HOW TO IMPROVE EFFICIENCY IN SUPERMARKETS

Madi Sakande - New Cold Systems
Marco Buoni - Centro Studi Galileo

Excerpt from 37th Informatory Note on Refrigeration Technologies / March 2018

Advancements in supermarket refrigeration

This Informatory Note was prepared by Renato Lazzarin, President of IIR Section E and Yunting Ge, Vice-President of Commission E1, with the assistance of Claudio Zilio, Secretary of Commission B2. It was reviewed by several experts from the IIR network.

Supermarkets are the largest energy users in the commercial refrigeration sector in many countries.

Refrigeration is mainly required by refrigerated display cabinets or fixtures located on the sales floor to store perishable food products that are for sale. Conventional supermarket refrigeration systems are also responsible for considerable CO2 emissions due to the direct effect of refrigerant leakage and the indirect effect of high energy consumption.

Energy consumption can be reduced by choosing a suitable indoor temperature and relative humidity. Other possible energy consumption reductions can be obtained with advancements in refrigeration technologies that modify the refrigeration plant layout and components. The new systems not only operate at higher efficiency, but also reduce refrigerant charge and refrigerant leakage.

Several improvements have been introduced in display cabinets in recent years, such as more efficient lighting, more widespread use of doors, more efficient fans etc. These advances in components for commercial refrigeration are beyond the scope of the present Informatory Note, which deals only with the recent developments in refrigeration systems.

The large majority of supermarket refrigeration systems employ multiplex refrigeration systems, which use direct expansion evaporators and multiple compressors piped with common suction and discharge lines. In an attempt to reduce refrigerant emissions, modified systems have been introduced with a lower refrigerant charge and groups of compressor racks located in fixtures throughout the supermarket. Other systems incorporate a secondary fluid chilled by refrigeration machinery in a plant room separate from the retail area. Systems were recently developed where each cabinet is equipped with its own compressor and a water-cooled condensing unit. Water circulated in a loop and cooled in a central chiller is used for heat rejection during condensation (Water-Loop Self-Contained (WLSC) systems).

Supermarkets are the largest energy users in the commercial sector in many countries. The IEA[1] reports that 3-5% of total electricity consumption in industrialized countries stems from supermarkets. Conventional supermarket refrigeration systems are also responsible for considerable greenhouse gases emissions. These emissions are due to the direct effect of refrigerant leakage and indirect CO2 emissions related to the energy consumed[2, 3, 4].

A 5000 m2 sales area supermarket, a very common size for new supermarkets, may require around 2 million kWh of electricity per year. Larger superstores might exceed 5 million kWh annually[5]. More than half of this energy use is related to the refrigeration system(s), whereas lighting may account up to about 20-25% of the total energy used[6]. The latter figure can be markedly reduced if highly efficient lighting systems (e.g. LEDs) are adopted instead of traditional lamps. The remainder comes mainly from HVAC (Heating, Ventilating, and Air Conditioning) and, to a lesser extent, from other services such as office equipment, computers, tap water heating, food preparation and bakery items. Refrigeration is mainly required by refrigerated display cabinets or fixtures located on the sales floor to store perishable food products for sale. Refrigeration must be provided also in cold rooms where perishable food is stored until placed in the retail fixtures. These fixtures can be classified according to storage temperature, either as Medium Temperature (MT) cabinets (Figure 1) with an evaporation temperature of -7/-10°C, for products that require a storage temperature above 0°C and lower than 4-7°C, or Low Temperature (LT) cabinets (Figure 2) with an evaporation temperature of -32/-35 °C, for frozen foods that require a storage temperature below -18°C.

Figure 1: Medium Temperature (MT) display cabinet, widespread in Italy for salamiandcheese retail

Figure 2: Typical Low Temperature (LT) display cabinet

The cooling load of the refrigerated display fixtures depends on space air temperature and relative humidity, the use of anti-sweat heaters used to prevent condensate formation on doors and outside surfaces of display cases, and display lighting and evaporator fans. Energy consumption can be reduced by choosing suitable ambient parameters (a lower temperature or relative humidity reduces the refrigeration load and anti-sweat heaters operation) and ancillary equipment (efficient cooler fans or efficient lighting, for example LEDs instead of halogen lamps in cabinets). Moreover, some other obvious measures such as better insulation can be implemented.

