formation of ice in these areas. The lowest temperatures and the greatest mechanical effort are found, naturally, at floor level, and this makes it particularly important to maintain the floor correctly. For example, it is important to prevent freezing of the floors of freezing chambers or tunnels, through the underground installation of electrical resistances or ventilated ducts.

Use of doors makes them one of the points where it is most frequent to find deterioration. Whilst, generally speaking, it is usual to recommend maximum heat flow of 6 W/m^2 for walls, doors should present no more than 1.7 times this heat flow and sealing will play a fundamental role in ensuring that these conditions are met. Figure 9 shows guideline measures for improving door sealings,

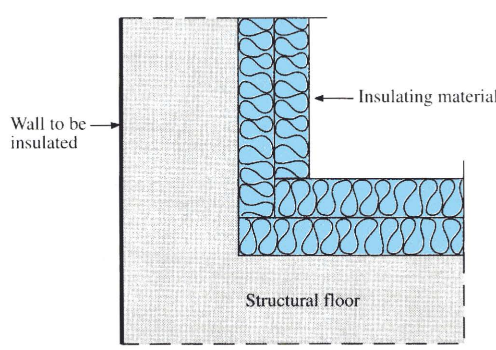


Figure 8. Correct insulating for walls.

consisting of fitting frames and counterframes, as well as replacing existing frames. Other improvements which yield positive results regarding energy and cost savings are the installation of double doors, even if only through the use of plastic curtains, and the sealing of access corridors.

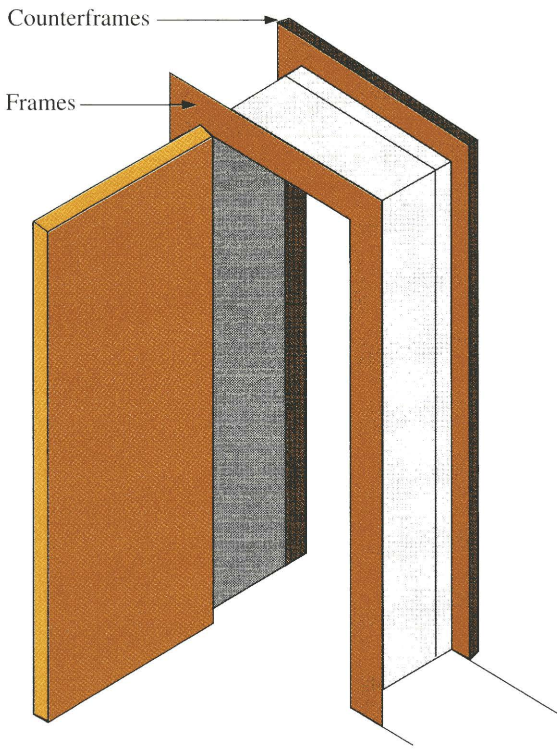


Figure 9. Correct position of frames and counterframes in order to restore sealing deteriorated by use and mechanical impact.

In many cold stores, piping and automation points are not insulated and are installed in corridors, causing important formations of ice. Figures 10 and 11 show certain details of the correct placement of piping, with particular

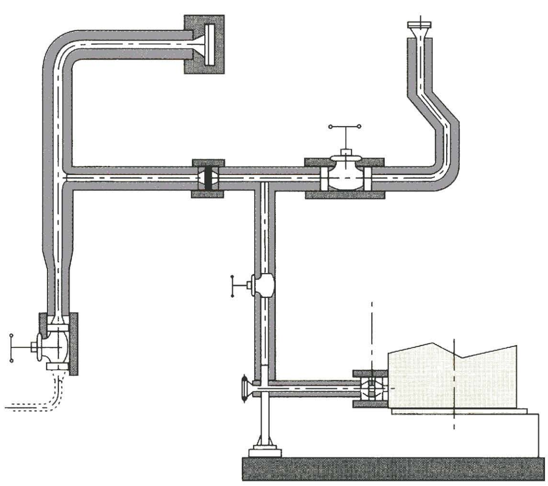


Figure 10. Insulation of pipes, control and automation points.

emphasis on control and automation points. The insulation of these points brings with it not only energy savings, but also other benefits, by increasing the durability of equipment and improving the conservation of the surrounding installations.

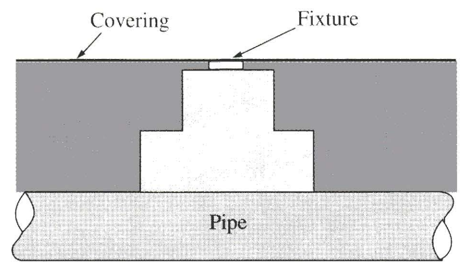


Figure 11. Possible arrangement of injection insulation in rigid covering, leaving the control switch uncovered.

4.4 Computer control of refrigeration consumption and production

The complete automation of cold production and distribution has several important advantages, both from the energy point of view and in terms of operation, maintenance and process quality. Thanks to recent advances in automation technologies, the implantation of these systems in refrigerating installations of a certain size (refrigerating plants with various high-power compressors) is both technically and economically viable.

Generally speaking, refrigerating plants which are not computer-controlled are regulated by a system of contact manometers which, according to the pressure determine the different compressor stages to be switched on or off. Regarding cold distribution, temperature at the different points of cold consumption is regulated by conventional thermostats which act on the solenoid input valve, switching on the evaporators.

Computerised automation and control improves the functioning of the refrigerating plant through the installation of a pressure gauge in the aspiration line, which transmits readings to the central computer (see Figures 12 and 13). As long as suction pressure stays within certain pre-set limits, the computer does not modify the working conditions of the machine room. However, if suction pressure exceeds the upper set point, it emits the command to switch on another compressor stage. It then allows a certain period of time to pass to allow the system to become stabilised before taking another reading. If this reveals that pressure is still above the set limit, the computer orders another stage of the compressor to be switched on. If not, the system is maintained in the same conditions. This control and adjustment cycle is repeated until pressure is once more within the given limits.

If pressure decreases to below the lower set point, the operational sequence is the inverse of that described above: compressor stages are progressively switched off with the possibility of the entire refrigerating plant being stopped. The computer memory has a list of start-up and switch-off preferences for the compressor stages in order to prevent the start-up of a compressor if there is another already working but with stages not functioning. This order of preferences means that compressors work as close as possible to maximum performance point.

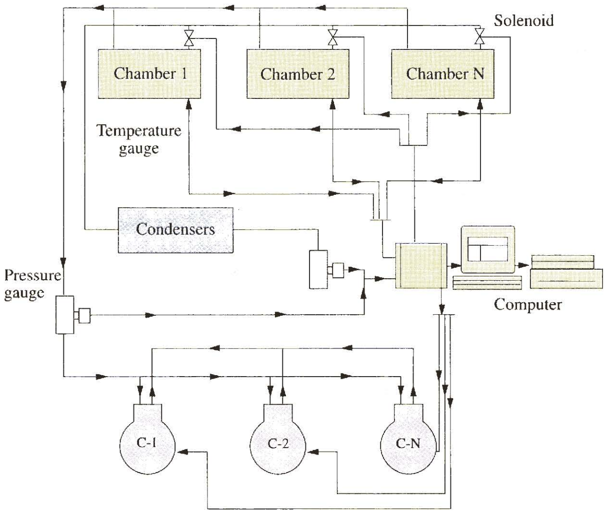


Figure 12. Schematic diagram of a computer control system for a refrigerating plant.

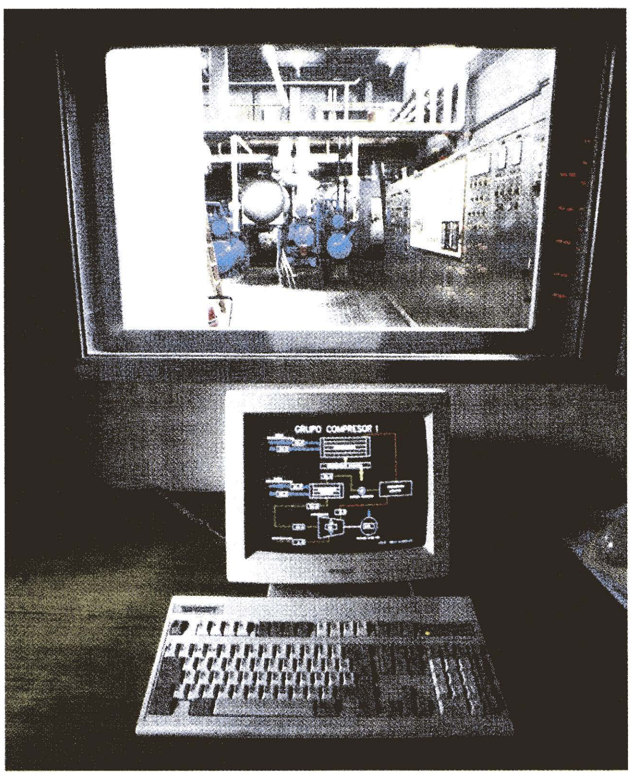


Figure 13. Computer control system for a refrigerating plant.

Computer systems are also generally equipped with protection alarms system for each compressor, activated if the pressure of the oil or refrigerant passes certain limits or the magnetothermical control of the compressor's electrical engine is activated. In such events, the system informs the technician, switches off the compressor affected and automatically starts up another fully operational compressor.

Computer control systems can also be applied to cold distribution circuits, in this way optimising the energy consumption of the compressors according to cold demand and tariff periods with time differentiation. In the case of cold stores, the system can read and record operating ambient temperatures in these stores. When, during peak-rate periods, the temperature in a chamber slightly exceeds the maximum permitted, the computer delays starting up more compressor stages to satisfy increased demand until flat or off-peak rate periods begin.

Computer control and management systems can be applied to cold production and consumption in beer-making, a process with relatively high cold consumption. By incorporating these control systems, a brewery reduced energy consumption for refrigeration by 10%. As indicated in Figure 14, computer control and management systems for refrigerating plant has to be integrated into the operational decision-making structure of the entire factory.

