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INTEGRATED CO_2 SOLUTIONS FOR SUPERMARKETS

Armin Hafner[1] and Petter Nekså[1,2]
[1)] Norwegian University of Science and Technology,
Kolbjørn Hejes vei 1D, 7491 Trondheim, Norway; armin.hafner@ntnu.no
[2)] SINTEF Energy Research

ABSTRACT

Supermarkets represent a refrigeration application area which is spearheading towards the total phase in of natural working fluids. Exposed to demanding customers where reputation is an important part of the business, focus is given to cost of ownership, and therefore the energy efficiency of the technical equipment, and the environmental profile. Due to the EU F-gas regulation, vendors supplying conventional, non-natural working fluid refrigeration equipment are facing challenges related to the legislative requirements and supply shortages. It forces them to implement less conventional refrigerants with lower Global Warming Potential (GWP) in their new products. The newly introduced next generation of hydrofluorocarbons (HFCs) with ultra-low GWPs do have a very short (atmospheric) lifetime, however, the decomposing products are highly toxic in combination with water, and distributed everywhere it becomes a question whether they represent a safe and sustainable alternative. As Gustav Lorentzen said: "We should not try to solve a problem by introducing another problem".

Natural working fluids like CO_2 have demonstrated to be an energy efficient and environmentally benign alternative, especially for supermarket applications. Since its fluid- and thermosphysical properties are quite different from most other working fluids, the refrigeration system designs have to be carefully adapted to the properties of CO_2, thereby maximising the energy efficiency and minimising the total cost of ownership.

Integrated CO_2 systems can simultaneously provide refrigeration capacities at various temperature levels, air conditioning (AC) & dehumidification, heating and even sanitary hot water at adequate temperature levels. A further integration of advanced thermal storage devices can enable centralised supermarket refrigeration systems to become a valuable element within smart (thermal) grids. Well designed and integrated systems can demonstrate reduced power consumption typically by more than 30 %.

The article gives examples of the latest system developments applicable in commercial refrigeration / supermarkets.

Keywords: CO_2 refrigeration systems, cold thermal energy storage, commercial refrigeration

NOMENCLATURE

AC	Air Conditioning	HFC	Hydrofluorocarbon
CO_2	Carbon Dioxide	LT	Low temperature (-30 to -25 °C)
CTES	Cold Thermal Energy Storage	MT	Medium temperature (-5 to 0 °C)
GWP	Global Warming Potential	PCM	Phase change material

1. INTRODUCTION

The EU-F-gas regulation [EU, 2014] and the Kigali amendment [UNEP, 2016] introduces a new era for the refrigeration society. The consequences of the radical quota policy within the EU are nowadays directly visible to vendors and end-users. As shown and described by [Zaremski. 2018] the cost of HFC-404A nowadays is more than ten times higher compared to the time before the EU F-gas regulation came into force. Therefore, changes are required and successful developments have to be performed considering the fact that current working fluids are not the preferred solution of the end-users any more. There are two potential directions the companies can choose if they want to be in the business 10 years from now.

They might continue with their current design philosophy and replace the high GWP fluids with lower GWP fluids and later on with new ultra-low GWP fluids. Intensive risk assessments are required, due to health and safety concerns. The intermediate detour by applying at least stable (HFC-152a, HFC-32, etc.) fluids requires in the first run only a careful safety concept, due to flammability issues. To implement the ultra-low GWPs may turn out to be a scenario with an unexpected outcome due to the lack of knowledge and concealment related to the health, safety and environmental risks related to the decomposing products of the short living double bonded substances (U.S.Dep.H&HS, 2005; Hurley et al. 2008; Solvey 2012).

On the other hand, there is an increasing number of innovative companies, which already have chosen the opposite direction, away from HFCs, by exclusively applying natural working fluids in their products and sites. These vendors and end-users are able to concentrate their effort on the further development and improvement of long-lasting products and heat pumping technologies, not facing the risk of legal restrictions in the near future nor wasting time and resources retrofitting old inefficient units with short term fluid mixtures.

The evolution of CO_2 booster systems for supermarket applications can be summarised as indicated in Figure 1. **The 1st generation**, i.e. the booster system (left), is the most widely applied solution. The system fits best to cold climates, where the demand for AC is low or not present. In this system, the LT cabinets/evaporators are connected to a separate, booster compressor – hence the name booster system – which lifts the pressure to the medium temperature level. The discharge gas from the booster is then merged with the gas coming from MT evaporators. As the outlet temperature from the LT compressor is generally high, up to 90 °C, de-superheating is recommended before mixing of the fluids. Heat from the de-superheater may also be utilized for different purposes, such as production of domestic hot water (DHW).

