Mota Babiloni, A.; Navarro Esbri, J.; Barragán Cervera, Á.; Moles, F.; Peris, B.; Verdú Martín, GJ. (2015). Commercial refrigeration - An overview of current status. International Journal of Refrigeration. 57:186-196. doi:10.1016/j.ijrefrig.2015.04.013.

Commercial refrigeration - An overview of current status

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Abstract

Commercial Refrigeration comprises food freezing and conservation in retail stores and supermarkets, so, it is one of the most relevant energy consumption sectors, and its relevance is increasing. This paper reviews the most recent developments in commercial refrigeration available in literature and presents a good amount of results provided these systems, covering some advantages and disadvantages in systems and working fluids. Latest researches are focused on energy savings to reduce CO_2 indirect emissions due to the burning of fossil fuels. They are focused on system modifications (as dedicated subcooling or the implementation of ejectors), trigeneration technologies (electrical, heating and cooling demand) and better evaporation conditions control. Motivated by latest GWP regulations that are intended to reduce high GWP HFC emissions; R404A and R507 are going to phase out. Besides hydrocarbons and HFO, CO_2 appears as one of the most promising HFC replacements because its low contribution to global warming and high efficiencies when used in transcritical and low-stage of cascade systems.

Keywords: Commercial Refrigeration; Supermarket; Energy Saving; HFC replacement; Control; Review.

Nomenclature

Abbreviations

AHRI	Air-Conditioning, Heating, and Refrigeration Institute
COP	Coefficient of Performance
DX	Direct Expansion

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GHG	Greenhouse Gas
GWP	Global Warming Potential
HCFC	HydroChloroFluoroCarbon
HFC	HydroFluoroCarbon
HFO	Hydrofluoroolefins
ICF	Integrated CO_2 factor
LCCP	Life Cycle Climate Performance
TEWI	Total Equivalent Warming Impact

1. Introduction

Commercial Refrigeration comprises all equipment used by retail outlets (supermarkets and food sales) for preparing, holding and displaying frozen and fresh food and beverages for customer purchase [1]. Approximately half of the energy consumption in a supermarket is associated with the refrigeration system [2]. Supermarkets produce a significant global warming impact due to greenhouse gases (GHG) emissions: indirect CO_2 emissions from electricity generation in power stations and high GWP (Global Warming Potential) HFC direct emissions, leakaged from vapour compression systems [3].

On the one hand, refrigeration systems performance (related to refrigerant choice, system design and selection) affects greatly to the CO_2 emissions [4]. 15% of the electricity consumed worldwide is used for refrigeration and the cold-chain accounts for approximately 1% of CO_2 emission in the world [5]. Braun et al [6] carried out a regression analysis and predicted that the 2030-2059 electricity consumption is thought to rise by up to 5.5% with 2.1%, being the central estimate. The study realized by Gschrey et al. [7] concludes that contribution of F-gases to global warming will increase from approximately 1.3% (2004) to 7.9% (2050) of projected total anthropogenic CO_2 emissions.

On the other hand, commercial refrigeration systems that use HydroFluoroCarbon (HFC) contribute to a large degree to the greenhouse effect [8]: The annual leak rate for stand-alone and medium&large commercial applications is 2% and 11%, respectively. Besides, the typical refrigerant charge varies between 3 and 30kg; and 30 and 300 kg, respectively.

At present, the HFC R404A and R507A [9] are the refrigerants most extended in commercial refrigeration in developed countries for freezing and conservation needs. They replaced the ozone-depleting HydroChloroFluoroCarbon (HCFC) R22 and R502 due to the Montreal Protocol application [10], even though they present lower energy performance [11, 12].

Due to European F-gas regulation [13], high GWP refrigerants (as R404A and R507A) are going to be phased out in most of refrigeration and air conditioning applications, in order to reduce GHG direct emissions. This regulation will produce relevant changes in existing European commercial refrigeration systems [14], Table 1.

Table 1. Placing on the market prohibitions by the EU Regulation No 517/2014 [13] that affects commercial refrigeration.

