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## Advancements in supermarket refrigeration

*The IIR publishes Informatory Notes designed to meet the needs of decision-makers worldwide, on a regular basis. These notes summarize knowledge in key refrigeration-technology and refrigeration-application domains. Each note puts forward future priority developmental axes and provides IIR recommendations in this context.*

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In an attempt to reduce refrigerant emissions, modified systems with a lower refrigerant charge and groups of compressor racks located in fixtures throughout the supermarket have been introduced. Other systems incorporate a secondary fluid, which is chilled by refrigeration machinery in a plant room separate from the retail area. Systems where each cabinet is equipped with its own compressor and a water-cooled condensing unit were recently developed.

This Informatory Note considers the advantages and disadvantages of possible alternatives to the traditional solutions.

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## Abstract

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 CO<sub>2</sub> 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).

This Informatory Notes considers the advantages and disadvantages of possible alternatives to the traditional solutions.

## Introduction

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

The IEA <sup>[1]</sup> reports that 3-5% of total electricity consumption in industrialised 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 CO<sub>2</sub> emissions related to the energy consumed <sup>[2, 3, 4]</sup>.

A 300 m<sup>2</sup> sales area supermarket, a very common size, may require around 2 million kWh of electricity per year. Larger superstores might exceed 5 million kWh annually <sup>[5]</sup>. 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 <sup>[6]</sup>. 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 salami and cheese 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.

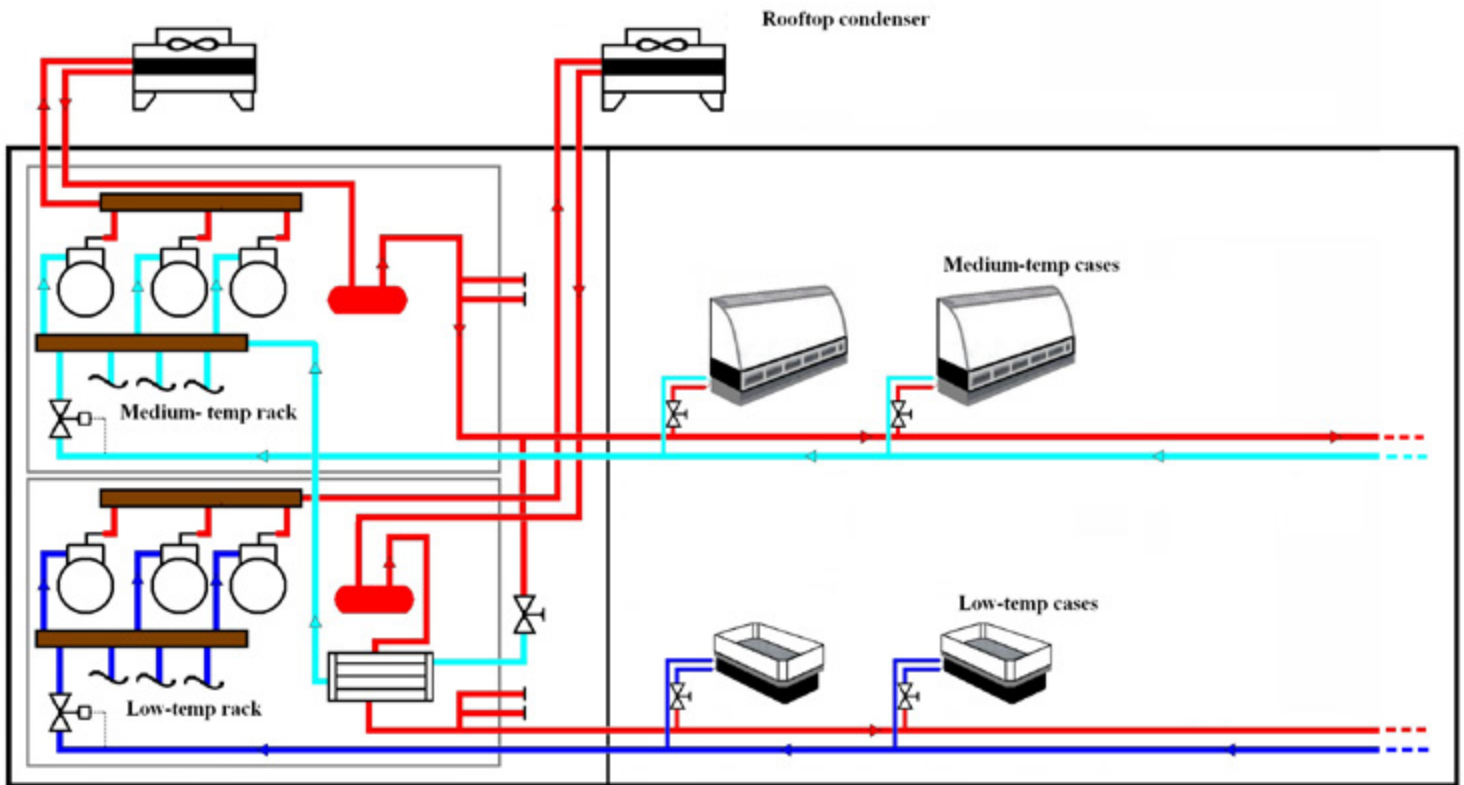
Other possible energy consumption reductions can be obtained through advancements in refrigeration system technologies that modify the usual layout of the refrigeration plant that serves the MT and LT refrigerated fixtures. The new proposed systems not only operate at a higher efficiency, but also reduce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