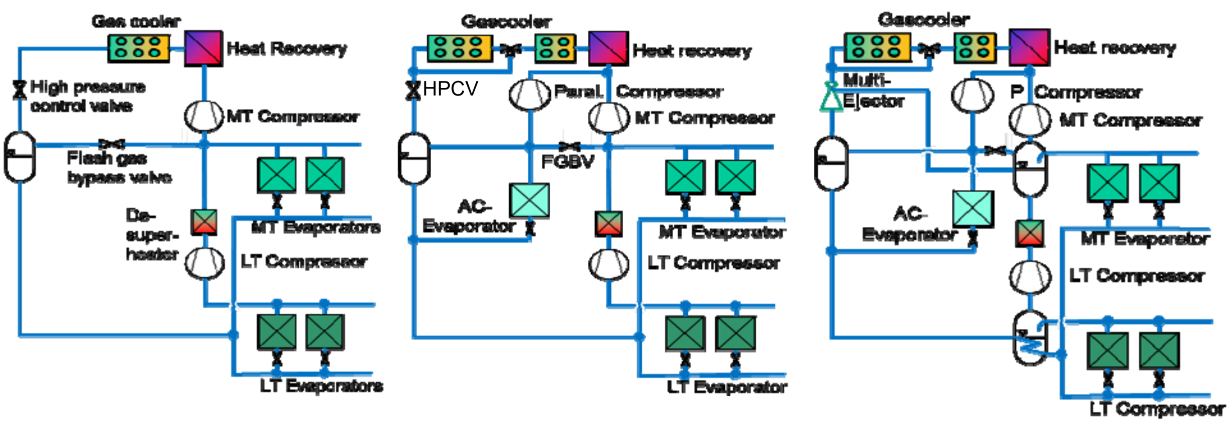

Figure 1. Evolution of CO_2 Booster systems from simple booster (left), parallel compression (centre) and ejector supported parallel compression unit (right)

After the gas cooler, CO_2 is throttled by the high-pressure control valve to the intermediate pressure receiver (separator). Liquid from this receiver is throttled further to either to LT or MT level, whereas flash gas is taken to the MT compressor through a flash gas by-pass valve (FGBV). The FGBV is crucial in controlling the pressure level in the separator, which enables a stable supply of liquid refrigerant to all evaporators. In case of relative high separator pressures and low capacities on the LT side, the liquid content downstream of the FGBV can cause challenges to maintain the superheat at the MT compressor inlet.

The simple booster system will have a slightly reduced energy efficiency in warm climates, when the gas cooler outlet temperature on the CO_2 side is high, due to higher expansion losses and increased heat rejection losses. A possible solution to this challenge is implement an external mechanical subcooler, which cools down the CO_2 leaving the gas cooler, leading to reduction in the vapour fraction at the separator inlet, and consequently to a performance improvement. A subcooling system will however increase the investment costs, and these systems have had reliability issues related to the durability of subcooler heat exchanger as well. Alternatives for an external subcooling unit are for instance an additional gas cooler with evaporative/wet cooling, or heat rejection to an energy well, providing a temperature level below ambient temperature during the warm season or the warmest hours of a summer day.

The second generation are booster systems with parallel compression, as shown in the central part of Figure 1. The amount of vapour downstream of the high-pressure control valve increases as the external temperature rises. The reduced specific cooling capacity leads to an increment in the amount of refrigerant which has to be compressed from medium to high pressure, implying a growth in the power consumption associated with the MT compressors, especially during summertime. A solution to this challenge is to adopt an auxiliary or so-called parallel compressor with the purpose of sucking either a part or preferably the entire amount of vapour from the separator pressure level and compress this directly to the gas cooler pressure. Having parallel compressors reduces the losses due to flashing and prevent MT compressors from liquid slugs. These parallel compressors are only operative if there is a sufficiently large amount of flash gas available. If the amount of flash gas is low, e.g. during wintertime, it is throttled via the FGBV as in a standard booster system.

Furthermore, energy efficient integration of AC is possible with parallel compression. The AC evaporator outlet enters directly into the separator. As an alternative, the AC evaporator can also be located between the high-pressure control valve and the separator (see also Figure 8), either in the main stream or in a parallel arrangement with a flow control device. In any case, the AC cooling capacity is provided and maintained by the parallel compressors, determining the pressure level of the separator.

Nowadays, the state of the art CO_2 commercial refrigeration technology for warm climate locations is to replace the high-pressure control valve with ejectors enabling for expansion work recovery, as illustrated in Figure 1 (right) and defined as the **3rd generation of booster systems**. This is particularly important for CO_2 systems operating in warm climates, in which case the expansion losses are high. However, this ejector configuration can also be applied in cold climate locations. The ejector entrains partly the low-pressure fluid downstream of the MT evaporators by means of high-pressure fluid coming from the gas cooler, accelerated in the motive nozzle of the ejector. Kinetic energy is converted into static energy, i.e. the pressure level between the suction nozzle and ejector discharge is equal to the pressure difference between the MT evaporators and the separator. The amount of vapour pre-compressed by the ejectors and discharged into the separator is determined by the available expansion work. The ejectors extend the operation time of the parallel compressors by increasing the amount of vapour to be compressed. Ejectors hence shift a part of the MT compressor load to the parallel compressor, which has to overcome a significantly lower pressure lift, hence reducing the total power demand.