This paper aims to provide the current state of the art of commercial refrigeration, covering different important aspects related to energy consumption and GHG (CO_2 and HFC) emission savings, since commercial refrigeration is one of the applications most contributing to the global warming. In section 2, this article reviews the last investigations on supermarket energy consumption analysis and models. In section 3, the latest developments in supermarket models are presented. In section 4, the recent refrigeration cycle improvements are collected. In section 5, last studies on trigeneration are shown. In section 6, the HFC replacements are shown. Finally, section 7 contains the main conclusions of this paper and future recommendations.

2. Supermarket energy consumption analysis

Some energy savings methods are easily achievable with very low paybacks (less than 3 years) [15], even though the modifications must be analyzed individually for each situation to fully optimize performance and therefore to maximize energy savings.

Some basic parameters can play an important role on final supermarket energy consumption. Mossad [16] highlights the great relevance of design, commissioning and maintenance phases to reduce the energy consumption in refrigerated food cabinets. Evans et al. [17] calculated the relationship between the cold store volume and its energy use: for chilled cold stores, 93% of the variation in energy was related to store volume; and for frozen stores and mixed stores, 56% and 67%, respectively. In addition to the store volume relevance, the store relative humidity can also play an important role in the supermarket energy consumption; Bahman et al. [18] demonstrated that a reduction of 5% in humidity results implies a decrease of 4.84% in total store energy load.

Prior to install refrigeration system, supermarket energy models can be used to predict the energy usage and to identify potential energy saving methods. Ducoulombier et al. [19] developed a supermarket energy model that takes into account some irreversibilities. They demonstrated that the energy requirement (as a function of the external temperature) depends on the following non-dimensional parameters: heat recovery, building thermal insulation and internal load. Then, Ge and Tassou [20] developed a supermarket model (SuperSim) that integrates refrigeration, building and HVAC models to investigate the interactions between these systems (impact of outdoor ambient conditions) and determines the energy consumption.

3. Control

In addition to analyze supermarket energy consumption, freezing and conservation control is another energy saving method that does not produces system modifications, and therefore less expensive than others. A good control of operating conditions is necessary to obtain optimum food and beverages quality and it. Although the temperature control of food products in supermarkets (or food stores) is essential, it is proved that this regulation is not thoroughly done [21]. Additionally, a better refrigeration system control (along with system redesign) also reduces the refrigerant charge, and hence, the refrigerant leakage [22].

Wisniewski et al. [23] studied the synchronous operation of all display cases since the temperature in a display case influences the temperature in other display cases, leading to higher energy consumption.

Hovgaard et al. [24] developed a novel economic model predictive control scheme to reduce the operating cost of supermarket refrigeration system through energy usage diminution. Otherwise, O'Neill and Narayanan [25] developed a lumped and dynamic model (using a System Identification Method and Extended Kalman Filter) of the cold room temperature dynamics where most of the predictions are within ±10% error band of the sensor data.

Lawrence Ricker [26] proposed a predictive hybrid control for minimization of compressor cycling. It consists of decentralized predictive control of display case temperatures combined with predictive control of suction manifold pressure. Bach et al. [27] applied the hybrid control to a R404A walk-in cooler refrigeration system at different conditions. Koeln et al. [28] demonstrated for R134a and R404A that greater system efficiency (up to 9%) can be achieved using an alternative system architecture and extremum seeking control to operate the system at the optimal condenser subcooling.

The heat recovery potential of an all-CO_2 cascade refrigeration system in a supermarket can be increased by increasing the condenser/gas cooler pressure [29]. However, the optimum level of heat recovery will vary during the year and the control system should be able to continuously optimize this level based on the relative cost of energy.

4. Refrigeration cycle improvements

This section reviews some basic cycle improvements for energy performance increase. Last efforts are intended to develop subcooling and ejector technologies. Other recent basic cycle modifications developed to increase energy efficiency are also identified and reviewed in this part.