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 a remotely 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. Therefore 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

alongside 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 <sup>[9]</sup>. 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 <sup>[10]</sup>. 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 <sup>[11, 12]</sup>.

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

## **Distributed compressor system**

In this system groups of compressor racks (3 to 5) are located in fixtures throughout the supermarket (Figure 4). They are close to the display cabinets with a suction pressure related to the cabinets they serve. The refrigerant lines are shorter than in a multiplex system, with an associated reduction in the refrigerant charge. The main disadvantages are related to the required area within the store for the refrigeration plant and the compressor noise in the retail area. The use of scroll compressors instead of reciprocating compressors for the higher pressure ratio LT system limits the noise, however, it may lower the efficiency compared to that of reciprocating compressors at the fixed nominal rotating speed.

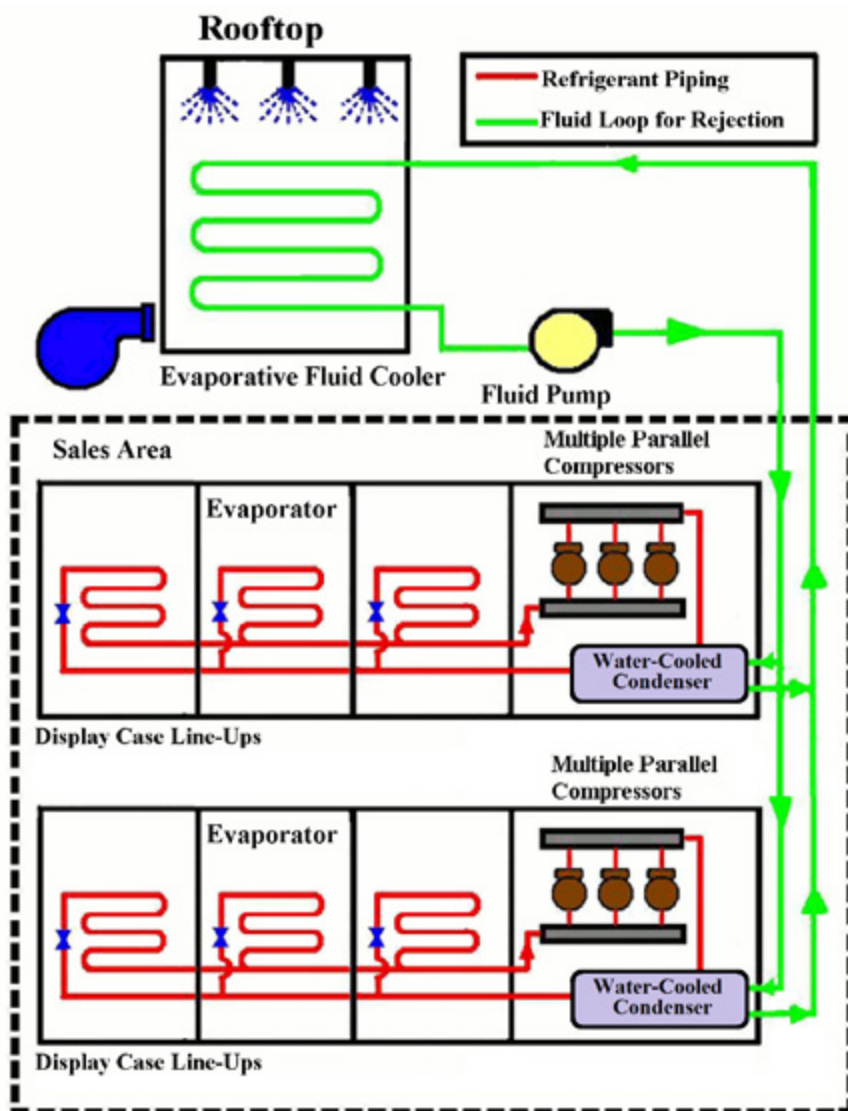


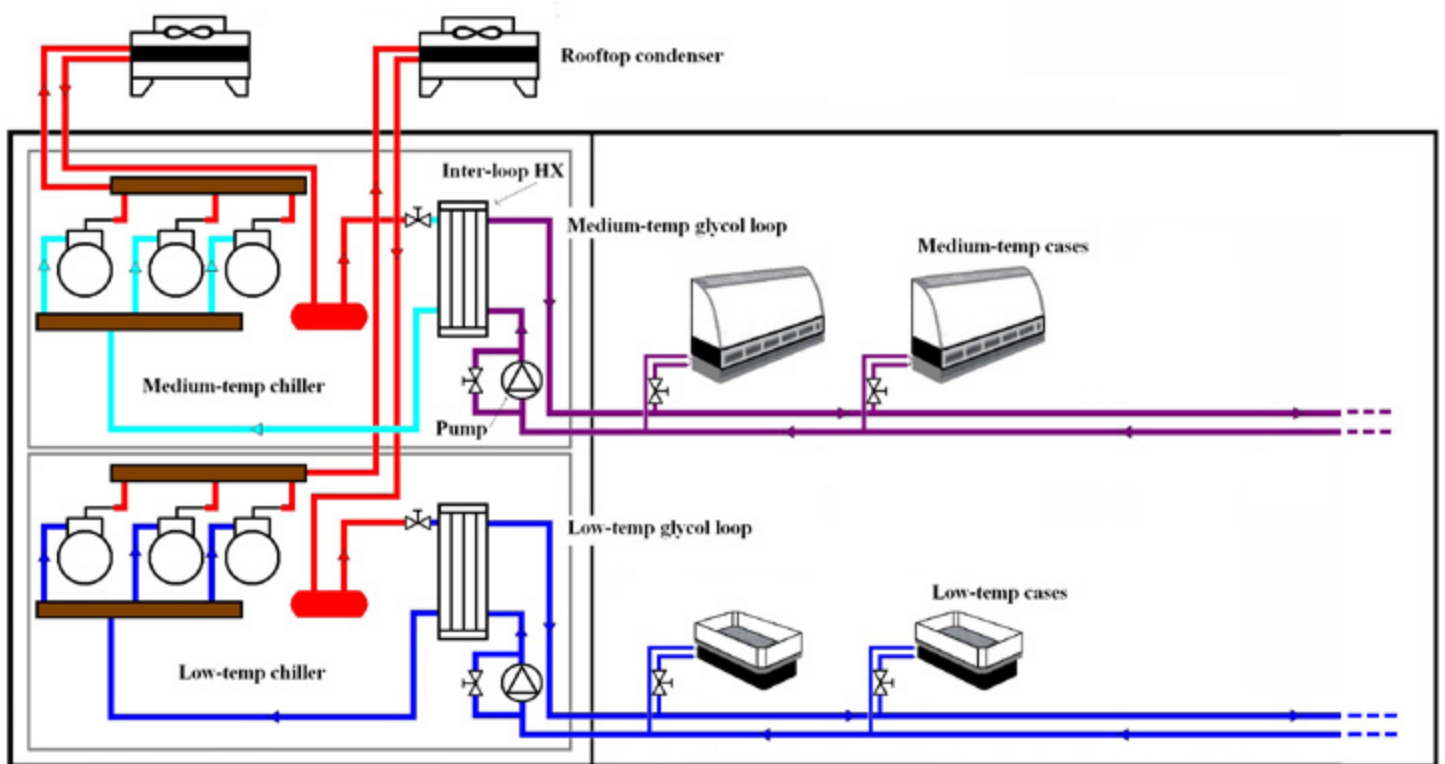
Figure 4: Schematic of a distributed compressor system