Moreover, in standard DX evaporators, a significant part of the evaporator has to provide superheating of the refrigerant, reducing the heat transfer rate. When applying ejectors it enables to operate the evaporators without any superheat, i.e. in flooded mode, in a safe and reliable way all year long. This leads to increased heat transfer rate and better utilization of the heat exchanger area, allowing significantly higher evaporation temperatures (around -2 °C with optimal design of the display cabinets) and hence increased overall energy efficiency for the system.

End-users, i.e. owners of supermarket chains and high performance buildings, are having a real demand for integrated refrigeration units applying CO_2 as working fluid. By replacing all conventional refrigeration units and integrating these functions into centralised units, the energy efficiency of the entire supermarket can be improved as well as the service and maintenance cost can be reduced.

2. INTEGRATED SYSTEM SOLUTIONS

Integrated system solutions are characterised by the ability to provide all of the heating and cooling demands within a certain area or part of a building, even possibly export surplus heat or cooling towards buildings or industrial processes in the neighbourhood.

In most refrigeration/heat pump applications the cooling load and or heating request is seldom constant, implementing capacity control measures is one way to maintain a certain evaporation temperature within a certain temperature band and to avoid start/stop operation of the compressors. To be able to provide the required cooling/heating capacity at various capacity levels a commonly a range of compressors is implemented in most industrial/commercial CO_2 refrigeration systems. A wide-range single CO_2 compressor, as initially developed at SINTEF and NTNU (Hafner et al. 2013), would reduce the number of compressors needed, especially where space in the machine rooms of supermarkets is limited. The latest developments from leading compressor manufacturers enable vendors to build compact refrigeration packs by implementing CO_2 compressors with volume flow rates of up to ~85 m^3/h. However, also the part load operation has to be taken care of. Therefore, it is necessary to carefully define the size of the various compressors at the different suction groups. To avoid high installation costs and to improve the compactness of the refrigeration packs with various annual cooling demands of various suction groups, Hafner et al. (2016) recommended enabling a switching (pivoting) of the compressor suction towards the different suction groups. Figure 2 shows the principle of pivoting four of six compressors. Depending on the status of the on/off valve upstream of the compressor (Aux2/MT5 - Aux5/MT2) the compressors are either connected to the MT- or AC-suction group. In case the shut-off valve is closed, the compressors are connected to the MT-suction group via the check valve. If a valve is open, the suction pressure level increases and the check valve closes the connection to the MT part. The compressors do have a common discharge manifold connected to the various heat rejection and heat recovery devices downstream of the compressors.

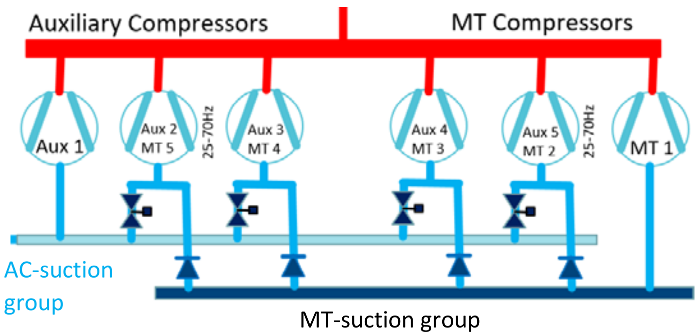

Figure 2: Pivoting four of six compressors.

Integrated commercial refrigeration systems for warm climate locations

Figure 3 shows a proposed integrated system for supermarkets located in Southern Europe or the Middle- and Far East. The system is able to provide a certain heating demand during the winter season due to its heat pump function if needed depending on the location.

The LT compressors are maintaining a suction pressure of around 17 bar ($t_o \approx$ -25 °C) for the attached LT cabinets and cold storage rooms (-20 °C product / room temperature). The LT evaporators are also operated without superheat, to improve the performance and reduce the losses during heat transfer. In case of overflowing liquid, the suction accumulator upstream of the LT compressors collects the liquid refrigerant, which is evaporated by the integrated (or external) heat exchanger, i.e. it further subcools the liquid supplied to both the LT- and MT evaporators. The compressed refrigerant of the LT compressors should be de-superheated before entering the AC compressor suction group. Dependent on the capacity and minimum size of the parallel compressors, the flash gas can be directed to the MT suction group via the FGBV. Connecting the LT compressors to the AC compressor suction group significantly extends the operation hours of the AC compressors.

The pivoting principle, described above is applied to most of the compressors. In this case, only one compressor is connected directly to the AC and MT suction group. This configuration allows reducing the total number of frequency converters required in the system. It even might be possible to use only one frequency converter to the pivoting compressors.