4.1 Subcooling

Dedicated subcooling can be used for easily increasing cooling capacity and efficiency, being this increase inversely proportional to ambient temperature variation [30], Figure 1. In these systems, the refrigerant at the outlet of condenser is subcooled by an additional heat exchanger, known as subcooler. She et al. [31] employed the expander output power to drive a compressor of the auxiliary subcooling cycle and they found that this configuration is very beneficial for R744, R404A and R507A.

Figure 1. Schematic of a vapor compression cycle with dedicated mechanical subcooling [30].

Yang and Zang [32] studied the introduction of a subcooler between the medium-temperature and the low-temperature supermarket refrigeration system. Maximum energy savings, considering optimal subcooler size and subcooling control, are around 27% for R404A system and 20% for R134a system (compared with basic refrigeration system). They also studied the addition of multiple subcoolers [33], recommending the sequence: 1) Medium Temperature - Low Temperature systems, 2) High Temperature - Medium Temperature systems, and finally 3) High Temperature - Low Temperature systems. The energy saving achieved when the three subcoolers are activated is up to 16% (considering small HVAC energy demand supermarket).

4.2 Ejector

The inclusion of an ejector instead of an expansion valve (Figure 2) in the refrigeration system can also result in energy efficiency increase compared to basic refrigeration cycle, with the advantage of simplicity in construction, installation and maintenance [34]. Besides, the additional pressure drops due to the inclusion of ejector are almost negligible.

Ersoy and Sag [35] quantified the increment in R134a COP due to ejector inclusion between 6.2 and 14.5%. Although R404A presents lower COP improvements than

R134a [36], this is an interesting modification in a two-stage system. Memet and Mitu [37] obtained a R404A COP increment of 6.6% for a two-stage ejector-vapor compression refrigeration cycle compared to the traditional one.

Figure 2. Ejector a) schematic diagram and b) P-h diagram.

4.3 Other system and component modifications

The review made by Barbosa et al. [38] presents recent investigations in fundamentals, design, and application aspects of compact and miniature mechanical vapor compression refrigeration systems. Patil [39] concluded that the cooling capacity and the Coefficient of Performance (COP) of a R404A system can be increased up to 10% and 17% using a micro-fin tube instead of a smooth U-tube condenser.

Finally, Bagarella et al. [40] obtained a 57% reduction of CO_2 emissions using a water-loop self-contained solution instead the traditional multiplex system (through refrigerant charge reduction), Figure 3.

Figure 3. Water-loop self-contained supermarket layout [40].

5. Trigeneration

Supermarkets have electrical, heating and cooling consumption. They can be supplied together providing energy savings beyond only optimize or modify refrigeration cycle. As Fricke [41] asserts, one of the most interesting options from an economic and energetic point of view is to consider heat recovery systems.

Trigeneration supermarket studies using CO_2 as working fluid of the refrigeration cycle are very common. In a microturbine trigeneration system [42], this system can generate more than 90% of the required electricity power by consuming much more gas to meet the space heating and cooling demands. Suamir et al. [43] modelled supermarket conventional and integrated CO_2 refrigeration and trigeneration energy systems. It provides fuel energy savings and CO_2 emission savings around 30% and 43% (over the conventional system), being 3.2 years the payback period. Cooling produced by trigeneration systems ensure subcritical operation throughout the year condensing CO_2 fluid [44].

Marimón et al. [45] studied diverse options of trigeneration systems (two commercial R717/water chillers) with an indirect refrigeration cascade system in low and medium temperature cabinets, Figure 4. The lowest payback obtained was 4.6 years and the CO_2 emission savings was approx. 22.7 tons CO_2.

Figure 4. Integration of trigeneration system with conventional refrigeration system [45].

6. High-GWP HFC replacement

Since detrimental effect of HFC emission over the atmosphere was discovered, they were intended to be replaced by fluids with lower GWP values. R404A and R507A present a GWP of 3922 and 3985 [46], being two of the refrigerants most commonly used with highest GWP.