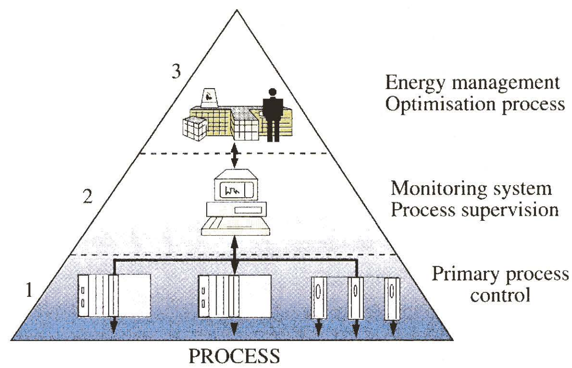


Figure 14. Computerised control system for cold production and consumption at a brewery.

4.5 Cold accumulation technology.

If hourly cold demand for each working day at an agrofood factory follows the same pattern as that indicated in Figure 15 (power consumed in the screw compressor room of a slaughterhouse), the incorporation of a cold accumulation system should be considered.

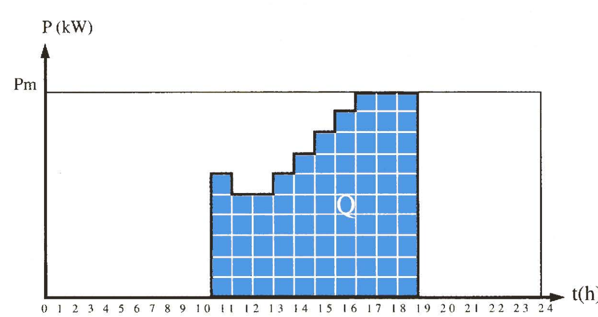


Figure 15. Typical histogram of irregular refrigeration demand at an agrofood enterprise.

Such a system could enable the production of cooling during those periods when it is not consumed, a subsequent reduction of the capacity of the plant and a more balanced and efficient operation from the point of view of energy, as is shown in Figure 16, where:

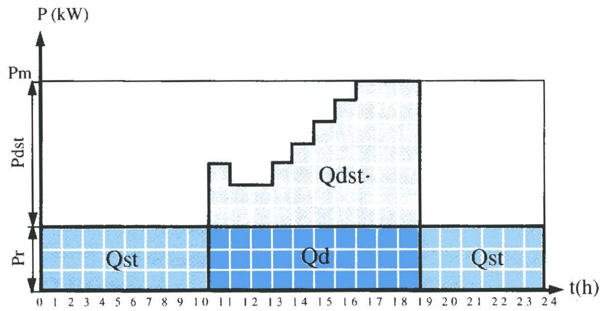


Figure 16. Partial cold accumulation.

Pr = the reduced frigorific power of the new plant, in kW.
Pdst = the power capacity from cold accumulation, in kW.
Qd = the quantity of cold produced directly per Pr during operation.
Qst= the quantity of cold stored, produced by accumulation at times when there is no cold consumption. It should be equal to Qdst.
Qdst = the quantity of cold required by the enterprise not produced by Pr, obtained from accumulation.

Cold accumulation systems have the following advantages:

(1) Installed refrigeration power is reduced to Pr.
(2) Energy consumption is distributed throughout the day in a more rational manner, with electricity consumption at night to take advantage of off-peak rates. Moreover, it is possible to work during periods when condensation temperature is lower, due to the fact that ambient temperature is also lower. Such conditions make for economic and energy savings, as the refrigerating plant works with greater energy efficiency.
(3) The reliability of the refrigerating plant is increased, as cold is consumed from two sources, a dynamic Pr system and a static Qst system.

If the accumulation of chilled water at around 5°C is used with return water from points of cold consumption at a temperature of 12°C, accumulated cooling energy of 8.1 kWh/m^3 is achieved. This performance can be increased by lowering the temperature of the stored water and raising that of return water. For example, if return water temperature is increased to 15°C, the previous figure is increased to 11.6 kWh/m^3, though it will be necessary to increase evaporator surface by 30%. If water with anti-freeze is used, chilled water could be accumulated at -5°C. In such conditions the accumulated refrigeration energy would be 19.7 kWh/m^3. Finally, if chilled water at -5°C is accumulated and returned at 15°C, accumulated refrigeration energy in the water will be 23.2 kWh/m^3.

Another way of accumulating cold is by storing ice. This procedure means that smaller storage tanks can be used, as the theoretical heat from the melting/freezing process of the water is 93 kWh/m^3. In practice, cooling capacities of only 40-50 kWh/m^3 are achievable, since there are always volume losses in ice storage tanks due to the location of cooling pipes or plates and the free spaces which must be left to allow the water to circulate around the accumulated ice.

If sensible heat stored from 0°C to 12°C is taken into account, some 10 kWh/m^3 can be added to this figure, and output of the thermal accumulation of ice would be around 50-60 kWh/m^3. Therefore, ice accumulation systems are cheeper than water accumulation systems, since storage tank volumes could be reduced to one fifth.

There are, basically, three ice storage techniques:

(1) **With positive heat transfer**

This is the system most commonly used by the dairy products industry, and consists of an insulated ice storage tank made of galvanised steel or concrete. The internal part of the tank contains a series of metallic plates or tubes which form the evaporator of the refrigerating plant.

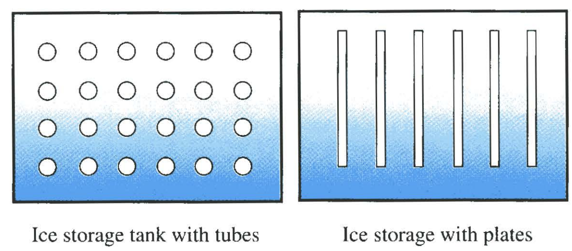


Figure 17. Cold storage tanks in a system with positive transfer.

The outer surface of the plates or tubes (see Figure 17) serves as a support for the accumulated ice. The cold water supplied to consumption points in the factory is recirculated inside the ice storage tank and enters into contact with ice (Figure 18). In these systems, heat transfer always takes place in the same direction -from the ice or melted ice to the tubes or plates- for which reason they are known as "positive transfer systems".

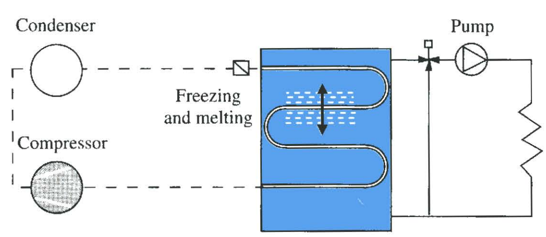


Figure 18. Basic diagram of an ice accumulation system with positive transfer.

(2) **With alternative heat transfer, with tube bundle.**

In these systems, the ice storage tank contains a bundle of thin tubes, generally made of plastic, uniformly distributed, mounted either spirally or accordion-style (Figure 19). The tubes contain water mixed with anti-freeze, which is periodically cooled to negative temperature, as shown in Figure 20.

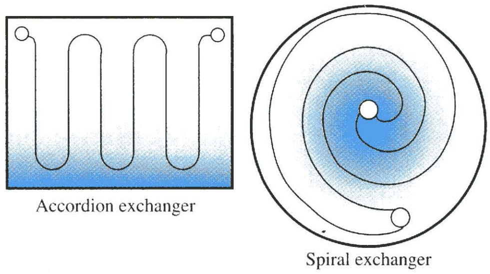


Figure 19. Arrangement of tubes of the ice storage tank in a system with alternative transfer.

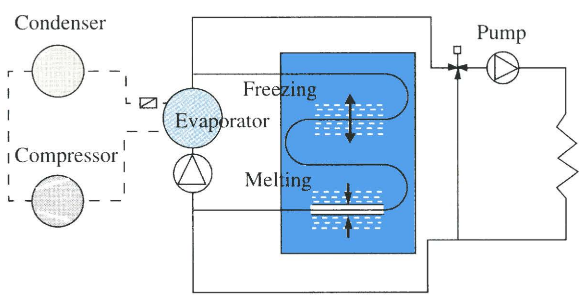


Figure 20. Basic diagram of an ice accumulation system in a system with alternative transfer.

The external surface of the tubes supports the ice. The cold water used at these consumption points is recirculated inside the tubes and does not enter into direct contact with the stored ice.

In this way, heat transfer takes place from outside to inside the tubes in the ice storage phase and, from inside to outside during the ice melting stage.

(3) **With alternative heat transfer and filling bodies**

In this system the ice storage tank is made of insulated

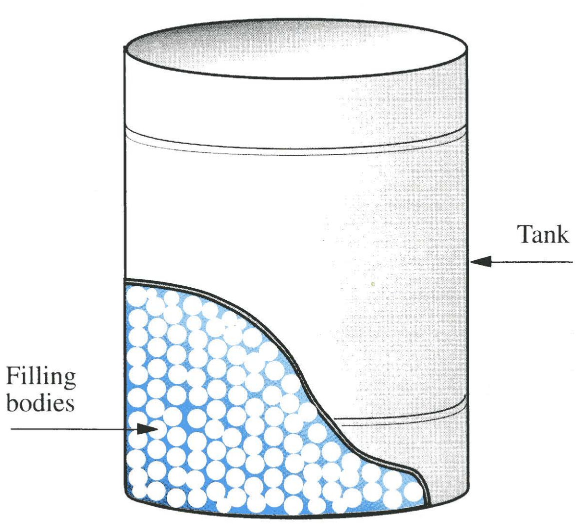


Figure 21. Storage tank of an ice accumulation system with filling and alternative transfer.

steel or concrete. The tank contains a large quantity of water-filled "filling bodies" (see Figure 21). On freezing, the water in these filling bodies forms the cold accumulation.

A solution of water and anti-freeze circulates among the filling bodies. This solution acts as a refrigerant at negative temperature for freezing the water in the filling bodies during the cold accumulation stage or as a refrigerant for cold consumption points in the factory, where it is recirculated through the filling of the cold storage tank (see Figure 22). In this way, according to whether the temperature of the solution is positive or negative, the water contained in the filling bodies will freeze or melt.