Other possible energy consumption reductions can be obtained through advancements in refrigeration system technologies that modify the usual layout of the refrigeration plant that serves the MT and LT refrigerated fixtures. The new proposed systems not only operate at a higher efficiency, but also reduce refrigerant charge (which in many existing supermarkets can be up to 3,000 kg [7]) and leakage (which can amount to a loss of up to 30% of the total charge annually [4]).

This Informatory Note describes and analyses conventional and advanced refrigeration systems. It presents information on different technical solutions and discusses their merits and disadvantages, taking into account technological criteria such as annual energy consumption, refrigerant choice, refrigerant charge, ease of construction, easy and efficient refrigeration capacity control, noise, and recovery of refrigeration systems' rejected heat.

Multiplex system

A large majority of supermarket refrigeration systems employ direct expansion air-to-refrigerant evaporator coils located inside retail cabinets or store coolers. Compressors are located in a machine area outside the sales area, and condensers are often located on the roof. These systems, called “multiplex refrigeration systems”, require a large refrigerant charge and a large number of piping and pipe joints, which are often the cause of high refrigerant leakage rates. The term “multiplex” indicates that multiple compressors have a common suction line and discharge manifolds (Figure 3). The discharge gas is piped to are motely located condenser, and then piped back to a liquid receiver. Supermarkets usually have two compressor racks, one for the MT and one for the LT refrigeration systems.