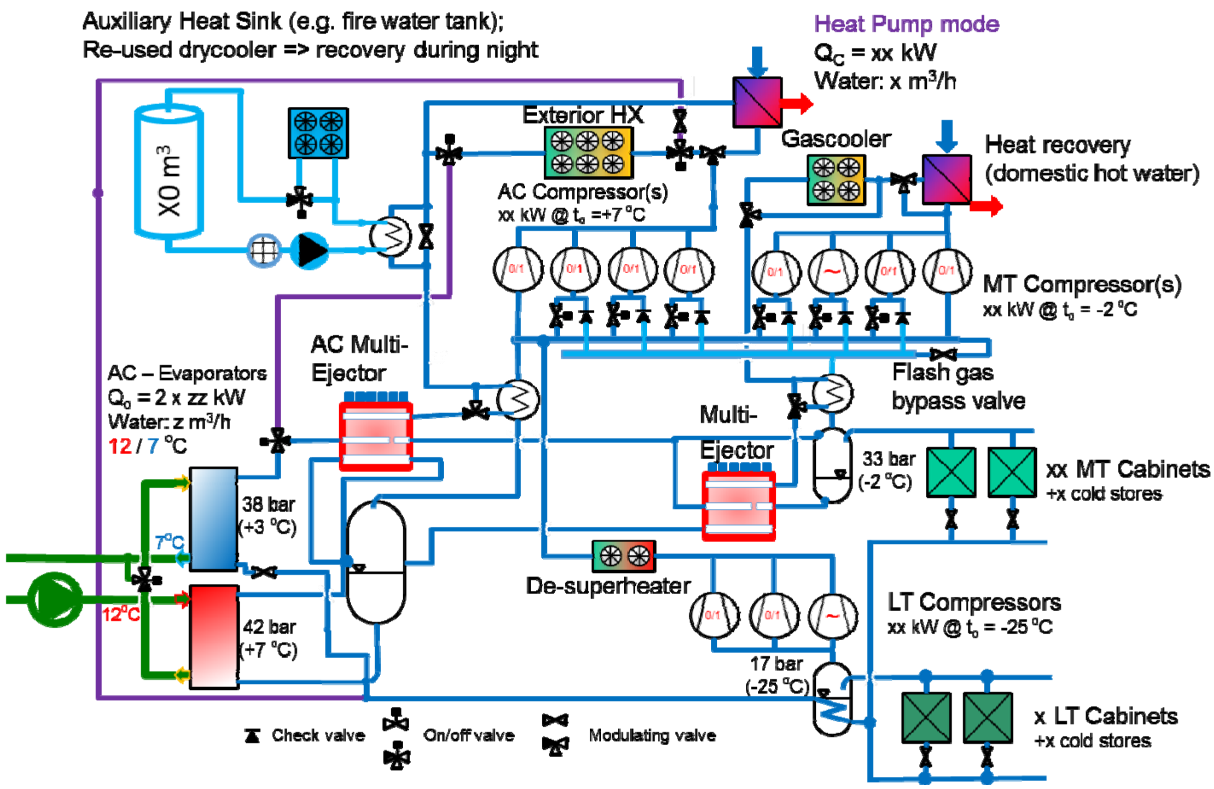

Figure 3: Integrated CO_2 refrigeration Pack for South European locations with LT and MT cooling loads, hot water demand, heating & cooling demand for the building and an auxiliary heat sink.

The heat rejection and heat recovery part of the system is divided into two sections. The right-hand side is devoted to operations outside the summer season, with the gascooler designed to reject the heat from both LT and MT cooling demands. In case of domestic hot water demand, the heat recovery has priority, i.e. less or no heat is rejected to the ambient. The left-hand side is devoted to the extreme climate conditions occurring during the hottest and coldest days of the year. The heat recovery unit provides heated water to the heating system of the building during wintertime. The exterior heat exchanger is operated as an ambient air evaporator, i.e. air is the heat source for the heat pump function. The AC Multi Ejector sucks the entire mass flow rate from the exterior heat exchanger. Since the ambient temperatures in these regions are seldom below 0 °C[1], the pressure in the separator providing the liquid to the evaporators can be kept above 38 bars, allowing a safe supply of liquid refrigerant also during heat pump operation. When AC is required, the exterior heat exchanger is the main heat rejection device (gascooler) for the parallel/auxiliary (AC) compressors. Beside evaporative cooling (Visser 2015) an auxiliary heat sink could be applied to further reduce the refrigerant temperature upstream of the high side pressure control devices during the warmest hours of the day. In the shown example, the water of the fire water tank is applied as auxiliary heat sink. The temperature of the fire water can be reduced during night hours with a dry cooler, e.g. by recycling the condenser of the previous HCFC system, which is successfully replaced by the integrated CO_2 unit.

The novel integration of the ice-water cooling evaporators (lower left-hand side of Figure 3) in combination with the AC Multi Ejectors, allows an elevated suction pressure of the AC compressors. The evaporators are divided into two sections. The first sections is connected to the separator tank at 42 bar ($t_o \approx +7$ °C). The liquid refrigerant is supplied by gravity and allows the pre-cooling of the 12 °C secondary fluid returning

[1] At lower ambient temperatures the system design has to be adapted, i.e. some of the AC compressors have to be connected directly to the outdoor evaporators.

from the building. If more cooling capacity is required the second evaporator is enabled to further reduce the temperature of the secondary fluid to 7 °C. The suction pressure is now 38 bar ($t_o \approx +3$ °C) due to the active use of the AC Multi Ejectors, which are able to suck all the vapour out of the second evaporator and supply it back to the separator where the AC compressors maintain the pressure level.