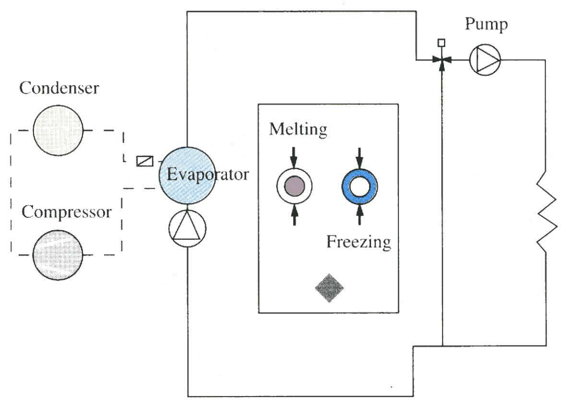


Figure 22. Basic diagram of an ice accumulation system in a system with alternative transfer and filling.

These ice accumulation systems can be used for total thermal accumulation -a system little used due to the high initial investment cost involved- or for partial thermal accumulation (Figure 16), which is a more attractive option.

In new refrigerating plants where cold demand is concentrated in peak-rate periods or with important discontinuity of demand, it is worthwhile considering the integration of a cold storage system in the plant. In the case of existing refrigerating plants which has to be extended or which have a similar irregular distribution of cooling loads, the use of a cold storage system can replace the compressors which would be required if an ice accumulation system were not employed. However, even when greater cooling power is not required, the savings obtained can justify the use of ice, a point which can be determined through the execution of a feasibility study.

4.6 Electronic humidifiers.

The humidification of a cold store chamber using ultrasonic electronic humidifiers produces a certain refrigerating effect, and also allows evaporation temperature to be raised, improving the energy efficiency of the refrigerating plant.

Electronic ultrasonic humidification consists in injecting a small quantity of cold water vapour at the outlet of the evaporator (Figure 23). The result is an increase of the relative humidity inside the cold chamber and a improved heat transfer coefficient. Therefore, the same quantity of heat is extracted from the stored food but at a higher evaporation temperature of the refrigerant fluid.

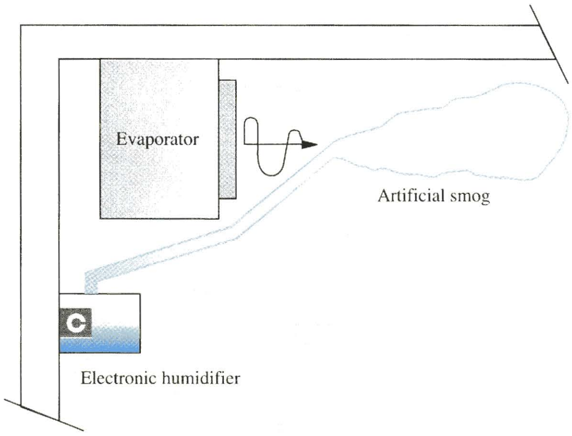


Figure 23. Arrangement of an electronic humidifier in a cold store.

The system is recommended for cold stores at around 0°C when relative humidity does not exceed 90% when the evaporator is working at full capacity, thus decreasing weight loss in stored food. For example, water losses without humidifiers can be as high as 15 kg water per day in a fruit cold store with around 3.5 kW installed cooling power. The installation of such a humidifier can reduce water loss by some 35%, with energy savings of around 5%.

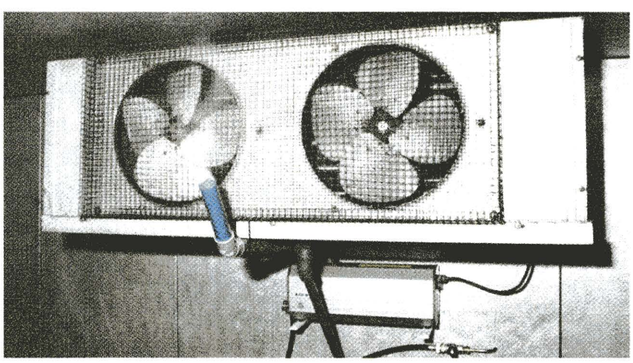


Figure 24. Electronic humidifiers

4.7 Heat recovery in condensers. Heat pumps.

Any refrigerating plant can be considered as a heat pump, as both types of machine transfer heat from a cold ambient (evaporator) to a hot one (condenser). However, unlike the heat pump, the energy discharged in the condenser of a refrigerating plant is generally evacuated into the environment (water or air) without any energy recovery.

There exist various systems for recovering the condensation energy in the cooling cycle. For example, in a large cold store, the energy employed for producing all the cooling required is, generally, much greater than that used to cover such services as heating offices, cleaning, heating the floors of frozen stores, etc. The heat recovered from the condensers through heating water or air could be used to cover this heat demand.

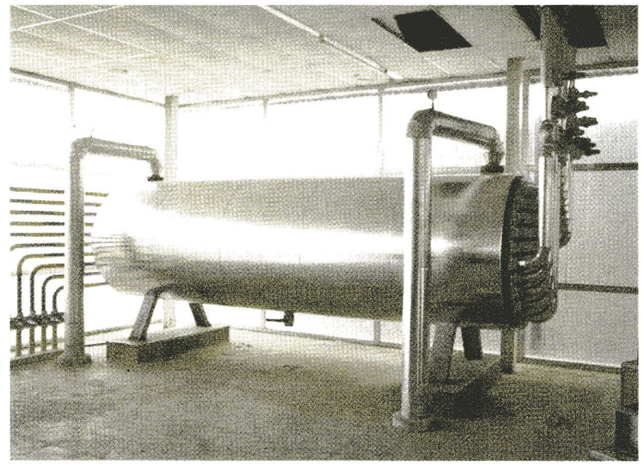


Figure 25. Heat exchanger recovering heat from refrigerating plant condensers.

In practice, however, there exist certain limitations which could make heat recovery from the condensers not viable. These are: where there is a long distance between condensers and heat consumption points; where heat recovery and possible use are not simultaneous in time; and the fact temperatures of only 25-35°C can be obtained from an air or water condenser with complete energy recovery. The heat from the superheated vapour can be recovered at a higher temperature at the compressor discharge, obtaining air or water at a temperature of 60-70°C, but the energy recovered is only 5-15% of the total evacuated by the condenser. In any case it is not advisable to increase condensation temperature with the aim of recovering heat from the process, as this would reduce the energy efficiency of the refrigerating plant.

Direct heating of the air in the condenser would be the most efficient form of energy recovery, but if there is a relatively long distance between the heat consumption points and the condenser it will be necessary to use an intermediate heating fluid, such as water. For refrigerating plant which uses ammonia as refrigerant, intermediate heating fluids also need to be used for safety reasons.

For refrigerating plant of a certain power, such as those using screw compressors, oil coolers exist from which energy can also be recovered to obtain water at 35-40°C, recoverable energy being 10-25% of that discharged in the condenser.

The use of heat recovery systems is recommended where there is hot air or water consumption for processes, cleaning or heating close to the site of the refrigerating plant and where such demand is simultaneous with the working times of the refrigerating plant. Pay-back periods on such investment tend to be relatively short.

For example, in the case of sausage drying installations, the recovery of heat from the condensation process is of great interest as there will normally be simultaneous consumption of heat and cold at relatively low temperatures. During stoving, at the beginning of the drying phase, in order to activate sausage fermentation, heat is required to stabilise temperature at around 19-20°C and 95% humidity, whilst the temperature required for the drying phase itself is 16-17°C. Humidity is gradually reduced during subsequent stages, with cooling being necessary to bring the air to dew point and to dry it. Sausage drying plants equipped with systems for heat recovery from condensation, used to reheat air previously dried in cold evaporators can produce energy savings of 25% compared to conventional dryers supplying heat by means of vapour and without heat recovery from condensation. Simple heat recovery from condensation has, however, the temperature limits mentioned earlier, and the stoving process requires extra heating to be supplied from electrical coils, as if this is not applied required temperature levels cannot be reached.

Another system for recovering heat from the condenser of refrigerating plant is through the use of heat pumps, which can be arranged in either of the following two ways: through the installation of a water-water heat pump to recover the heat from the condenser output water; or by installing a heat pump in cascade with the refrigerating plant so that the condenser of the refrigerating plant is also the evaporator of the heat pump. This latter solution presents the greatest efficiency of energy recuperation from the condenser.

With modern heat pumps it is possible to obtain temperatures of 110-120°C in air or water. The interest in the installation of a heat pump rises with the number of hours the plant works and as the difference falls between evaporation and condensation temperatures in the heat pump circuit. In general, the temperature difference should not be greater than 45-55°C and annual working hours should not be less than 2,000.

In some cases, it may be advisable to use a reversible heat pump which allows the functions of the evaporator and the condenser to be reversed. This allows the machine to be used to produce heat or cold, reaching higher temperatures than the simple recovery of heat from the condenser. Such machines also offer the possibility of simultaneously using the cold produced and the heat from condensation, as is the case with reversible heat pumps employed to dry sausage products (see Figure 26). These are used as air drying plant with recovery of the air required to reheat the dry air (they can also be used to heat water) and as a heat pump for stoving, to obtain a certain air temperature. In this way, no extra heat has to be supplied by electrical coils in order to obtain the higher temperatures needed during the stoving stage. Specific energy consumption in the case of continuous dryers with reversible heat pump is 0.6 kWh/kg product, compared to 1.1 kWh/kg product for conventional batch dryers.

4.8 Refrigeration by absorption systems.

In any cold production system, calorific energy is transferred from a lower temperature level to a higher one. According to the second law of thermodynamics, these refrigerating systems have to consume energy in order to carry out this "unnatural" operation. When a system is "dithermal" there are two heat sources: a cold source at temperature Te (evaporator) and a hot source at temperature Tc (condenser). In this case, mechanical energy is consumed and the theoretical coefficient of performance is, as mentioned in section 4.1.