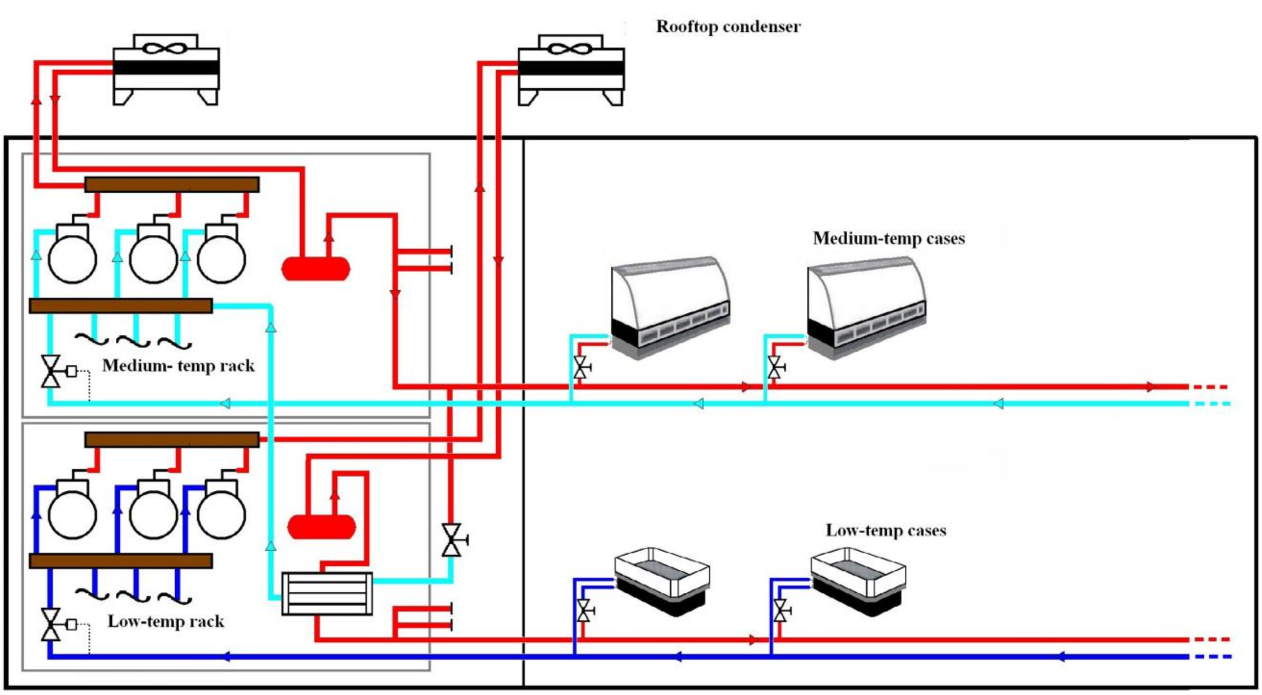


Figure 3: Schematic of a multiplex refrigeration system

The main advantage of multiplex systems is their relatively simple construction. Refrigeration capacity is easily controlled by turning one or more compressors on the rack ON-OFF. One of them is sometimes modulating. As the compressor racks are located in a machine room separated from the sales area, the system is noiseless with regards to the sales area. The heat rejected from the refrigeration plant can be used for both water and/ or space heating. Water heating may require an increase of the condensing temperature, particularly in winter when the condenser could be operating at temperatures as low as 20 °C. There fore the heat reclaim should be balanced against any reduction in Coefficient of Performance (COP) of the refrigeration system.

The main disadvantages of this system are the length of refrigerant pipes and associated large refrigerant charge (commonly ranging from 1,400 to 2,300 kg). The most commonly used refrigerant is currently R404A[8]. The progressive phase out of refrigerants with high Global Warming Potential (GWP) will result in the application of other refrigerants (dealt with later in this Informatory Note). Long refrigerant lines usually mean more fittings and connections, which means a greater chance of refrigerant leaks. Annual refrigerant leakage rates as high as 15% of the total charge are reported, with some systems leaking as much as 30% of the charge per year[4]. In addition, the length of refrigerant pipes can cause high pressure drops, which reduce the COP. Pressure drops need to be considered a long side the need to keep refrigerant velocities above a level allowing oil to be returned to the compressor. In many systems, the suction pressure is fixed and common to all compressors: a higher pressure for MT and a lower pressure for LT racks.

Conventional mechanical controls keep a fixed suction pressure to control the fixture temperature in display cabinets. Control settings are usually based on the highest load conditions, for example for occupied store hours and hot weather conditions. In this situation, no benefit is achieved from a load reduction which may occur during the winter when cooler and dryer store conditions reduce the fixture evaporator loads and the sub-cooling of liquid refrigerant is greater than in the summer months [9]. A load reduction would allow a higher suction pressure which would result in a higher COP. Then, the possible COP improvement for a higher pressure of some fixtures is not exploited. COP can be improved through the adoption of a control paradigm with the so-called “floating suction pressure”, permitting a higher evaporation pressure for lower loads. The suction pressure may float in these systems as a function of the load. However, the suction pressure is determined at any time by the minimum evaporation pressure required by any of the cabinets linked to the common suction line.

The multiplex system has been improved in recent years by implementing low-charge designs[10]. The layout is quite similar to that of the previous system. By carefully controlling the system, the liquid receiver capacity can be reduced, as the refrigerant liquid charge is limited to what is needed to supply the display cabinet evaporators. The refrigerant charge is usually 2/3 or even 1/2 of that in a traditional multiplex system.

Improvements in the low-charge multiplex do not change the length of suction and return lines, refrigerant pressure drop, and percentage of leakage of a refrigerant charge that, even when halved, is still large.

The display cabinets in a multiplex system are usually equipped with thermostatic expansion valves (TEV) that need a minimum pressure head for correct operation. Then most control systems cycle condenser cooling fans between ON-OFF with the purpose of keeping condensing pressures from falling below a minimum level even if outdoor ambient temperatures might allow lower condensing pressures. As a result, the condensing temperature does not fall below a set temperature of about 20°C, even in cold winter conditions. Using an electronic expansion valve (EEV) allows the system to operate with lower head pressures. In this case the limiting condenser temperature depends on the minimum pressure difference between suction and discharge in order to maintain proper oil flow for lubrication[11, 12].

It can be even as low as 4 °C for the LT cabinets and 15 °C for the MT cabinets.