The investigations about replace currently used refrigerants are focused on finding safe, stable, energy efficient and environmental friendly replacements (drop-in or retrofit alternatives if possible) [47]. Unfortunately, there are no refrigerants in the horizon that completely meet these requirements [48]. The possible options to replace R404A and R507A in commercial systems can be classified as [49]: hydrocarbons, natural refrigerants or lower GWP HFC and HydroFluoroOlefin (HFO) fluids. The main characteristics of each candidate are shown in Table 2.

Table 2. Considerations about candidates to replace high-GWP refrigerants used in supermarkets.

6.1. Hydrocarbons

Hydrocarbons are flammable fluids with low GWP values that can be considered in non-occupied systems or low-charge applications [50]. Cleland et al. [51] studied the performance and safety of propane-ethane (R290-R170) mixture in on-farm milk cooling equipment. Coulbourne and Espersen [52] studied the flammability risk of R290A within horizontal type ice cream cabinets. They found the risks negligible compared to background, especially when the fan is on.

Hwang et al. [53] compared R290, R404A and R410A at medium evaporation capacity matching capacities. On an equal first cost basis, LCCP of R410A is 4.2% lower and the LCCP of R404A is 1.8% higher than that of R290. In small charge walk-in refrigeration systems [54], R290 COP and Life Cycle Climate Performance (LCCP) is under that of R404A based on different assumptions and load conditions. Mastrullo et al. [55] tested two light commercial vertical freezer prototypes. The conclusion was that a reduction up to 50% of the refrigerant side volume at the heat exchangers allows reducing the refrigerant charge of about 30% (with negligible effects on energy consumptions). The replacement of R404A with R290 in a freezer reduces the energy consumption of the system by 34%. He et al. [56] compared pure R290 and mixtures to R134a in a large capacity chest freezer. Experimental tests show that the R290 power consumption is lower by 26.7% than that of R134a and that the optimal ratio of R290/R600a is 93.75/6.25% (mass percentage), being the power consumption 27.5% lower than that of R134a.

6.2. Natural refrigerants

Carbon dioxide (R744) is the only natural refrigerant replacement known to be nontoxic, nonflammable, and not harmful to the environment. It is one of the most promising refrigerants for refrigeration systems [57]. Ammonia (R717) is a very energy efficient [58] but flammable and toxic natural refrigerant that can be considered for non-occupied and controlled spaces [59].

Some authors claims that transcritical R744 heat pump and refrigeration systems will become much more common than HFO systems [60]. Sharma et al. [61] compared a R404A multiplex direct expansion (DX) system with seven R744 refrigeration systems. The transcritical booster system with bypass compressor performed equivalent to or better than the R404A system only in northern US portion (cold climate). Srinivasan [62] evaluated the optimum inter-stage pressure for two-stage transcritical R744 refrigeration cycles, obtaining values above the typical pressure index of 0.5.

Ge and Tassou [63] studied the parameters that affect the R744 booster system energy performance, Figure 5. The conclusion was that to increase COP, the intermediate pressure and high temperature compressor efficiency ratio should be as low as possible. Ge and Tassou [64] demonstrated also that R744 booster system performance will benefit from a lower ambient temperature and a sizeable heat recovery. Heat recovery can satisfy 40% of the supermarket space heating demand.

Figure 5. R744 booster system applied in supermarket refrigeration system [63].

Sawalha [65] studied a R744 transcritical system with heat recovery. It has lower energy consumption than conventional R404A with separate heat pump for heating needs and it is an efficient solution in cold climates. If an economizer is introduced in a one-stage transcritical R744 refrigeration machine, it can decrease the total cost of the final product. In hot climates it achieves an approximate cost reduction of 14% [66].

Hafner et al. [67] investigated an R-744 supermarket system layout with ejectors and heat recovery for different climate conditions and they found improvements in system efficiency of up to 30%. Minetto et al. [68] developed a new method for overfeeding multiple evaporators connected in parallel in a R744 refrigeration system (Figure 6): a two-phase ejector circulates liquid from the low pressure receiver back to the intermediate pressure receiver. This method consumes 13% lower energy when compared to classical thermostatic control (at test conditions).