However, there exists another class of refrigerating plant which consumes calorific energy in order to produce cooling. These have three heat sources, making them known as "trithermal" systems: one at Te (evaporator), as second at Tc (condenser) and a third at Tm (corresponding to the "motive" heat source). In these cold production systems, it will necessarily true that Tm > Tc > Te, so that

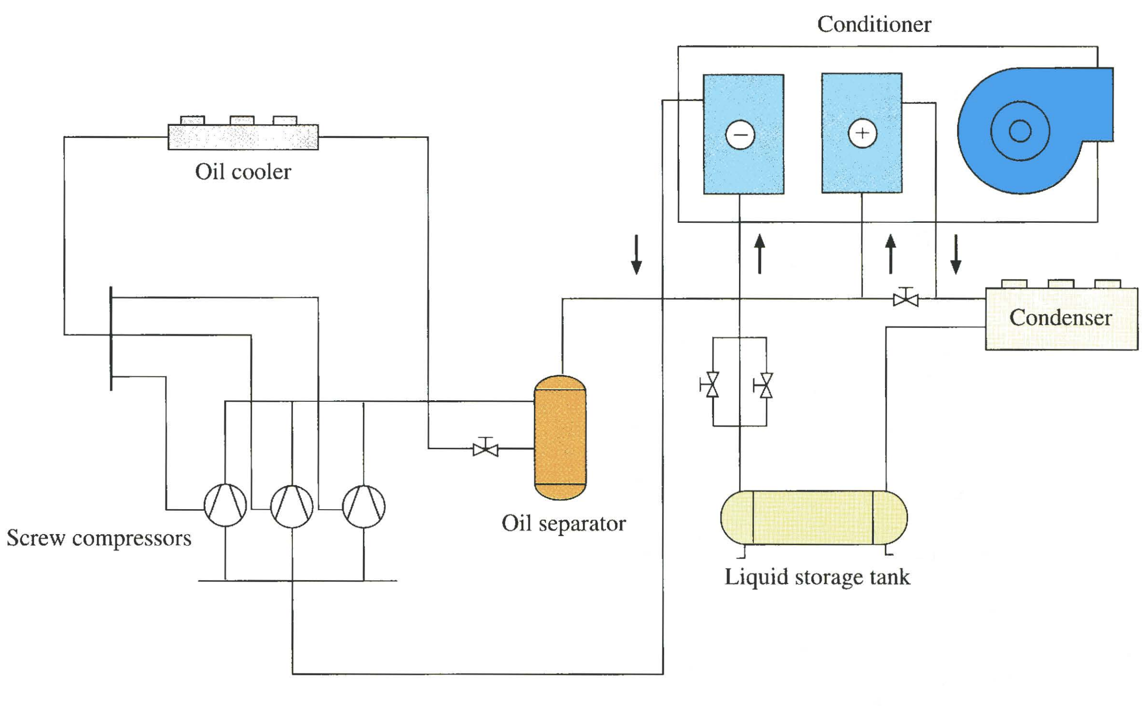


Figure 26. Schematic diagram of a reversible heat pump applied to a continuous dryer for sausages.

the theoretical coefficient of performance, if defined as the ratio between the heat discharged from the cold source and the heat supplied by the "motive" source, will be:

$$\frac{Te}{Tc - Te} \times \frac{Tm - Tc}{Tm}$$

It will be observed that, as the first term of this product is the coefficient of performance of dithermal systems and the second is lower than unity, trithermal systems will in principle have a lower coefficient of performance than those consuming mechanical energy. Nevertheless, it has to be taken into account that it is much easier to obtain heat, from simple combustion, for example, than mechanical energy, and that moreover trithermal cold production systems have the great advantage of being able to use as "motive" heat sources the waste heat from:

- excess vapour and hot water from the industrial process at low, medium and high pressure.
- heat discharged from a cogeneration system.
- vapour or hot gas from exhaust gas heat recovery (turbine or motors).
- heat recovered from furnaces, dryers, etc.
- solar energy systems which can produce temperatures of over 80°C.

Among cold production systems consuming heat are absorption refrigeration systems, which use the reciprocal affinity between the molecules of a volatile substance, the refrigerant -or agent of cold production in the evaporator-, and those of a liquid, the absorbent. Liquids which can be used as absorbent include, among others, water -using, for example, ammonia as a refrigerant and with the requirement of a heat source at 100-120°C- or lithium bromide (BrLi). The latter uses water as a refrigerant and the heat source can be at a temperature of only 60-80°C.

Figure 27 shows the functioning principle of absorption refrigeration systems. These systems can be used in the agrofood industry at any temperature range, but are almost always used for cooling water which is employed, in turn, as a secondary refrigerant for cooling process air or liquids.

Inside the evaporator of such a refrigeration system is the tube bundle through which the water to be cooled passes. Over the tube bundle is a water applier, in this case the refrigerant, so that the tubes are covered by a thin layer of water which is evaporated at low temperature (5°C, for example) extracting the heat from the water to be cooled. Inside the evaporator a vacuum of for example 6.5 mm Hg (corresponding to the previously mentioned evaporation temperature of 5°C) is maintained.

Next to this evaporation zone is the absorber, where a concentred BrLi solution is applied in the form of drops, absorbing the water vapour which forms in the evaporator. As the BrLi becomes diluted and loses its absorption capacity, it is necessary to continuously apply the concentrated solution, and the absorbed water must also, therefore, be continuously separated off. To do this, the BrLi solution is pumped to the "generator/separator", where heat is applied to bring the diluted solution to boiling point and thereby evaporate and separate off the water. Energy required for pumping is negligible. The generator can have two stages: one working at high temperature and the other heated at low temperature (lower boiling point) by the vapour produced during the first stage. This double-effect system decreases energy consumption, but the heat supplied to the system has to be at a higher temperature, as high as 150°C if the couple BrLi/water is used; however the size of the condenser and the cooling tower can be reduced by around 25%.

The water vapour produced by the generator is sent to the condenser, where a water condensation system with

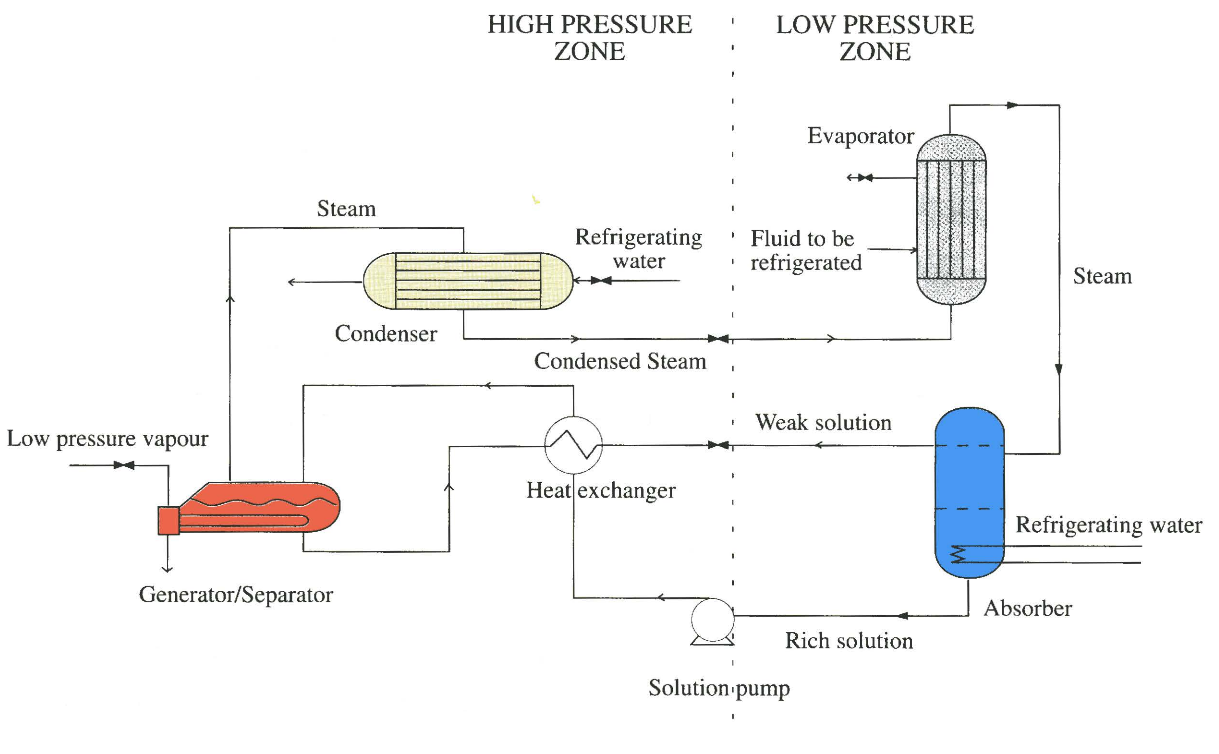


Figure 27. Basic diagram of absorption cold production system.

cooling tower can be used. The condensed water will be returned to the vacuum evaporator, closing the cycle.

The principal advantages of an absorption refrigeration system coupled to a cogeneration plant are:

- they contain practically no moving parts, excepting the pump for the concentred solution, thus reducing noise and maintenance and increasing useful life.
- calorific energy consumption is in certain cases cheaper when using cogeneration systems, though with the limiting factor that temperatures have to be higher than, approximately, 80-90°C.
- the refrigerant is environmentally safe.
- continuous power variation is possible with a wide margin, and control of the machine is very simple.

5. CASE STUDIES

5.1 Case 1

Pom'Alpes, France

Variable speed compressors

This is a company specialised in the harvesting, storage and distribution of apples. In 1990 the company had four 370-ton capacity refrigerated storage chambers, functioning with controlled atmosphere. Each chamber was fitted with independent refrigeration equipment.