## Secondary loop system

Secondary loop systems incorporate a secondary fluid (referred to as “brine” for the remainder of this Informatory Note) that is chilled by refrigeration machinery in a machine room separate from the retail area.

An aqueous solution of propylene glycol or potassium formate is most frequently used as a secondary fluid. Pumps circulate the secondary fluid through the chiller evaporator in the machine room, where the fluid is cooled, and then to the display cabinets and to the storage coolers (Figure 5).





**Figure 5:** Schematic of a secondary loop system

The configuration of the system is quite similar to the multiplex system: at least two compressor racks (MT and LT) send refrigerant vapour to the rooftop condensers. Liquid refrigerant is then piped to the evaporators (medium and low pressure) where the secondary fluid is chilled. Pipes connect the evaporators with the display fixtures and storage coolers. The temperature drop of the secondary fluid through the display cabinets must be limited to within a few degrees ( $^{\circ}\text{C}$ ), so the fluid must be circulated at high flow rates, generally at about  $1\text{ ms}^{-1}$ . The flow rate of the fluid is controlled by a valve controlling temperature in the display cabinet.

The evaporators in the display cabinets and other coolers do not then need to be connected to a remote condenser. Consequently, the refrigerant charge is dramatically reduced, often to one tenth of that of a multiplex system due to the reduction in refrigerant piping. The compressor suction pressure is governed by the temperature of brine returning from the retail area.

The main disadvantages of secondary loop systems are:

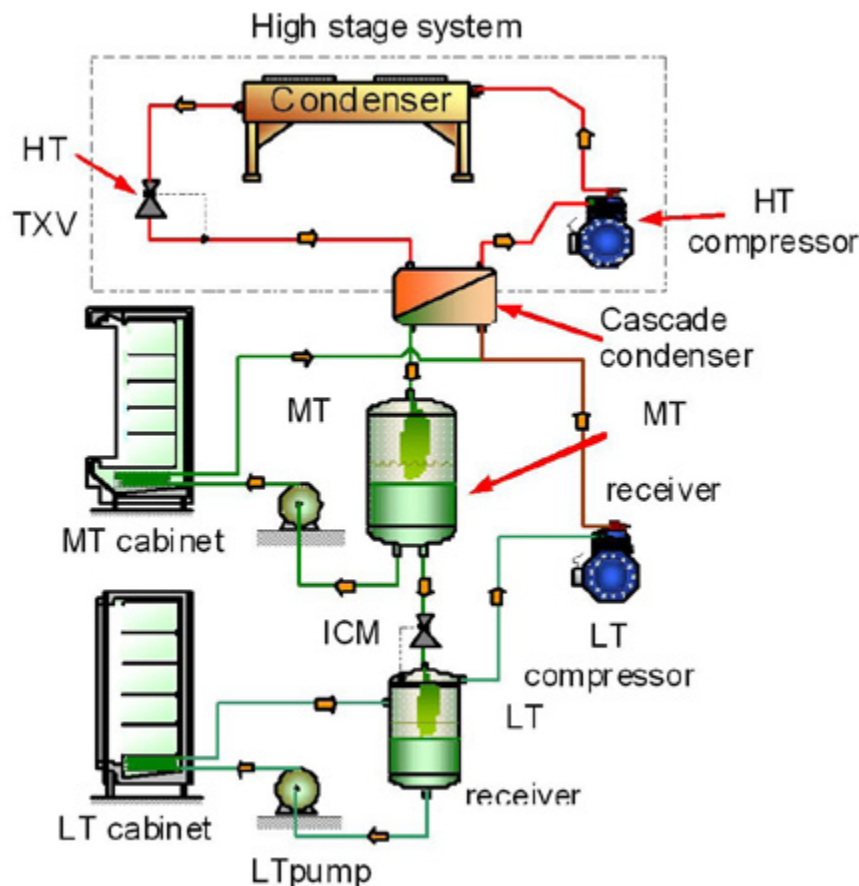
- the introduction of an additional heat exchange between the refrigerant and brine, which reduces performance with respect to multiplex systems;
- the energy consumption of the brine circulation pumps: common secondary fluids are highly viscous, especially at low temperatures.