Since the revival of CO_2 as refrigerant initiated by Lorentzen et al. (1992), it is known that the superheating of fluid flows out of evaporators is not beneficial for the performance of CO_2 refrigeration systems, due to its high $\Delta p/\Delta t$ ratio and the high heat transfer coefficients that can be obtained on the refrigerant side. The habit of maintaining the request for a superheat out of heat exchangers, even for CO_2 systems, has led to system configurations for example for commercial refrigeration units applying the same evaporation temperatures as for HFC systems. However, for chilled food applications with a CO_2 refrigeration unit an evaporation temperature of -10 °C means that the suction pressure must be around 26.5 bar. New adapted system configurations, as shown above, taking into account the safe handling of liquid downstream of evaporators and the high heat transfer performance of CO_2 can provide the required cooling capacity without superheating at evaporation temperatures of -2 °C with a corresponding elevation of the suction pressure towards 33 bar. This has also a significant effect on the number of defrost cycles required in the chilled food cabinets and correspondingly on the shelf life of the products. Dependent on the indoor climate, the number of defrosts can be as low as one time per week.

Proper handling of liquid refrigerant and lubricant downstream of the evaporators is crucial to ensure a safe operation of the compressors. There are several ways to manage the direction of the liquid flow. Ejectors, driven by the normally lost expansion work are one way to return overflowing liquid back to the separator on the upstream side of the evaporators, pumps are a solution, too. Another flow direction of the liquid and lubricant can be implemented if the system has a continuously LT cooling demand. However, the LT compressors have to be able to return all the lubricant transported into the LT section back to the compressors of the MT- and/or AC suction group.

Integrated commercial refrigeration systems for cold regions

A proposal for the general outline of an integrated CO_2 system for locations with a high demand of heating at different temperature levels and generally low ambient temperatures is shown in Figure 4.

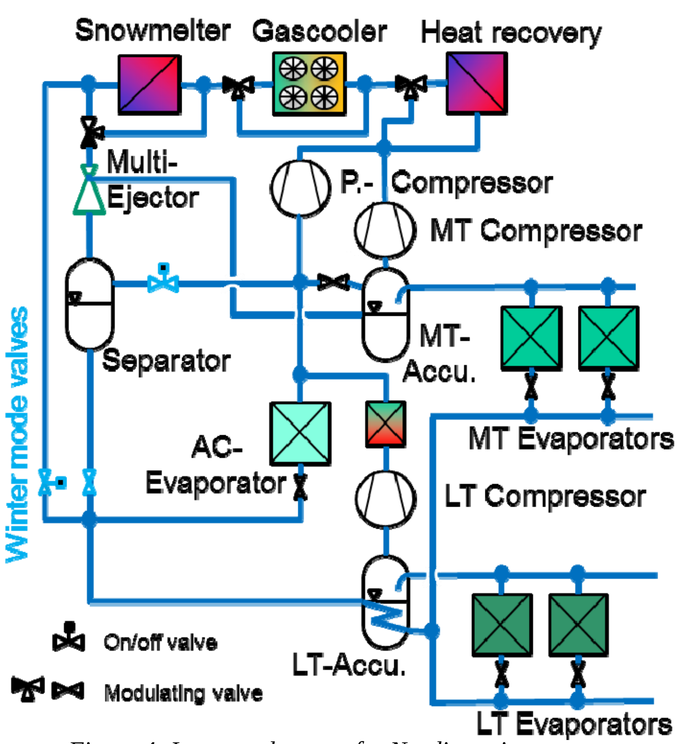

Figure 4: Integrated system for Nordic regions.

The pivoting principle as describe above can be applied here as well; however, it is not implemented into the flow circuit to keep it simpler. Heat rejection can take place at three different temperature levels. Downstream of the compressors the highest temperature level can be achieved, applicable to high temperature heating such as for domestic hot water. This heat exchanger can be active also during the warm period of the year.

The second heat exchanger downstream of the compressors is the air-cooled gascooler, enabling a proper heat rejection of the entire heat to the ambient during summer. During the cold period, the airside gascooler can be bypassed most of the time, since the available heat can be utilised in the first and third heat exchanger downstream of the compressors. The main purpose of a third heat exchanger can be preheating of domestic hot water or providing heat to the outdoor floor heating system (snow smelter), replacing direct electrical heating which is applied in some countries to keep the entrance and delivery area free of ice.