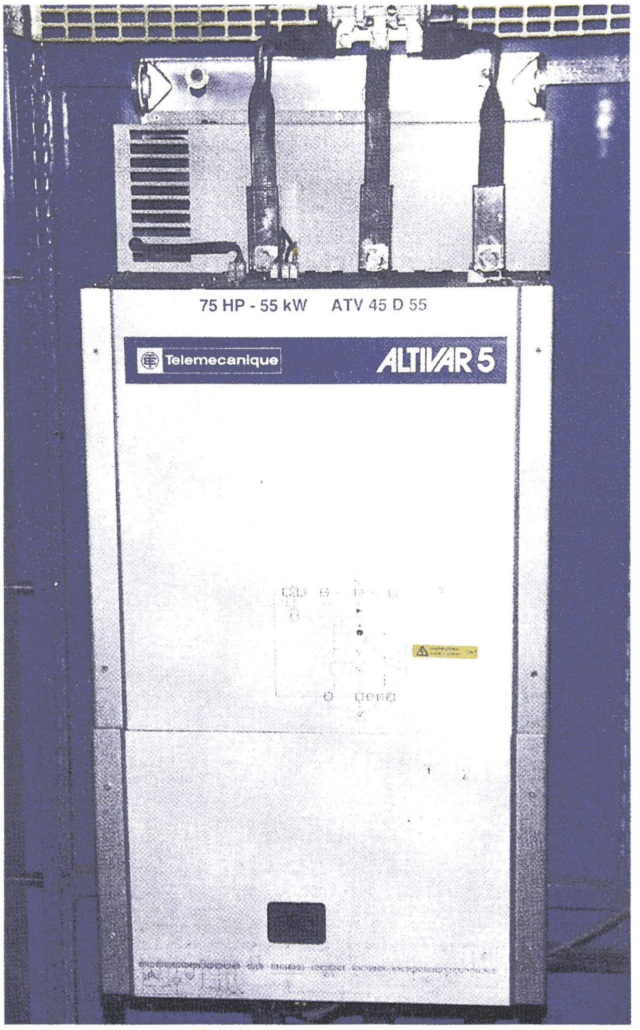


Figure 28. Variable speed drive system

That same year it was decided to increase storage space by opening two more cold rooms with capacity of 260 and 100 tons respectively. The capacity of this latter has since been increased to 310 tons. Subsequently, increased production, with corresponding increase in storage requirements, rendered the existing refrigeration equipment insufficient, resulting in rising temperatures in the storages chambers. A study was therefore made of available refrigeration equipment.

The solution proposed was a system of centralised cold production which took into account the fact that a fruit company has large cooling demand during the harvest (in September) but considerably lower demand during the storage period (October to May). It was therefore necessary to install a suitable cooling power regulation system. The system adopted was a cold production system with two variable speed screw compressors (speed can be varied by varying frequency) in the drive engines. This system allows cooling production to be continuously adapted to requirements.

The installation of this refrigeration system has produced a 20% decrease in specific energy consumption, from 268.6 kWh/ton to 215 kWh/ton, at an investment cost of 102,957 ECU (1 ECU = 6.5269 FF). The installation payback has been approximately 3 years.

5.2 Case 2

Casademont SA, Spain

Heat pump and heat recovery from condensers

Casademont, SA, is one of the leading Spanish sausage producers. In such industries, the production stage which has undergone the greatest evolution is the drying process, which has notable influence on product quality and is also an operation involving high energy consumption.

The sausage drying process consists of four stages and takes two weeks, during which a quantity of water equivalent to two thirds of the sausage's initial weight is eliminated. In order to activate fermentation, stoving takes place during the first stage, requiring the addition of heat to raise its temperature to around 19°C-20°C and to obtain ambient humidity of 95%. Drier temperature is then maintained at 16°C-17°C and ambient humidity is gradually reduced over the three following stages, during which cooling is required.

Originally, the factory had driers which used cold from independent refrigeration systems and steam from the boiler room. Later, in order to increase production capacity, 19 new driers of different power and sizes were installed. In these, the cold required to take the air to dew point and dry it is supplied by the evaporator of the refrigeration system, whilst the heat later required to raise air temperature back to 16-17°C is extracted from the condenser of the same refrigeration system. Excess condensation heat is dissipated by an additional exterior condenser connected in series to the heat exchanger used to heat the air.

The heat recovered from the refrigeration systems and used to dry the air allowed 25% energy savings in the sausage drying process. But it was still necessary to add heat in the form of steam from the boiler room to heat the

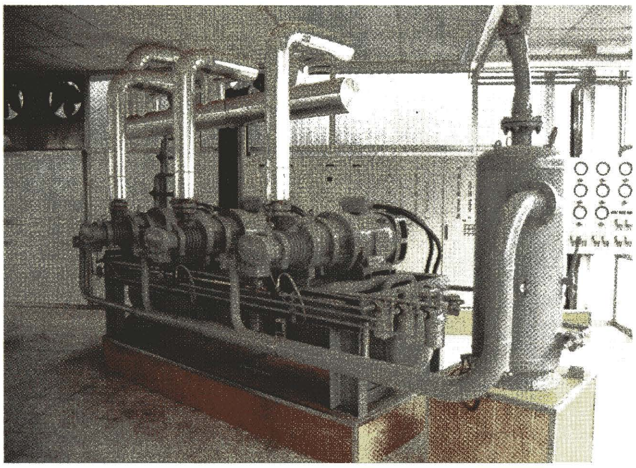


Fig 29. Screw compressors of 55 kW unitary power.

air in the drying room during the stoving stage. The company therefore decided to install a 36 kW reversible heat pump which could invert the functions of the evaporator and the condenser so as to be used during the stoving stage. By means of this reversible heat pump, the need to use steam during the drying stage was completely eliminated and the evaporators could be defrosted much more quickly.

Subsequently, Casademont increased production capacity through the installation of continuous driers designed at the firm itself. This new system takes advantage of the fact that various stages in the drying process are going on at the same time (when one stage needs heat, another occurring at the same time needs cold), favouring energy recovery from the refrigeration system.

These improvements reduced installed power from 300 kW to 165 kW, with electrical energy savings of 129,400 kWh/year. The table below compares the results obtained by the continuous drier with the conventional drying system, considering 1 ECU = 162.7 PTA.

(Values per drier unit)	Continuous drier	Conventional drier
Surface occupied (m^2)	585	127
Production capacity (kg/day)	6,380	767
Electric power (kW)	165	36
Energy consumption (kWh)	4,536	5,256
Energy saving (ECU/year)	8,113	-
Investment (ECU)	534,726	92,194

Apart from the reduction in energy consumption, the new continuous drier increases the productivity of the plant, reduces the surface required by half and substantially improves quality and uniformity of products. For these reasons, the pay back period of the installation, which has cost 534,726 ECU, is around three years.

5.3 Case 3

Ind Coope Burton Brewery, UK

Heat exchanger surface area adjustment.

Ind Coope Burton Brewery (ICBB) is part way through a major project to replace obsolete brine chillers which used CFC 12 centrifugal compressors. A water chilling load has been met by a dedicated high evaporating temperature plant. Variable speed drives will be used to reduce the energy used by the brine pumping systems. New brine chillers use plate heat exchanger (PHE) evaporators,

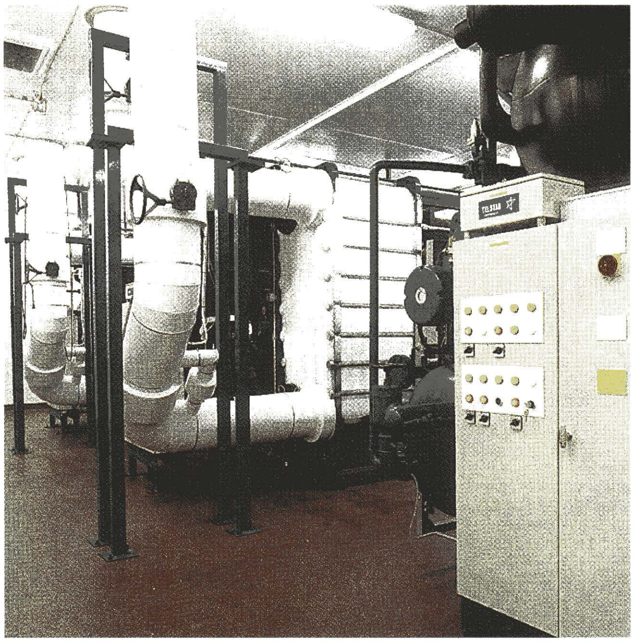


Figure 30. New Brine chillers use plate heat exchanger evaporators.

ammonia screw compressors and evaporative condensers. Heat exchangers have been generously sized. The evaporator uses a 1.5°C approach between evaporating temperature and leaving brine temperature (a more conventional approach would be to use an approach of 3-5°C in a shell and tube). The design condensing temperature is 32°C whereas more typical UK practice would be 35°C. Also, very important, the condensing temperature is allowed to float down when ambient temperature or load are below their design levels. These features have generated energy savings of around 20% (630,000 kWh/yr) compared with more conventional heat exchanger sizing. The total cost of the replacement of the obsolete refrigeration system was 2,965,247 ECU, with annual electricity savings of 142,332 ECU and maintenance savings of 47,444 ECU per year (1 ECU = 0.8431£).

5.4 Case 4

MD Foods, Troldhede Dairy, Denmark

Ice-water pre-cooling unit.

At MD Foods, Troldhede Dairy the ice-bank refrigeration system was improved in 1990 by the installation of an ice-water pre-cooling unit. The Troldhede Dairy is specialized in cheese production. The energy efficiency for the total ice-water cooling system has been increased by 27% when compared with the situation before the improvement.

For cooling purposes the dairy needs ice-water at 0°C. In the existing plant ice water was produced in a traditional way by evaporator coils submerged in a water-filled tank.