These drawbacks can be mitigated by the use of a phase-change secondary fluid.  $\text{CO}_2$  was recently employed as a secondary fluid in different layouts.

## CO<sub>2</sub> cascade system

The use of CO<sub>2</sub> as a secondary fluid in supermarket refrigeration systems can minimise the use of conventional secondary fluids, reduce the power consumption of liquid pumps, enhance heat transfer in associated heat exchangers, and ultimately improve the overall performance of the refrigeration system.

CO<sub>2</sub> secondary loop systems are similar to those with brine, as shown in Figure 6 for chilled (MT) and frozen (LT) food refrigeration [13]. However, in the MT secondary loop, a CO<sub>2</sub> liquid receiver is installed between the cascade condenser and the CO<sub>2</sub> liquid pump to ensure liquid flows to the pump. To produce the refrigeration effect, the medium temperature CO<sub>2</sub> liquid is then pumped to the evaporator of the chilled display cabinet or storage cooler where it evaporates. The CO<sub>2</sub> liquid flow rate should be well controlled so that the inner surfaces of the evaporator remain wet. In addition, when the CO<sub>2</sub> liquid from the MT secondary loop receiver is further expanded into a LT receiver, the low temperature CO<sub>2</sub> liquid can then be pumped and evaporated in the LT cabinets before returning to the LT receiver, as depicted in Figure 6. In a saturated vapour state, CO<sub>2</sub> fluid will thus be withdrawn by the LT compressor, compressed and mixed with the stream from the MT cabinet outlet before flowing into the cascade condenser. Subsequently, both MT and LT CO<sub>2</sub> secondary loops can be integrated with a common high-stage-side primary refrigeration system used for heat rejection. Natural refrigerants such as ammonia, hydrocarbons or even CO<sub>2</sub> may be used as primary refrigerants.



**Figure 6:** Schematic of a CO<sub>2</sub> secondary loop systems: combined MT and LT

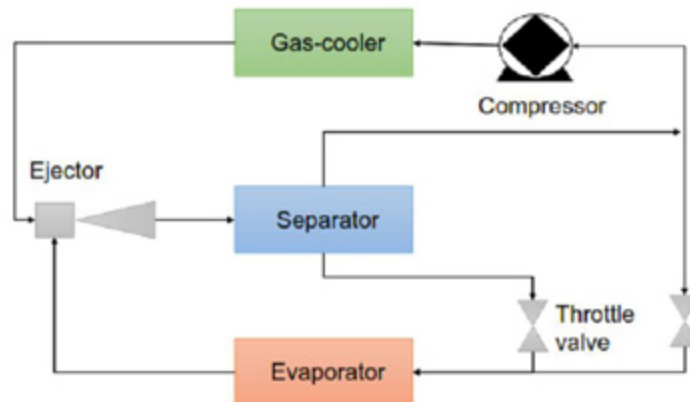
It must be noted that the CO<sub>2</sub> secondary fluid passes through a series of phase changes including evaporation and/or condensation, while there is no phase change for conven-



tional secondary fluids. The phase change processes in both display cabinets and cascade condensers can greatly enhance the heat transfer in heat exchangers. Moreover, other favourable factors include the superb thermophysical properties of CO<sub>2</sub>, specifically low liquid viscosity, high liquid thermal conductivity, high liquid specific heat capacity, and high vapour density. Its low viscosity can significantly reduce the pressure drop of the CO<sub>2</sub> secondary loop and therefore overall liquid pump energy consumption when compared to those of the conventional brine secondary loops at the same refrigeration load. Ultimately, the overall performance of the refrigeration system can be considerably improved [14].