Low ambient temperatures can be a challenge for traditional CO_2 booster systems, when the CO_2 temperature downstream of the heat rejecting devices becomes lower than 5 °C. Since this temperature represents the saturated temperature inside the separator at 40 bar. If the refrigerant temperature upstream of the separator drops below the saturation temperature, the pressure inside the separator is reduced due to partial condensation of the vapour inside the separator. Therefore, extra safety measures have to be implemented to protect the separator pressure, which secures the liquid supply to all evaporators. However, this again reminds of the pressure maintenance actions required for HFC systems. To avoid the system to be dependent on the separator pressure a so-called winter mode upgrade for booster systems is proposed. When the ambient temperature is below a certain value, the separator is taken out of the main system circuit, i.e. the liquid refrigerant downstream of the heat rejection devices is directly supplied to the evaporator feeding valves, like in traditional subcritical systems. The main controller operates the total opening of all feeding valves to maintain a certain and safe high side pressure. If the amount of refrigerant in the circuit is insufficient, for example detected by continually superheated evaporator outlet conditions and the absence of a liquid level in the MT-accumulator, liquid refrigerant is supplied into the main circuit from the bottom part of the separator. On the other hand, if the refrigerant level is too high, vapour is rejected into the separator by opening intervals of one of the motive nozzle valves inside the multi ejectors, or another high-pressure control device upstream of the separator.

If more heat is required due to the building structure or if export possibilities towards neighbours are present, energy wells (Hafner et al. 2014) can be employed to supply additional external low temperature heat into the system. Since the temperature level in the ground is above to the freezing point of water, an efficient integration into the MT evaporator loop ($t_o \approx -2$ °C) can be done, providing sufficient heat to avoid costly auxiliary heating devices. The energy wells are excellent heat sinks during warm summer days, too, if the gascooler upstream of the high-pressure control device is connected to the well circuit.

Heat storage devices (water or PCM reservoirs) are advisable in such systems to allow the CO_2 system to operate at optimum conditions most of the time. Balancing of the daily heat demand variations should take place by applying storage devices, such that the system avoids to 'hunt' set-point movements. Peak heat requests from the building site are supported from the storage devices, while the CO_2 system charges them continuously. Reduction of seasonal power demand of integrated concepts like the ones described has proven reduced seasonal power demands of more than 30% (Titze 2017).

Smart grid & integrated CO_2 refrigeration systems

Thermal energy storage systems (Fidorra et al. 2016; Manescu et al. 2017) are soon becoming key system components for commercial refrigeration systems, which are active partners of a smart energy grid. Innovative solutions are under development and implemented in CO_2 commercial refrigeration, especially for cold thermal storage. Placing cold thermal storage as close as possible to the chilled and frozen products is essential to provide additional and valuable features such as:

- securing cooling during power cuts and thereby reducing the loss of valuable food,
- extending the shelf life and maintaining the food quality of the stored products, due to stabilizing of the temperature inside the food storage devices.

In combination with the elevated evaporation temperatures very close to the freezing point of water, as mentioned above, the defrosting demand can be dramatically reduced when applying flooded CO_2 evaporating for chilled food applications. On the other hand, if the next generation of display cabinets is able to perform defrosting during periods when an integrated thermal cold storage device is absorbing the heat, it will be possible to keep the product temperature much more constant than today.

There are various ways to implement cold thermal storage. Space constrains are the most limiting factors for how much cooling energy can be stored. By locating the cold storage on the bottom- or in the wall part of a cabinet, its active volume-to-space ratio might become less attractive to shop owners. For wall type cabinets, nowadays equipped with glass-doors, the only possibility is the space above the cabinet. This area/volume is in most cases not occupied today and storage of food/goods does not take place above the display cabinets.

Figure 5 shows a schematic layout and the different operation modes (a, b, c, d) of a vertical cabinet with an integrated cold thermal storage device on top. The circuit adapted evaporator (2) remains on the bottom of the display cabinet. There are two additional valves (4 and 6), which allow to cut off the cabinet from the central refrigeration system. In addition, these valves enable the control of the charge inside the thermosiphon system. The cold thermal storage (1) is connected to the evaporator and the refrigeration cycle via two valves (7 and 8).