Inside the coils the cooling media was evaporated at -10 to -15°C. The evaporator coils also served as an ice bank source by ice accumulation on the surface of the coils during the night. The cold storage capacity by ice-accumulation typically corresponds to 10-30% of the total cooling demand during the day. At MD Foods, Troldhede the ice-water in the return loop is now pre-cooled to a temperature of 1-2°C before entering in the ice-water tank. The pre-cooling is done by a separate refrigeration plant with an evaporator temperature of only -1 to -2°C. The return water is cooled in a flat plate heat exchanger.

The pre-cooler unit removes about 75% of the total heat withdrawn from the return ice-water. Because of the higher evaporation temperature in the pre-cooler unit the heat can be removed at a higher COP (Coefficient Of Performance), which means at a reduced electricity consumption of the refrigeration compressors per unit of heat removed and at reduced electricity peak-load.

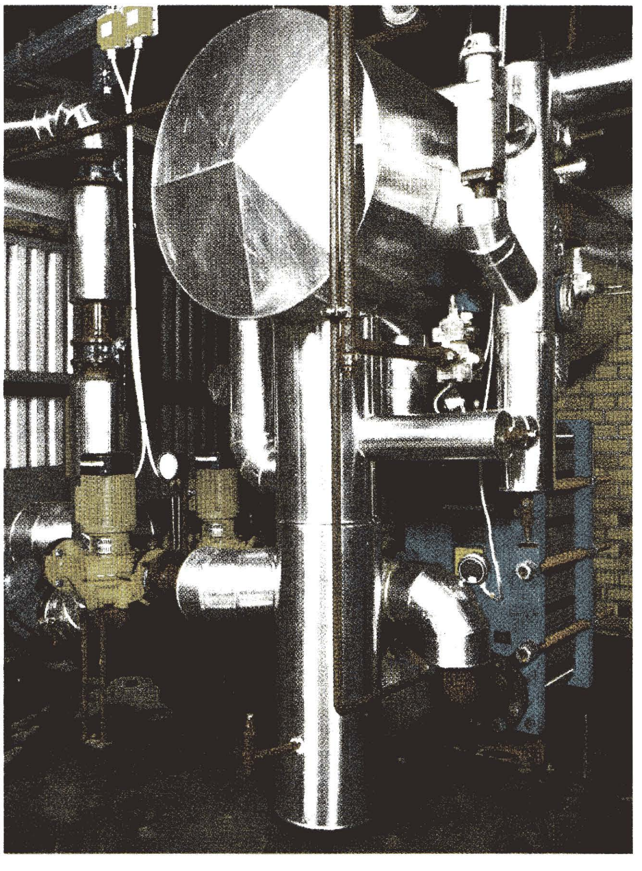


Figure 31. Ice-water pre-cooling unit.

At Troldhede the specific electricity consumption for the ice-water cooling system was reduced from 0.333 kWh to 0.243 kWh per kWh of heat removed.

The installation of the pre-cooler unit was the main part of an expansion of the cooling capacity from 150 kJ/s to 550 kJ/s. The higher capacity demand required the installation of a new screw compressor with a COP of 4.5 at -2°C evaporation temperature. The compressor peak-load demand is 45 kW smaller in comparison to a traditional solution.

The cooling plant is in full load operation corresponding to 12 hours per day all year around, which means a saving in electricity consumption of about 215,000 kWh/year. With an electricity price of 0.055 ECU/kWh the annual savings are 11,388 ECU (1 ECU = 7.2645 DKR).

Apart from the screw compressor the installation costs of the ice-water cooler was 41,297 ECU.

The pay-back time of the ice-water cooler was 3.6 years.

Total annual energy savings	215,000 kWh
Total annual energy costs	32,211 ECU
Total annual energy costs traditional plant	44,050 ECU
Annual savings	11,838 ECU
Installation costs excl. additional compressor	41,297 ECU
Pay-back time	3.6 years

5.5 Case 5

Casa Tarradellas SA, Spain

Refrigeration by absorption and cogeneration

Project supported by the THERMIE Programme.

Casa Tarradellas, SA is a firm producing a well-known type of sausage as well as other pork products, with total output of over 6,500 tonnes per year. Its production processes require heat in the form of steam, cold and electrical energy. Previously, the steam was generated by three boilers, two using gas-oil and the other solid waste, whilst refrigeration needs were covered by mechanical compression systems (heat pumps and conventional equipment).

When the firm decided to expand its premises in order to increase production capacity, it was foreseen that such a move would be accompanied by a large increase in electrical energy demand. In view of the already large thermal energy demand of the plant, it was therefore decided to install a cogeneration-absorption plant, which was put into operation in 1992.

Cogeneration - absorption technology consists of coupling a cogeneration system to an absorption cold production system recovering waste heat from the turbine exhaust fumes or consuming part of the steam produced in a steam generator which uses this waste heat. In this way, electricity and heat (high and low temperature) requirements are covered by just one centralised system. The cogeneration system at Tarradellas consists of a gas turbine coupled to an alternator producing an average power of 3.4 MW and a steam generator to recover the heat from the turbine exhaust fumes, with flow of 17 kg/s and a temperature of around 500°C. This pyrotubular, single-step steam generator generates 9,000 kg/h of saturated steam at 7 bar (relative pressure). For the generation of electrical energy, there is a 5 MVA synchron alternator, coupled to the turbine axis, generating at 6 kV connected to a single transformer which raises tension to grid connection level (25 kV). The transformer output is connected to the utility grid and to the company's internal distribution system. The system also includes a 2,322 kW cold production plant, powered by part of the steam produced by the recovery boiler, with maximum steam consumption of 7,600 kg/h. This plant uses ammonia as refrigerant and has a two-stage absorption system to produce cooling at two temperatures (-12°C and -30°C), as well as a single generation stage. The absorbers are cooled by water from a cooling tower (345 m^3/h with a thermal step-up from 31°C to 41°C. Cooling is supplied to the various consumption points by a glycolated water network.

The steam produced by the steam generator and not consumed by the absorption plant (around 20% of the total) is used to supply for production processes.

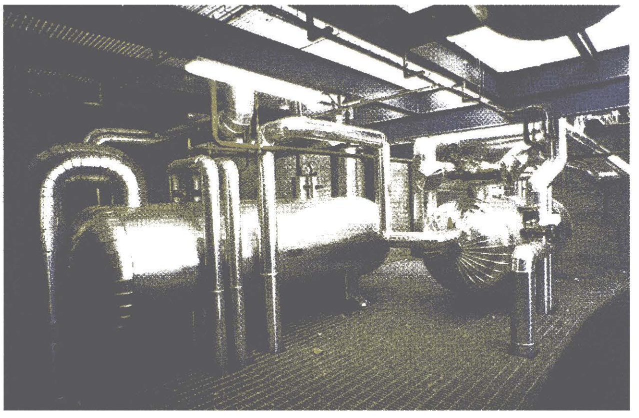


Figure 32. Absorption cooling system

As the natural gas network does not reach the factory, a gasification plant had to be installed to supply the cogeneration plant. This has maximum gasification capacity of 1,500 Nm^3/h at 13 bar (relative pressure), and storage capacity of 120 m^3 of LNG.

Total investment was 5.5 million ECU, with a gross operating margin in the first year of 0.5 million ECU obtained, for the most part, from the sale of suplus power to the electricity company, and energy savings of 1,464.7 Toe.

5.6 Case 6

Waterford Foods Plc, UK

Ice-bank refrigeration system

Project supported by the THERMIE Programme.

Waterford Foods Plc is an international food company engaged in the manufacture and sale of consumer products, dairy commodity products and animal feedstuffs as well as trading in general agri-business. The company is now the largest dairy processor in Ireland.

The Ice-Bank refrigeration system is installed in the main processing centre in Dungarvan, Co. Waterford, Ireland. This site has a capacity to process 500 Mlitres of milk annually. The main products manufactured on this site are various milk powders, casein and a number of butter products. Because of the perishable nature of the product that is being handled, there is a big demand for chilled water for cooling purposes both in the process and to store milk and cream. This cooling requirements is supplied by chilled water from three Grasso refrigeration plants using ammonia (R717) as refrigerant. The most recent of these plants was installed in 1987 and is the basis of the Ice-Bank refrigeration system as well as being used as a conventional hydro-cooler. Chilled water at a temperature of approximately 2°C is used in the process in plate heat exchangers or jacketed vessels for cooling of milk, cream and various concentrates.

The Ice-Bank principle is based on allowing a layer of ice to build up on the coils of the evaporator, 35 mm in this case. This evaporator is well insulated so that the ice can be stored and used when necessary. The energy saving is based on utilising the cheaper electricity that is available during the night-time (i.e. 23:00 to 8:00 hours). The plant is used to its maximum capacity during this period to build up two banks of ice. This ice bridges vertically but not horizontally to allow for proper circulation of the chilled water through the bank. It is agitated by compressed air or air pumps fitted locally to the ice bank. This ice bank is then burnt off during the day-time when the actual operation of the plant is kept to a minimum. When the ice is completely burnt off the system can be used as a conventional hydro-cooler in an extremely efficient manner. Thus, considering 0.8163 IR£/ECU.

Night rate electricity	=	0.028 ECU per kWh
Day rate electricity	=	0.074 ECU per kWh
Saving by using night rate	=	0.045 ECU per kWh

Further savings were achieved in this system by the design of a bigger evaporative condenser which condenses at 30°C and an ice-bank evaporator working at -5°C and -2°C as hydro-cooler. This condenser was a first of its type in the world in conjunction with reciprocating compressors (2 x 110 kW electrical motor driven reciprocating compressors using ammonia as refrigerant). Formerly three refrigerating plants with a total electrical input of 1,000 kW were required, prior to ice-bank installation. Now 440 kW of power is required.

Results:	
Total capital cost	289,722 ECU
Savings per annum	61,252 ECU in 1987
Current savings per annum	73,502 ECU
Pay-back period (without EC Grants)	4.7 years
Pay-back period (with EC Grants)	2.8 years

5.7 Case 7

Irish Cold Stores Ltd, Ireland

Improvement measures in the refrigeration systems

The Irish Cold Stores plant was established in 1980 to provide cold storages facilities for foodstuffs, particularly meat and butter. Initially there were two cold rooms with a combined internal volume of 42,500 m^3. Each room had 150 mm insulation giving an average heat gain at working

Figure 33. Refrigeration system.

temperatures of 3.6 W/m^2. Electric underfloor heating was provided to prevent damage to the concrete being caused by freezing of the top soil.