Other configurations are (please refer to the IIR informatory notes for details):

- Distributed compressor system
- Secondary loop system
- CO2 cascade system
- Ejector-supported CO2 cascade
- Water-loop self-contained (WLSC) System

An evaluation of different systems in the technical literature

Various authors have carried out an evaluation of the different systems, taking diverse aspects into account such as energy expenditure, TEWI (Total Equivalent Warming Impact), investment cost, annual operating costs, among others.

A comparison of many characteristics can be carried out with the system descriptions, but quantitative analyses are needed to compare costs. The main difficulty of comparison is the many variables that can influence the final results.

These include:

- type of supermarket (retail area size, number of MT and LT display cases, type and size of cold rooms);
- climate at the supermarket's location;
- indoor conditions (temperature and relative humidity);
- refrigerant leakage.

In addition, the technical performance of the equipment has a major impact on performance indicators.

Various comparisons available in the literature are not always consistent.

A possible reason is that older, non-optimized systems are sometimes compared with new optimized ones.

In principle, all authors agree that the conventional multiplex system has the lowest initial costs, highest operating costs, and highest annual refrigerant leakage rate. An improvement can be obtained with low-charge multiplex systems, particularly if they are equipped with EEVs. The main disagreement between the available comparisons is regarding the relative merits of other systems, with different evaluations of performance. While one author assigns the best evaluation to the distributed compressor system, and the worst to the WLSC system, but with ON OFF controlled compressors[10], another author[5] gives the worst rating to the glycol secondary loop. Other authors [22], on the basis of experimental data from a real supermarket, indicate a possible annual saving of more than 15% for a WLSC system with respect to a traditional multiplex, even if the savings are reduced to 8% if a multiplex with a floating suction pressure EEV is considered.

The main advantages of WLSC systems have been identified as a lower required compression ratio, independent for each cabinet, lower pressure drops in the lines, and heat recovery via a heat pump that does not require an increase of condensing pressure as for the other system configurations, as mentioned above. At the same time, the above advantages are partly offset by pumping energy and the existence of a double refrigeration cycle. The initial cost of investment is estimated to be about 30% higher than for the conventional multiplex, due to the need for a LT chiller and a heat pump, and the higher specific cost of compressors (several compressors are required, one for each cabinet, even if at lower capacity). This higher cost of investment is partly counterbalanced by a lower installation cost. In fact, as the compressors and the refrigeration piping are contained in the cabinet, the cabinet manufacturer can carry out several of the installation operations, standardizing the process.

In conclusion, the design of a new supermarket or the refurbishment of an existing installation should be carefully evaluated by expert engineers with adequate simulation in order to select optimal equipment options.

The final results can be quite different even with similar refrigeration systems. Climate conditions with winter heating requirements, cold or mild winters and the distribution of low and medium temperature display cabinets can produce significant differences in identified advantages and disadvantages between the systems up for consideration.

Conclusions

In the past, most supermarkets had multiplex refrigeration systems. The main drawback of the traditional concept is the large refrigerant charge, and the subsequent large annual refrigerant leakage.

The multiplex design was modified to reduce this drawback, lowering refrigerant charge and moving from fixed suction pressure to floating suction pressure. Different systems have been introduced since, at first with compressor racks distributed in the supermarket, which eventually evolved into compressors installed within each single cabinet, as in the WLSC system.

Another concept is to separate refrigeration equipment and display cabinets and connect them with secondary loops. This approach found a mixed solution with the use of CO2 in a secondary loop, which may include a refrigeration cycle for the LT cabinets.

These alternative concepts limit the refrigerant charge compared to the conventional multiplex system and, as a consequence, limit the risks of leakage. Regarding cost, alternative solutions are generally more expensive when it comes to the cost of investment, but the possible reduction of operating costs usually more than compensates for this higher investment. The final result highly depends on the application (i.e. size and location of the supermarket). The technological advancements described above can produce important benefits as regards energy costs and the environment. Careful examination of the different technical options is thus suggested for every project for a new or refurbished supermarket in development.

End of Excerpt from 37th Informatory Note on Refrigeration Technologies / March 2018

PowerSaver

Functional description

PowerSaver is a food simulator that makes the system cooling according to the needs of the food and not the air temperature.