Figure 6. Schematic diagram of system proposed by Minetto et al. [68].

Da Silva et al. [69] compared R404A/ R744 cascade system with R404A and R22 direct expansion systems. They found many advantages using the cascade proposed, like reduction of the electric energy consumption, lower environmental impact or more compact installation, among others.

One of the most promising cascades refrigerant pairs is R717/R744 (R717 at high stage and R744 at low stage) [70], Figure 7. For the same conditions, when compared to R404A partial injection two-stage refrigeration system; this cascade can compete at low evaporating temperatures (between -50°C and -30°C) regarding energy, security and environmental parameters (even though ethanol performs the best at high stage) [71]. Cecchinato et al. [72] studied different different lay-out and technological solutions using natural refrigerants. The most efficient solution is a cascade using R717/R744 that enables an annual energy saving higher than 15% with respect to the baseline solution. Fernández-Seara et al. [73] demonstrated that the use of a cascade R717/R744 in plate freezers represents a viable alternative to systems currently in use.

Figure 7. Schematic diagram of a two-stage cascade refrigeration system [70].

Inlow and Groll [74] developed a model for a secondary-loop refrigeration system for supermarkets using R717 in the primary-loop and R744 as a volatile secondary refrigerant. The results indicate that this system can provide a cost effective alternative.

6.3. Low-GWP HydroFluoroCarbons (HFC)

At different evaporation conditions, R152a has the best COP and lower power consumption (when compared to different refrigerants) [75]. R407C and R152a (GWP of 1774 and 124, respectively) show better average exergetic efficiency ratio (9% and 14%), lower Total Equivalent Warming Impact (TEWI) (27% and 25%) and Integrated CO_2 Factor (ICF) (34% and 51%) than R404A [76]. In addition, in the high stage of a cascade refrigeration system, R152a shows better performance results than R404A, R507A and R134a [77].

Han et al [78] tested a non-azeotropic mixture of R161/R125/R143a (0.15/0.45/0.40 in mass fraction) in a refrigeration system. Experimental results show that the new mixture can obtain a higher COP, by 6.3% to 12.1%, and a lower pressure ratio, by 1.8% to 6.6%, compared to R404A; although the discharge temperature of the new mixture is slightly higher than that of R404A.

Two HFC mixtures have been developed as R404A retrofit replacements, R407A [79] and R407F [80] (GWP of 2107 and 1824, respectively). They present similar cooling capacity and energy efficiency savings of up to 10%.

6.4. HydroFluoroOlefines (HFO) and mixtures

The Air-Conditioning, Heating, and Refrigeration Institute (AHRI) began a collaborative investigation to evaluate low-GWP alternative refrigerants including recently developed HFC/HFO mixtures [81]. The complete list of AHRI investigations is exposed and continuously updated and includes R404A replacement studies [82]. Alternatives proposed to substitute R404A are exposed in Table 3.

Table 3. HFC/HFO mixture alternatives to R404A.

AHRI published results for trailer refrigeration unit [83] and ice machines [84] (both systems designed for R404A), showing the following conclusions: in the first application, the cooling capacity at low and higher return air temperatures was -21% and 10% for L40, -19% and 5% for ARM-30a and comparable or 11% higher for DR-7, respectively. In the second one, the best performing refrigerant was N40 (good capacity and energy efficiency). Results obtained in the compressor calorimeter tests for DR-7 and L40 (glide around 6K and 7.7K, respectively) are shown in Table 4 [85-88]. A summary of AHRI tests performed until 2014 can be found in the Wang and Amrane review [89].

Table 4. Summary of compressor calorimeter test.