The plant had several limitations which resulted in unacceptably high operating costs. The minimum operating temperature which could be reached by the five two-stage reciprocating refrigeration compressors was -18°C. This restricted the range of products which could be stored.

In 1987 the company expanded their capacity by installing new blast freezing facilities and eight small cold rooms. At the same time they implemented a 183,756 ECU (1 ECU = 0.8163 IR£) investment programme to improve the existing cold storage installation. The main features of this programme were:

(1) Insulation thickness on cold room wall and ceiling surfaces was increased to 200 mm. This reduced the heat gains through the cold room ceilings and walls by 27%.
(2) Improved cold room doors and wider door sealing strips were fitted to reduce heat gains through the doors.
(3) A glycol heat transfer system was installed to recover heat from the refrigeration plant condensing system and transfer it to the cold rooms where it replaced the electric underfloor heating system.
(4) In addition glycol is tapped off this system to cool the compressor cylinder heads, which improves their efficiency.
(5) A second heat recovery system was installed at the intercoolers to reduce the superheated refrigerant temperature before it reaches the compressors. This has increased overall refrigeration system efficiency.
(6) Plant automation, implemented at a cost of over 36,751 ECU, permitted the introduction of unmanned operation.

Results:	
Operating efficiency has improved significantly. Annual electricity costs were reduced by	24,501 ECU
Plant automation reduced annual labour costs by	24,501 ECU
Operating the compressors at a high load factor at night has extended the intervals between maintenance inspections and reduced annual maintenance costs by	3,675 ECU
Investment required to implement these improvements Annual savings	183,756 ECU 52,677 ECU
Pay-back period of under	3.5 years

5.8 Case 8

Laiterie Unicopa, France

Ice accumulation

For all process refrigeration requirements in the factory, the Unicopa dairy company decided to set up a centralized station called an "ice water vat", with an evaporator consisting of parallel tubes immersed in a vat containing water. On one hand, the cooling unit creates ice around the evaporator tubes; on the other hand, the water network which flows in this vat causes the ice to melt as water cools. Although transporting cold water causes energy losses, the station can be monitored, managed and maintained more easily than several individual systems. The reliability of a large installation is greater because it is also better equipped with monitoring devices.

With this system cold can be accumulated in the form of ice in order to consume cheaper energy or to allow consumption peaks to be met. The melting capacity and that of use can vary greatly and be much higher than the power of the installed cooling unit (for example, at Unicopa's Guingamp factory, there are 2 compressors with a capacity of 755 kW, while water melting capacity (1-2°C) is 4,645 kW).

In this system, the cooling output falls as a function of the thickness of the accumulated ice. The capacity per refrigerator increases by 20% at half the thickness of that of the tubes without ice and by 35% at maximum thickness. This represents a gold mine of annual savings: 24,514 ECU (1 ECU = 6.5269 FF) for a site such as Guingamp if it is properly managed (for example, all the ice is melted at 8:00 p.m.; from 8:00 p.m. to 0:00 hours compressors start operating -producing a maximum quantity of ice during off-peak hours- and at 9:00 a.m., the amount of accumulated ice is sufficient to meet demand). The pay back was approximately 3.5 years .

5.9 Case 9

Mercabarna, Spain

Computer control of refrigeration production

Mercabarna, a firm based in Barcelona, is the largest agrofood wholesaler in Spain. Its Food Unit includes the central fruit and vegetable and fish markets, the slaughterhouse and meat market and the flower market, and is formed by over 800 companies.

The consortium has refrigeration and freezing store capacity of over 200,000 m^3, of which 26,000 m^3 of refrigerating chamber corresponds to the slaughterhouse, which produces 28,000 tonnes of meat per year. The following cold-intensive operations are carried out at the slaughterhouse: rapid cooling of carcasses soon after slaughter, cold storage of carcasses, meat freezing in freezing tunnel, and conservation of frozen products. These cold consumption points are supplied by four circuits conveying cold from a central production unit. One of these circuits also cools the two corridors of the refrigeration chambers and two dispatch rooms. Each circuit is connected to an independent screw compressor, and total installed power is 1,492 kW. Total cooling capacity is 3,715 kW.

The automation of the cold production control systems at Mercabarna optimised the energy consumption of the refrigerating systems and ensured conservation of stored products in perfect conditions. The new system is based on the incorporation of a PLC (Programmable Logic Computer) which processes data on the working conditions of each of the refrigeration chambers and the operating conditions of the refrigeration systems. The latter conditions are adjusted according to the former. The PLC is connected to a personal computer which monitors

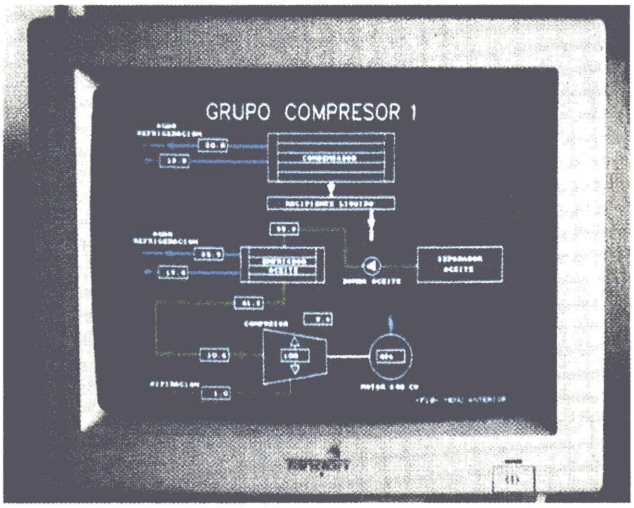


Figure 34. Computer control of refrigeration production.

working conditions at the different cold consumption points and the operation of the compressors, and which also has a programme for controlling defrosting processes which are, in turn, controlled by optic detectors. When these detect a set thickness of the ice, the sensor emits a signal for the defrosting cycle to begin. The defrosting operation is checked by flow detectors in the defrosting water outlet tubes. In order to ensure that the compressors function at maximum capacity with optimum energy efficiency each chamber is assigned a set temperature and another, slightly higher than the first and acceptable in terms of maintaining the quality of the products stored.

These improvements to the refrigeration control systems brought about significant energy savings: some 240,000 kWh/year, representing approximately 9% of the former consumption of the refrigeration systems (around 2,520,000 kWh/year). Moreover, the application of the system for monitoring the working conditions of cold consumption points and refrigeration systems has allowed the detection of other potential energy saving measures which, once implemented, are expected to raise electricity savings to 12% at minimal investment cost.

6. BIBLIOGRAPHY.

[1] BINON, P. 1986. Gestion d'une installation de froid industriel par système à microprocesseur. *Rev. Générale du Froid*, oct.: 543-546.

[2] CASP, A., LOPEZ, A. 1994. *Gestión de la energía y el agua en la industria agroalimentaria.* Ed. Gobierno de Navarra, Pamplona.

[3] CLELAND, A.C. 1990. *Food Refrigeration Processes. Analysis, Design and Simulation.* Elsevier. London.

[4] EDF. 1987. Thermofrigopompe et chaudière électrique dans une fromagerie. *Rev. Générale du Froid*, march: 9-12.

[5] GAUTHERIN, W. 1988. Stockage froid dans l'agroalimentaire. Un concept judicieux. *Rev. Pratique du Froid et Conditionnement d'air*, 19:56-63.

[6] IIR. 1992. *Refrigeration, energy and environment.* Proc. Int. Symp. on the 40th Anniver. of NTH Refrigeration Engng., June 22-24, Trondheim, Norway.

[7] JAHN, J.J. (1991). Ajustes estratégicos de las empresas agroalimentarias. *Revista de Estudios Agrosociales*, 157: 33-63.

[8] KAYA, A. 1991. Improving efficiency in existing chillers with optimization technology. *ASHRAE Journal*, 33(10): 30-38.

[9] LOPEZ, A., CABEZAS, A. 1992. Possibilités d'économie d'énergie dans les systèmes frigorifiques de l'industrie agroalimentaire de Catalogne (Espagne). *COLD'92 International Congress of the IIR*, Buenos Aires (Argentina), 7-9 Sept.

[10] LOPEZ, A., SECANELL, P. 1992. A simple mathematical empirical model for estimating the rate of heat generation during fermentation in white-wine making. *Int. J. Refrigeration,* 15(5): 276-280.

[11] LOPEZ, A. 1992. *Las instalaciones frigoríficas de las bodegas. Manual de diseño.* AMV Ed., Madrid.

[12] LOPEZ, A., GRENIER, P. 1993. Consommation d'énergie électrique dans les systèmes frigorifiques au service de la vinification en blanc. *Rev. Générale du Froid*, oct.: 33-38.

[13] LOPEZ, A. 1994. Tecnologías energéticas eficientes en los sectores del vino, cava, cerveza y destilados. *Alimentación, Equipos y Tecnología*, 13(2): 75-80.

[14] LOPEZ, A. 1994. *Las instalaciones frigoríficas en las industrias agroalimentarias.* AMV Ed., Madrid.

[15] MOLINA, M. (1990). In *Energy Innovation and the Agrofood Industry*, by Corte, P., Fabry, C., Ferrero, G.L., Eds., EUR 13142 EN/FR, Brussels.

[16] SINGH, R.P. 1986. *Energy in Food Processing.* Elsevier, Amsterdam.

THE OPET NETWORK

Organisations for the Promotion of Energy Technology

Within each member state there are a number of organisations recognised by the European Commission as an Organisation for the Promotion of Energy Technology (OPET). It is the role of these organisations to help to co-ordinate specific promotional activities within Member States. These include staging of promotional events such as conferences, seminars, workshops or exhibitions as well as production of publications associated with the THERMIE Programme.