How today's refrigeration systems work

Today's refrigeration systems do not measure how cold food is, they measure the temperature of the surrounding air as this is much simpler. But the quality of food depends on the actual temperature of the food, and air temperature is a poor gauge of the food's condition.

Air temperature is not the important temperature

Because air has a much lower density than food, air temperature fluctuates often and rapidly. Food temperature changes very slowly and requires fairly little energy to remain cold. When the refrigeration system is continuously being "tricked" by the constant fluctuations in air temperature, it uses more energy wholly unnecessarily, while the food is not always kept uniformly chilled.

How does it work?
PowerSaver is an add-on module for the control sensor inside refrigeration systems.
It can be installed easily on the sensor and stops it from following the constant changes in air temperature. Instead, it now controls the refrigeration system based on the simulated food temperature.

What happens in systems?
With PowerSaver as an add-on to the sensor, the compressor runs based on the simulated food temperature. This means that your refrigeration system works in longer cycles, at a more uniform temperature. PowerSaver prevents the air from influencing the sensor and from causing it to start the compressor unnecessarily at the slightest change in air temperature.

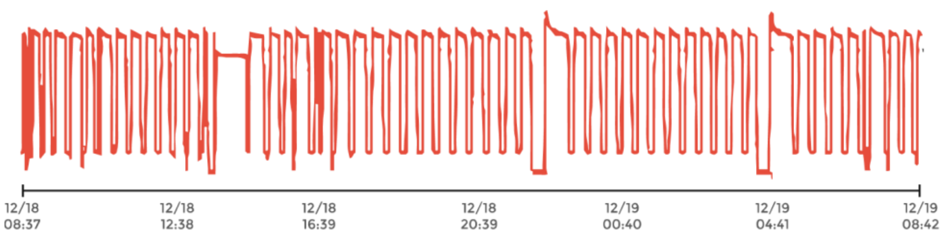
Whenever the compressor is started, the consumption is three times higher than when it runs continuously. This can be compared to an automobile which consumes more fuel when it starts from rest.

Our measurements from a well-known Swedish furniture warehouse clearly demonstrate the benefits of having PowerSaver assist the sensor in controlling the compressor.

79.3 % fewer starts (average)
17.8 % energy saving (average)

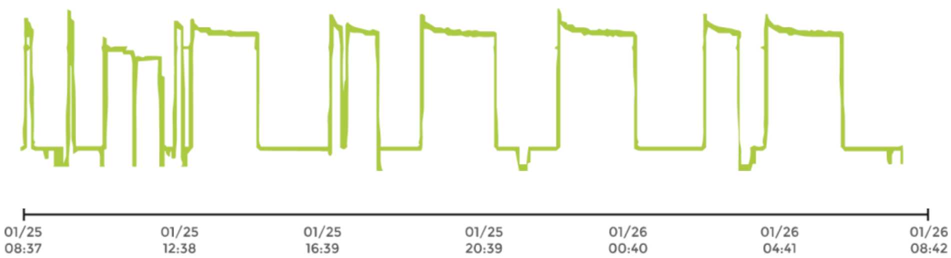
Even compressors need a break
When cooling cycles become longer, the compressor is deactivated for longer periods which allows it time to rest. This enables the system to equalize the pressure in the cooling system, thereby resulting in softer starts and reduced wear, and the compressor reaching its maximal effect faster. In addition, the oil is pumped around properly and your system attains better lubrication.

WITHOUT POWERSAVER



79.3%
Less compressor starts

WITH POWERSAVER



17.8%
Energy saving

No electronics

PowerSaver is easily installed on the sensor without any electrical connections. Because PowerSaver does not require any electricity or electronics, it has no negative impact on the system or on any existing warranty.
PowerSaver will have fully adapted to the system within 24 hours after installation. The system will then begin working in longer cycles, with fewer starts and stops, reduced wear and lower energy consumption.

Costs and the environment

- Up to 30 % in energy savings
- Reduced wear and increased service life for your machines
- Maintenance-free