Refrigerant manufacturers published the conclusions of their own experimentations. Dupont tested DR-7 and DR-33 in a reach-in freezer [90], the DR-7 energy consumption compared to R404A was between 3% and 8% lower for DR-7 and between 0 and 4% lower for DR-33. In display case (condensing unit), DR-33 energy consumption compared to R404A was between 3% and 4% lower at low temperature and between 8% and 12% lower at medium temperature conditions. In the case of Honeywell mixtures [91], N40 energy efficiency is higher than that of L40, being that higher than R404A. N40 cooling capacity is slightly higher than R404A but for L40, this parameter is lower. Due to the GWP limitation of 150 in Europe [13], Honeywell developed a mildly-flammable option with GWP of 145, HDR-110 [92]. In a R404A reach-in freezer it showed lower energy consumption and near match in capacity.

In a reciprocating compressor freezer application [93], L40 and DR-7 performed better than R404A. While DR-7 showed higher capacity compared to L40, N40 energy consumption was lower than R404A. Kujak et al. [94] discussed environmental friendly R404A alternatives using LCCP analysis in stationary and transport applications. Mota-Babiloni et al. [95] obtained good performance results for different R404A replacement mixtures in a theoretical analysis considering different configurations and the effect of glide.

The U.S. department of Energy also started a project in 2010 to develop low GWP refrigerant solutions for the Heating, Air Conditioning and Refrigeration market [96]. This project is expected to finish in 2016 and it is focused intensely on Commercial Refrigeration due to the large leak potential.

7. Conclusion

Commercial refrigeration systems are one of the most relevant sectors in terms of energy consumption and Greenhouse gas emissions to atmosphere. This paper reviews the state-of-art of recent developments and contains and covers important topics such as supermarket refrigeration system energy efficiency, GHG emission control regulations, HFC phase-out and low GWP alternatives. The main conclusions of the study are the following ones.

Commercial refrigeration technology is improving slowly and that is not enough to overcome its limitations. Perform an energy consumption analysis of each supermarket is very important to identify the most beneficial energy saving techniques. There are available in literature supermarket models that take into account majority of variables. A good supermarket control is necessary to obtain a good food quality and allows reducing energy consumption. In the last years new control techniques have been developed to allow better energy performance than conventional control methods. Among the refrigeration cycle improvements, ejector and additional subcooling of refrigerant are the advancements most researched last years. Trigeneration is an interesting option in supermarkets that produces great energy and CO_2 emission savings, especially when CO_2 is the working fluid selected.

New GHG regulations impose strong GWP limitations that are going to phase out currently used HFC refrigerants (in commercial refrigeration R404A and R507A). No refrigerant has yet imposed in commercial refrigeration and investigations propose different alternatives: propane in low charge applications, showing good performance; low-GWP HFC or HFC/HFO mixtures as drop-in or retrofit replacements (with little system modifications); and CO_2 systems in transcritical systems or at the low-stage of cascade systems.

Although that numerous investigations (the most relevant reviewed in this paper) have been carried out in order to reduce the direct and indirect GHG emissions, this is not enough to reduce the climate change to a sustainable condition. Retailers should integrate more energy efficient technologies or refrigerants, beyond cost savings through fiscal incentives; involving costumers in clean technologies [97]. As vapour compression system modifications implies small reductions in energy consumption, alternatives to classic vapour compression systems should be studied for food conservation [98] or new power generation systems can be included [99]. Finally, the most suitable refrigerant-system should be found and established for each application [100].

Acknowledgements

The authors thankfully acknowledge “Ministerio de Educación, Cultura y Deporte” for supporting this work through “Becas y Contratos de Formación de Profesorado Universitario del Programa Nacional de Formación de Recursos Humanos de Investigación del ejercicio 2012”.