### Ejector-supported CO<sub>2</sub> cascade

The performance of a CO<sub>2</sub>/CO<sub>2</sub> cascade system may be further improved by applying an ejector to the primary side. The operational principle of an ejector is based on the Venturi effect of a converging-diverging nozzle to first convert the pressure energy of motive fluid (primary flow) to kinetic energy to entrain a suction fluid (secondary flow), and then recompress the mixed fluids by converting kinetic energy back into pressure energy. An ejector in a refrigeration system can replace the expansion device to recover the compressor work usually lost in the expansion device, and therefore make the system more efficient. When an expansion device in a transcritical CO<sub>2</sub> refrigeration system is replaced with an ejector, as shown in Figure 7 [15, 16, 17, 18, 19, 20], refrigeration efficiency (COP) can be increased by over 10% [21]. It should be noted that in a transcritical CO<sub>2</sub> refrigeration system, the CO<sub>2</sub> compressor works with supercritical discharge pressure and subcritical suction pressure. In addition, the CO<sub>2</sub> gas cooling process operates at temperatures above its critical point, so there is no condensation involved. The CO<sub>2</sub> high-pressure-side heat exchanger is therefore called a CO<sub>2</sub> gas cooler.

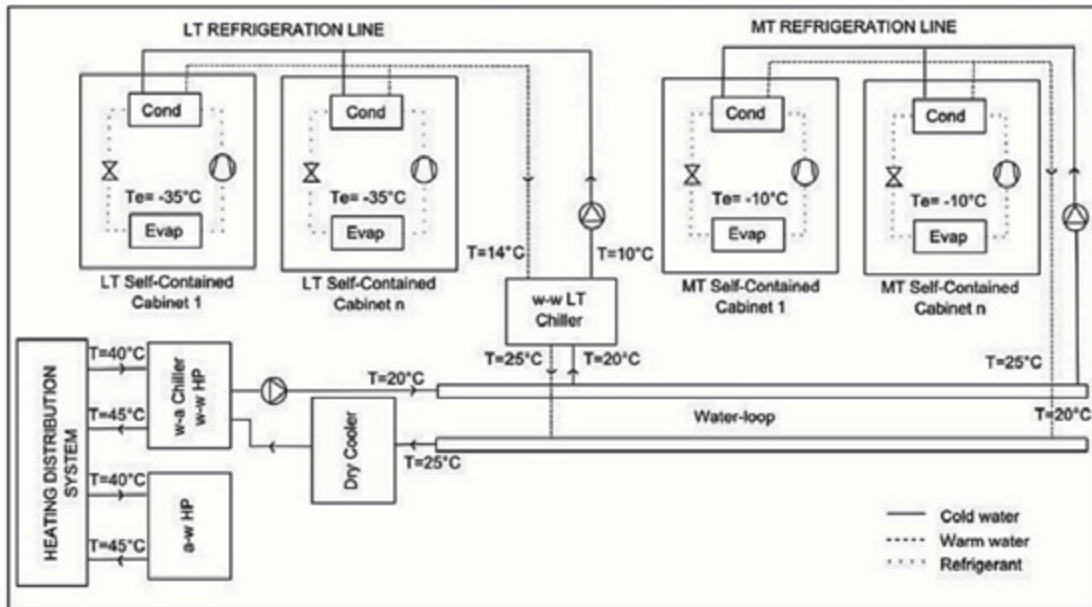


**Figure 7:** Transcritical ejector expansion refrigeration system

### Water-loop self-contained (WLSC) System

In these systems, each cabinet is equipped with its own finned-coil evaporator, compressor, expansion valve, water-cooled condenser, and often an inverter. Water circulated in a loop and cooled in a central chiller is connected to each cabinet condenser and used for heat rejection from the cabinet. Figure 8 illustrates a typical layout of a WLSC system [22, 23]. Two water loops are provided: a MT and a LT loop. In most systems, a dry cooler is used to provide free cooling (e.g., cooling from 25 °C to 20 °C) to the water loop. Should the external temperature be too high to cool down the water loop, the dry cooler fans are turned off and the water is cooled by a water-to-air chiller located downstream of the dry cooler. For extremely hot climates, where the dry cooler would not be very effective, only

the water-to-air chiller might be installed. Furthermore, the system can be implemented with a water-water heat pump so that if some heating is required, the dry cooler fans are turned off and the water is employed as the heat pump cold source. Thus, the water loop is cooled down as required, operating at the same time as heat recovery.