ADEME
27 rue Louis Vicat
F-75015 PARIS
Tel. 33 -1 -47. 65.20.21/56
Fax. 33 -1 -46.45.52.36

ASTER SRL
Via Morgagni 4
I-40122 BOLOGNA
Tel. 39 -51-23.62.42
Fax. 39 -51 -22.78.03

BCEOM
Place des Frères Montgolfier
F - 78286 GUYANCOURT Cedex
Tel.: 33 -1 -30. 12. 49. 90
Fax. 33 -1 -30.12.10.95

BRECSU
Garston, Watford
Hertfordshire
UK - WD2 7JR
Tel.: 44 -923 -66.47.56
Fax. 44 -923 -66.40.97

CCE
Estrada de Alfragide
Praceta 1 - Alfragide
P-2700 AMADORA
Tel.: 351 -1 -471.14.54/81.10/82.10
Fax. 351 -1 -471.13.16

CEEETA-PARTEX cps
Calçada da Estrela, 82 - 1º DTº
P-1200 LISBOA
Silva (PARTEX)
Tel.: 351 -1 -395. 56. 08
Fax. 351 -1 -395. 24. 90

CESEN S.p.A.
Viale Brigata Bisagno, 2
I-16129 GENOVA
Tel.: 39 -10 -550.46.70
Fax. 39 -10 -550.46.18

CORA c/o SEA
Saarländische Energie-Agentur GmbH
Altenkesselerstrasse, 17
D- 66115 SAARBRÜCKEN
Tel.: 49 -681 -976.21.74
Fax. 49 -681 -976.21.75

COWIconsult
Engineers and Planners AS,
Parallelvej 15
DK-2800 LYNGBY
Tel.: 45 -45 -97. 22.11
Fax. 45 -45 -97.22.12

CRES
19 Km - Marathon Avenue
GR-19009 PIKERMI
Tel.: 30 -1 -603.99.00
Fax. 30 -1 -603.99.04/11

EAB, Flottwellstr 4-5
D-10785 BERLIN
Tel.: 49 -30 -25.49.60
Fax. 49 -30 -25. 49.62.30

Energy Centre Denmark
Suhmsgade 3
DK-1125 KØBENHAVN K
Tel.: 45 -33 -11.83.00
Fax. 45 -33 -11. 83.33

ECOTEC
Research and Consulting Ltd.
Priestley House
28-34, Albert Street
BIRMINGHAM UK - B4 7UD
Tel.: 44 -21- 616.10.10
Fax. 44 -21- 616.10.99

ENEA
Via Anguillarese, 301
S. Maria di Galeria
I - 00060 ROMA
Tel.: 39 -6 -30.48.18/36.86
Fax. 39 -6 -30.48.64.49

ETM Consortium
Av. Louise 304, box 8
B- 1050 BRUXELLES
Tel.: 32 -2 -646.88.14
Fax. 32 -2 -646.14.40

ETSU
Harwell, Oxfordshire
UK - OX11 ORA
Tel.: 44 -235 -43.33.27
Fax. 44 -235 -43.20.50

EUROPLAN CHORUS
2203 Chemin de St-Claude
Nova Antipolis F - 06600 ANTIBES
Tel.: 33 -93 -74. 31.00
Fax. 33 -93 -74. 31 31

EVE - Cadem
Edificio Albia 1
San Vicente 8 - Planta 14,
E-48001 BILBAO
Tel.: 34 -4 -423.50.50
Fax. 34 -4 -424.97.33

FAST
Piazzale Rodolfo Morandi 2
I-20121 MILANO
Tel.: 39 2 76 01 56 72
Fax. 39 2 78 24 85

FIZ/KFA, FIZ Karlruhe
Postfach 2465 D-76012 KARLSRUHE
Tel.: 49 7247 808 351
Fax. 49-7247-808-134

KFA Jülich
Projektträger BEO
Postfach 1913 D-52425 JÜLICH
Tel.: 49 -2461 -61.37.29/59.28
Fax: 49 -2461 -61.69.99

FORBAIRT
Glasnevin IRL-DUBLIN 9
Tel.: 353 1 837 01 01
Fax. 353 1 837 28 48

Friedemann und Johnson - Consultants GmbH
Pestalozzistr. 88
D - 10625 BERLIN
Tel.: 49 -30 -312.26.84
Fax. 49 -30 -313.26.71

GEP
45 rue Louis Blanc
La Défense 1 Cédex 72
F - 92038 Paris la Défense
Tel: 33 -1 -47.17.61.39
Fax. 33 -1 -47. 17.67.47

GOPA - Consultants,
Hindenburgring 18
D-61348 Bad HOMBURG
Tel.: 49 -6172 -93.00
Fax. 49 -6172 -3 -50.46

ICAEN
Av. Diagonal, 453 Bis, Atic
E-08036 BARCELONA
Tel.: 34 -3 -439.28.00
Fax. 34 -3 -419.72.53

ICEU
Auenstrasse 25
D-04105 LEIPZIG
Tel.: 49 -341 -29.46.02 / 43.50
Fax. 49 -341 -29.09.04

ICIE
Via Nomentana 133
I-00161 ROMA
Tel.: 39 -6 -884.58.48/854.91. 41
Fax. 39 -6 -855.02. 50

IDAE
Pº de la Castellana 95 - P 21
E-28046 MADRID
Tel.: 34 -1 -556.84.15
Fax. 34 -1 -555.13.89

IMPIVA
Avellanas, 14 - 3ª F
E-46003 VALENCIA
Tel.: 34 -6 -392.00.05/04/03
Fax. 34 -6 -391.44.60

INET/ITE
Azinhaga dos Lameiros à Estrada do Paço do Lumiar
P-1699 LISBOA Codex
Tel.: 351 -1 -716.51.41/27.50/27.61
Fax. 351 -1 -716.65.69

INNOTEC - Systemanalyse GmbH, Kurfürstendamm 199
D-10719 BERLIN
Tel.: 49 -30 -882.32.51/34.32
Fax. 49 -30 -885.44.33

INSTITUT WALLON / ENERGIM 2000
10 rue Baron Huart
B- 5000 NAMUR
Tel.: 32 -81 -23.04.52
Fax. 32 -81 -23.07.42

IRO
P.O. Box 7261
NL-2701 AG ZOETERMEER
Tel.: 31 -79 -41.19.81
Fax: 31 -79 -41.97.64

KEMA Nederland B.V.,
Utrechtseweg, 310
NL-6812 AR ARNHEM
Tel.: 31 -85 -56.24.77
Fax. 31 -85 -51.73.62

LDK Consultants Engineers & Planners
7 Sp. Triantafyllou Str.
GR-113 61 ATHENS
Tel.: 30 -1 -856.31.81/2
Fax. 30 -1 -856.31.80

LUXCONTROL
Avenue des Terres Rouges, 1
L-4004 ESCH-SUR-ALZETTE
Tel.: 352 -54 -77.111
Fax. 352 -54 -79.30

MARCH Consulting Group,
Telegraphic House
Waterfront 2000
MANCHESTER UK M5 2 XW
Tel.: 44 -61 -872.36.76
Fax. 44 -61 -848.01.81

NIFES
8, Woodside Terrace
GLASGOW UK - G3 7UY
Tel.: 44 -41 -332.41 40
Fax. 44 -41- 333.42.55

NOVEM
Swentiboldstraat, 21
NL-6130 AA SITTARD
Tel.: 31 -46 -59.52.39
Fax. 31 -46 -52.82.60

OCICARBON
c/o Agustín de Foxá 29, 4º A
E-28036 MADRID
Tel.: 34 -1 -733.86.62
Fax. 34 -1 -314.06.46

PSTI
Offshore Technology Park
Exploration Drive
ABERDEEN UK AB23 8GX
Tel.: 44 -224 -70.66.00
Fax. 44 -224 -70.66.01

RARE c/o Rhonalpénergie
Rue de la République, 69
F-69002 LYON
Tel.: 33 -78.37.29.14
Fax. 33 -78.37.64.91

SODEAN
Bolivia, 11
E - 41012 SEVILLA
Tel.: 34 -5 -462.60.01/11
Fax. 34 -5- 462.63.01

SOGES S.p.A.
Corso Turati, 49
I-10128 TORINO
Tel.: 39 -11 -319.08.33
Fax. 39 -11- 319.02.92

SYNERGIA
Apollon Tower
64, Louise Riencourt Street
GR - 11 523 ATHENS
Tel.: 30 -1 -64.96.185
Fax. 30 -1 -64.96.186

TÜV RHEINLAND
(Kst 931)
Am Grauen Stein
D- 51105 KÖLN
Tel.: 49 -221 -806.0
Fax. 49 -221 -806.13.50

University College Dublin
Energy Research Group
School of Architecture
Richview, Clonskeagh
IRL-DUBLIN 14
Tel.: 353 -1 -269.27.50
Fax .353 -1 -283.89.08

VLAAMSE THERMIE COORDINATIE
Markiesstraat, 1
8e verdieping, B-1000 BRUSSEL
Tel.: 32 -14 -33.27.16
Fax .32 -14 -32.11.85

Zr-E
Wieshuberstrasse 3
D-93059 REGENSBURG
Tel.: 49 -941 -461.190
Fax. 49 -941 -464.19.10

These addresses are subject to possible change. For further information please contact:

OPET-CS
18, av R. Vandendriessche
B-1150 BRUSSELS
Tel.: 32 -2 -778.28.11
Fax: 32 -2 -771.56.11

Produced by:

Generalitat de Catalunya
Departament d'Indústria i Energia
Institut Català d'Energia

Av. Diagonal, 453 Bis, Àtic
E-08036 Barcelona
Tel.: +34-3-439.28.00
Fax.: +34-3-419.72.53
Catalunya-Spain

By order of:

The European Commission
Directorate-General for Energy (DG XVII)
Strategy-Dissemination-Promotion (D/1)
200, rue de la Loi,
B-1049 Brussels, Belgium

ISBN 84-393-3529-6

9 788439 335290