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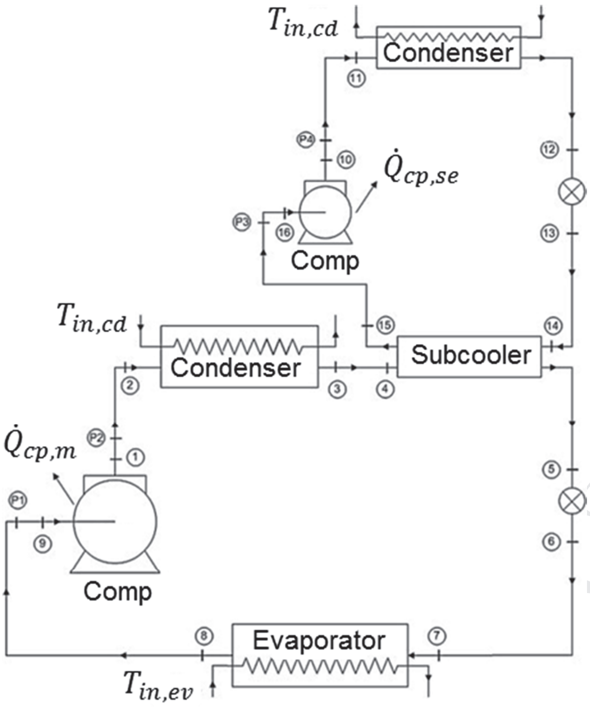
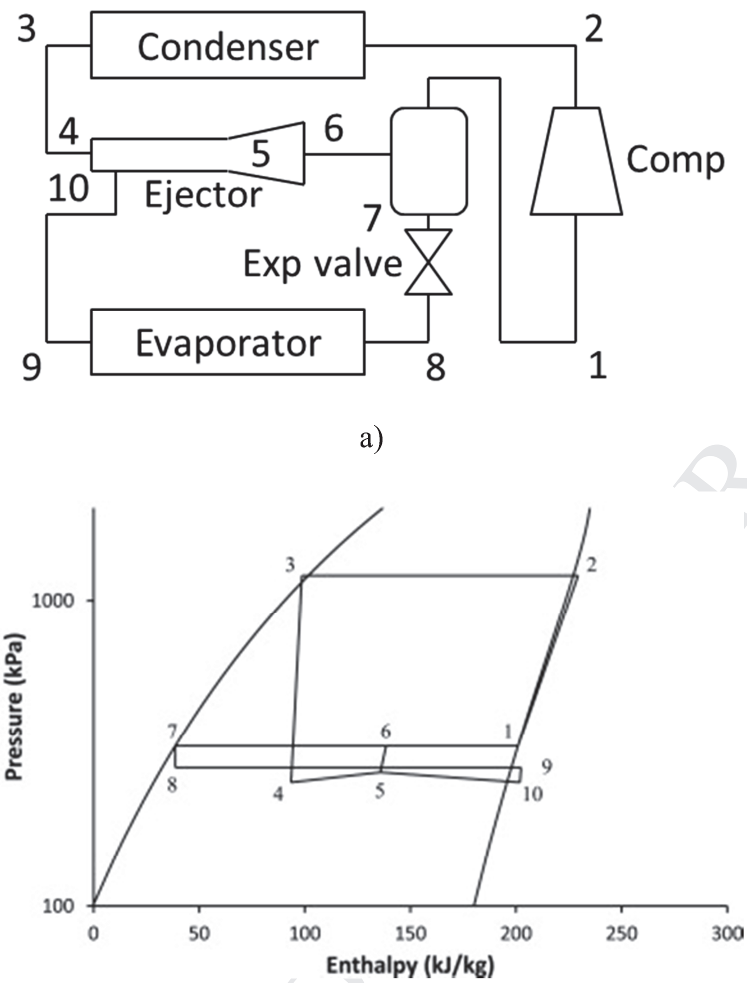


Figure 1. Schematic of a vapor compression cycle with dedicated mechanical subcooling [30].



a)

b)

Figure 2. Ejector a) schematic diagram and b) P-h diagram.