**Figure 8:** Schematic of a Water-Loop Self-Contained (WLSC) system

In order to both avoid high compression ratios in the LT line and increase the cooling capacity of the cabinets, the water temperature at the condensers inlets (e.g. 10 °C) in the LT line cabinets is lower than in the MT line cabinets (e.g. 20 °C). This is made possible by using a water-to-air chiller (w-w LT chiller) located upstream of the LT cabinets.

WLSC systems have several drawbacks. The most apparent is their complexity and, consequently, initial cost: two refrigerating cycles (in series) are needed to activate the water-to-air chiller when free cooling is not available. The first refrigerating cycle takes place inside the cabinet, the second in the water-to-air chiller. Each heat exchange introduces temperature differences with a COP reduction. If the same evaporating and condensing pressures are considered for WLSC and multiplex configurations, the specific compression work is lower for the latter alternative.

Another drawback of the WLSC system is that pumps are required to circulate water through the water loop, and the energy they consume further reduces the system's performance.

Yet another disadvantage is that compressors installed in each retail cabinet may introduce noise into the retail area.

The main advantages are that the suction pressure of each cabinet is completely independent. Thus, should a single cabinet require a lower evaporation pressure, the other cabinets can operate at different and higher evaporation pressures. The distances between evaporator, compressor and condenser are also minimal with very low pressure drops in the connecting lines and a substantial reduction in the refrigerant charge, which can be as low as 5-10% with respect to a multiplex system with the same capacity. This feature can be particularly interesting when using hydrocarbon refrigerants.

Performance penalties due to the double heat exchanges within the water loop can be more than offset by equipping a WLSC system with modulating compressors, inverters and electronic expansion valves [11, 12].

When modulating compressors are applied, the air temperature within each cabinet is then regulated by a variable-speed compressor. When modulation is required (and this is the most common condition in the cabinet operation), the refrigerant mass flow rate is reduced, and evaporation and condensation take place continuously most of the time, unlike for the ON-OFF operation [24]. Since a reduced refrigerant mass flow rate reduces capacity, the evaporation pressure is higher and the condensation pressure is lower than that of the ON-OFF control mode. Thus, the compression ratio is reduced and the refrigerator operates at a higher COP than when running at full load. Of course, the compressor must remain highly efficient, even when running at low speed. High-efficiency DC brushless motors and scroll compressors can help to keep an acceptable efficiency even at low speed. Furthermore, the energy cost of the inverter must be accounted for.

Recently designed inverters can keep inverter loss at about 3% of the total compressor power compared to more than 11% for previous devices, provided that the compressor operates at the optimum frequency.

### Heat recovery in supermarket refrigeration systems

Heat rejected from the refrigeration system can be recovered and used for supermarket heating. The vapour refrigerant de-superheating from the compressor outlet can provide heat reclaim by a dedicated heat reclaim coil that can exchange heat for water or space air heating in all the described systems except WLSC systems.

In the WLSC system, heat reclaim is performed by a heat pump whose cold source is the water loop normally dissipating the heat from the LT chiller or the MT refrigeration line.

Not all of the heat rejected by the rooftop condenser can be recovered at the normal condensation pressure. An increase in condensation pressure would instead be required for a suitable recovery temperature, which would result in a less efficient refrigeration system; consequently, the heat recovery might require more energy use than is saved [25]. This is the main reason why only the de-superheated refrigerant heat is usually recovered. Moreover, an increase of refrigerant charge is required to raise the condensation pressure. A larger liquid receiver must be provided to store the excess refrigerant when the plant operates at lower pressures. Whenever the heating load exceeds the recoverable heat from de-superheating, an auxiliary heating system is required. Recoverable heat can be between 20% and 40% of the total rejected heat, depending on the condensing temperature and the refrigerant circuit (i.e. MT or LT).