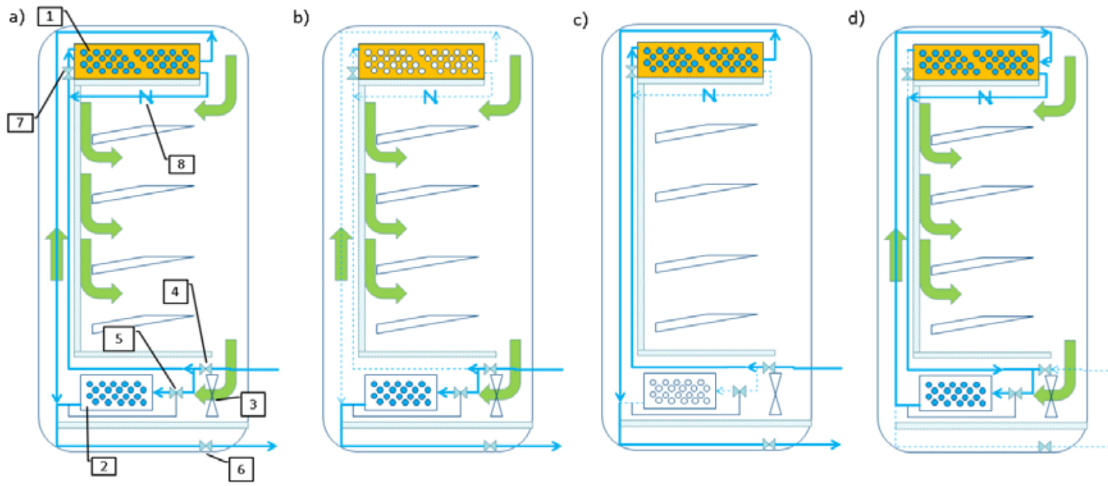

Figure 5: a) charging mode and normal operation of the cabinet b) normal operation, c) charging mode of the CTES d) discharging by thermosiphon circulation.

Integration of direct AC + heating

Figure 6: Direct heating and cooling fan coil unit inside a Supermarket (Girotto 2016).

Girotto (2016) describes the challenges when applying integrated AC and heating based on water circuits connected to the refrigeration unit. When water is used as the energy carrier several heat exchangers are involved, each of them introducing losses, which reduces the total efficiency of the heating and cooling system. Water itself is corrosive, i.e. measures to prevent corrosion have to be taken with a corresponding reduction in efficiency due to changes of the thermophysical and fluid properties of the water/inhibitor mixture. The water circuit does have a significant share of the total investment costs.

When applying CO_2 as the working fluid in refrigeration systems, it permits to utilize direct cooling and heating fan coils installed inside the building, as the roof installation shown in Figure 6. Also, the air curtains, mainly installed in the entrance area and the large delivery ports, can be designed in a similar way. These kind of units do not require space for water reservoirs and pump arrangements. The total cost of the heating and cooling equipment can be reduced as well as the energy demand to provide comfort and secure area temperatures during all seasons.

There is also a significant reduction of the time required to implement the HVAC installations. However, due to the high operating pressures present inside the public part of the building, special attention has to be given to the craftsmanship when installing the CO_2 pipes inside the building. The applied heat exchanger coils must be designed for dual operation, too.

Figure 7 shows a possible way of integrating the heating and cooling devices into the CO_2 circuit. During summer operation, when AC is required, the expansion devices upstream of the units provide throttling and a sufficient amount of refrigerant to the units operated as evaporators. When heat is demanded inside the building, the main outside air-cooled gascooler is bypassed, and heat is rejected directly into the building by the unit (fan coil or air curtain).

The circuit in Figure 8 is more sophisticated compared to the one in Figure 7. It enables to utilise a recovery of the expansion work in the ejectors also from the AC operation. The amount of two-phase refrigerant required to provide AC in the different heat exchangers is defined by the modulating 2/3-way-valve downstream of the ejectors. If there are more than one fan coil or air curtain, feeding valves have to be installed upstream of each device, to be able to provide individual capacity control.

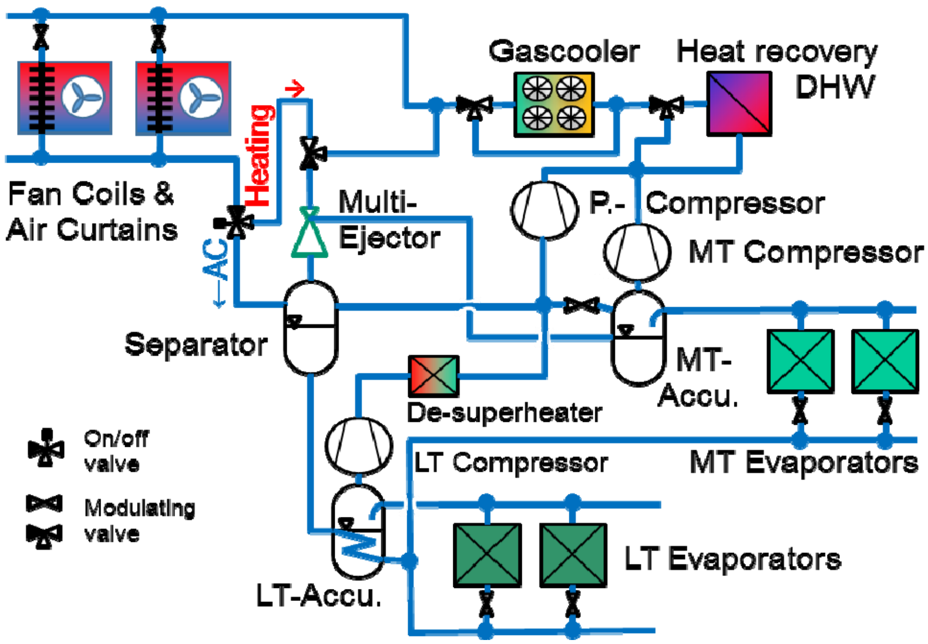

Figure 7: Integration of direct heating and cooling fan coils and air curtains in CO_2 commercial refrigeration units. Ejector partly bypassed during AC.