This limitation does not apply to the WLSC system where a heat pump may use a large portion of the rejected heat without negative effects on refrigeration system performance other than the cost of driving the heat pump. A comprehensive evaluation must take into account the different features of the various systems.

### Refrigerants in supermarkets

As previously mentioned, the most commonly used refrigerant today is R404A. R507A is also widely used. Both are now being subjected to a progressive phase-out due to their high Global Warming Potential (GWP). Japan approved the revision of its fluorocarbon regulations in 2013 [26]. According to this act, high-GWP refrigerants are subjected to a gradual phase-down, with a transition to either HFC-free refrigerants or to low-GWP HFC refrigerants being imposed by certain target years. R404A in particular must be replaced with refrigerants with a GWP < 100 in cold storage warehouses by 2019 and

with refrigerants with a GWP < 1500 in condensing and refrigerating units by 2025. The European Union F-gas regulation <sup>[16]</sup> established January 1<sup>st</sup>, 2020 and January 1<sup>st</sup>, 2022 as the deadlines for the substitution of R507A and R404A with mid-term replacements (GWP < 2500) and long-term replacements (GWP < 150), respectively. In 2015 the status of R507A and R404A was changed by the US Environmental Protection Agency <sup>[27]</sup> from acceptable to unacceptable in the temporal window from July 20<sup>th</sup>, 2016 to January 1<sup>st</sup>, 2020, depending on the application and the type and size of refrigerating unit.

The possible replacement fluids can be 'natural' (carbon dioxide, hydrocarbons, ammonia) or fluorinated. Only two HFCs (R161 and R152a) and a number of hydrofluorolefins (HFOs) in the latter category can be considered in order to reach the low-GWP target. Most HFOs are classified as "mildly flammable" (A2L according to ASHRAE Standard 34).

Hydrocarbons, in particular propane (R290) and propylene (R1270), can be used in some applications with reduced charge. The restrictions for flammable or A2L refrigerants are addressed in different countries by local regulations. Most countries in Europe refer to EN 378. Commercial refrigerating appliances with an incorporated compressor or a remote condensing unit have the IEC reference IEC 60335-2-89, which imposes a charge limit of 150 g for hydrocarbons. The latest revision of EN 378 (2017) partially relaxed the strict charge limitations of flammable refrigerants. The allowable charge calculation depends on the type of refrigeration system, flammability level of the refrigerant, and the occupied floor area (for systems with refrigerants that contain components that are in contact with occupied areas).

Centralised systems with a relatively large hydrocarbon refrigerant charge can operate provided that the components containing the flammable refrigerant are confined and a secondary loop is used. Similar considerations can be applied to the use of ammonia.

The use of carbon dioxide as a refrigerant in both transcritical systems and at the low-pressure stage of combined cascade systems has increased, especially in cold climates. The major constraints on the use of all the above mentioned refrigerants were discussed in a recent IIR Informatory Note <sup>[7]</sup>.

## **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-optimised systems are sometimes compared with new optimised 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 <sup>[10]</sup>, another author <sup>[5]</sup> gives the worst rating to the glycol secondary loop. Other authors <sup>[22]</sup>, 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, standardising 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 CO<sub>2</sub> 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.



## Recommendations

Refrigeration technologies have showed advancements with respect to the traditional systems, which are relatively economical and easy to install, but require a very large refrigerant charge and typically have large refrigerant leakage rates.

The new systems can limit the refrigerant charge and leakage, and can also save energy and provide better operational control.

Therefore, the IIR emphasizes the need to:

- develop effective worldwide campaigns that demonstrate the economic and environmental benefits of new refrigeration technologies for supermarkets, in order to raise awareness among supermarket managers, policy makers and industry representatives;
  - train refrigeration professionals in new supermarket refrigeration technologies by including specific courses on training programs and instructions on advanced modelling and simulation tools for designers and installers;
  - promote and provide funding for research on the performance analysis of advanced supermarket refrigeration technologies in different locations and climates;
  - set up incentive schemes to promote the refurbishment or decommissioning of old refrigeration systems with high refrigerant leakage in supermarkets.
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