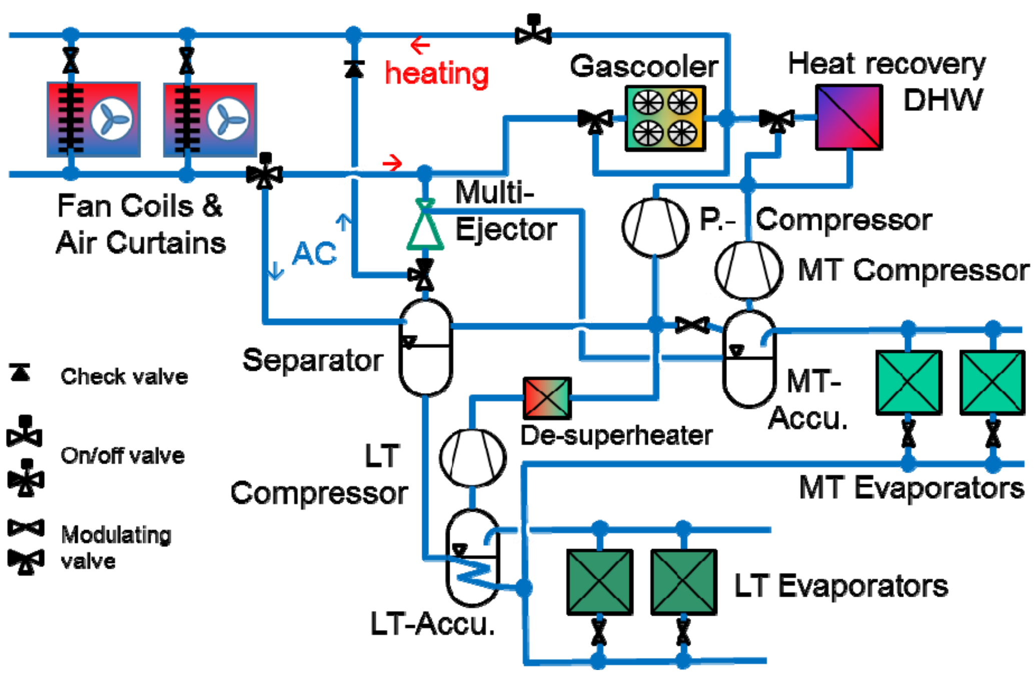

Figure 8: Integration of direct heating and cooling fan coils and air curtains in CO_2 commercial refrigeration units. Ejector utilised also during AC.

When heat is required inside the building, the on/off valve enables the warm high side pressure fluid entering from the port downstream of the first heat recovery device. The individual feeding valves control the total amount of warm refrigerant entering the fan coils and air curtains.

This principle of direct heating and cooling with the refrigerant can also be applied if a centralised air-handling unit is installed in the building, i.e. it represents a viable solution for small shops as well as large commercial building installations.

3. SUMMARY

A remarkable development of CO_2 refrigeration technology has taken place since the revival of the refrigerant in the late 1980s by Prof. Gustav Lorentzen. The development has led to efficient CO_2 systems especially for supermarkets represented by a remarkable number of successful market introductions globally. Additionally, it inspired the development of other innovative technologies that focus on improving the energy efficiency and reducing the total cost of ownership.

The integration of expansion work recovery devices like ejectors allows today's CO_2 commercial refrigeration systems to outperform HFC units on annual energy consumption in any climate region. The integration of further functions into the centralised refrigeration unit will be a key success factor for these sustainable vapour compression systems replacing HCFC and HFC systems globally.

The engineers spreading CO_2 technology should remember when designing all of the integrated functions, that the fluid properties are an asset, not a hindrance. Therefore, all CO_2 evaporators should be operated without superheat, heat recovery should be employed whenever there is a heat demand and domestic hot water production should be an ordinary feature of the systems.

Heat exchanger manufactures are able to provide safe and reliable air/CO_2 heat exchangers, enabling a direct integration of heating and cooling functions into the building envelope without costly water loop solutions.

Cold thermal energy storage as close as possible to the valuable food will become another important feature, since it guarantees the preservation of the food's quality, even when the power supply is unstable or as an alternative to electrical batteries for locally produced electricity from renewable energy sources.

Training and knowledge transfer is the key for a successful and fast phase in of CO_2 refrigeration units globally. Relative high first costs to install integrated CO_2 refrigeration systems are still the main barrier to a fast phase in of this technology on a global scale. Therefore, also the World Bank[2], the Multilateral Fund[3] and other funds should support global education, training and certification as well as covering additional first costs with affordable loans (no interest rate), so that the end-users can return the loan during the operational phase, since the new energy efficient CO_2 refrigeration system gives them a significant energy / cost saving.

[2] http://www.worldbank.org/

[3] http://www.multilateralfund.org

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