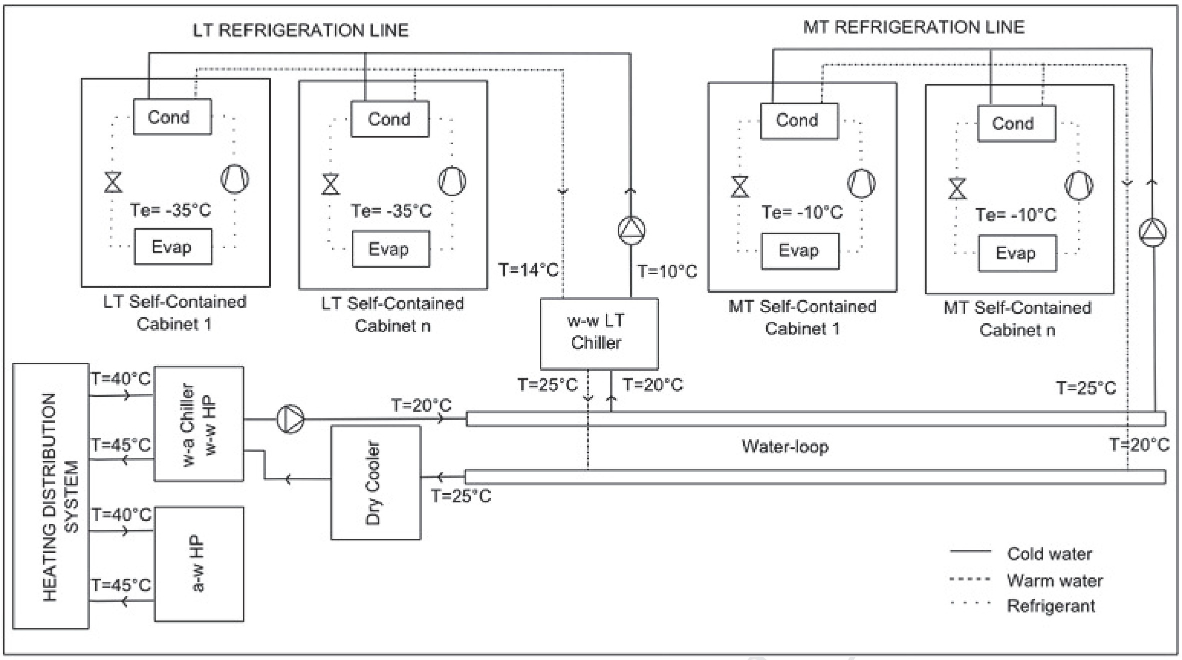


Figure 3. Water-loop self-contained supermarket layout [40].

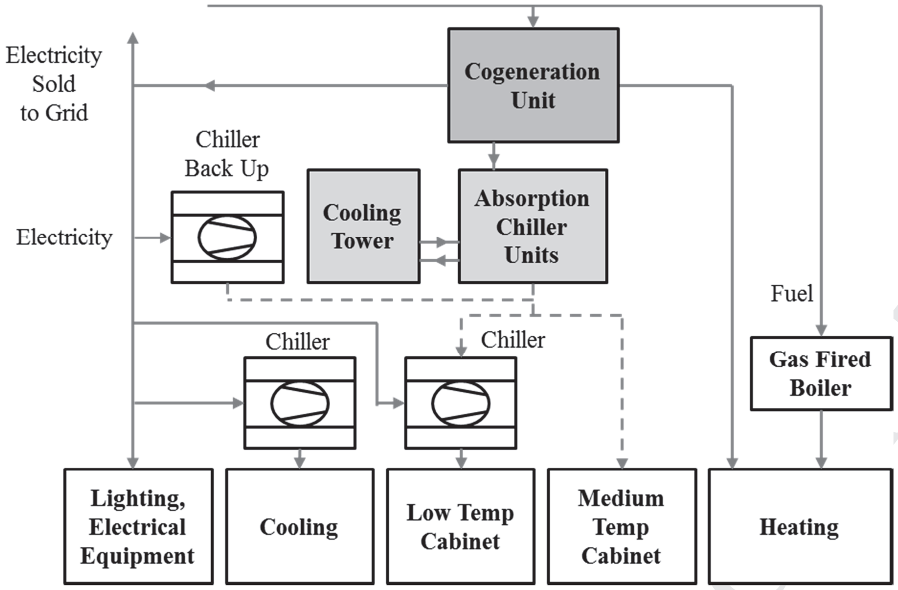


Figure 4. Integration of trigeneration system with conventional refrigeration system [45].

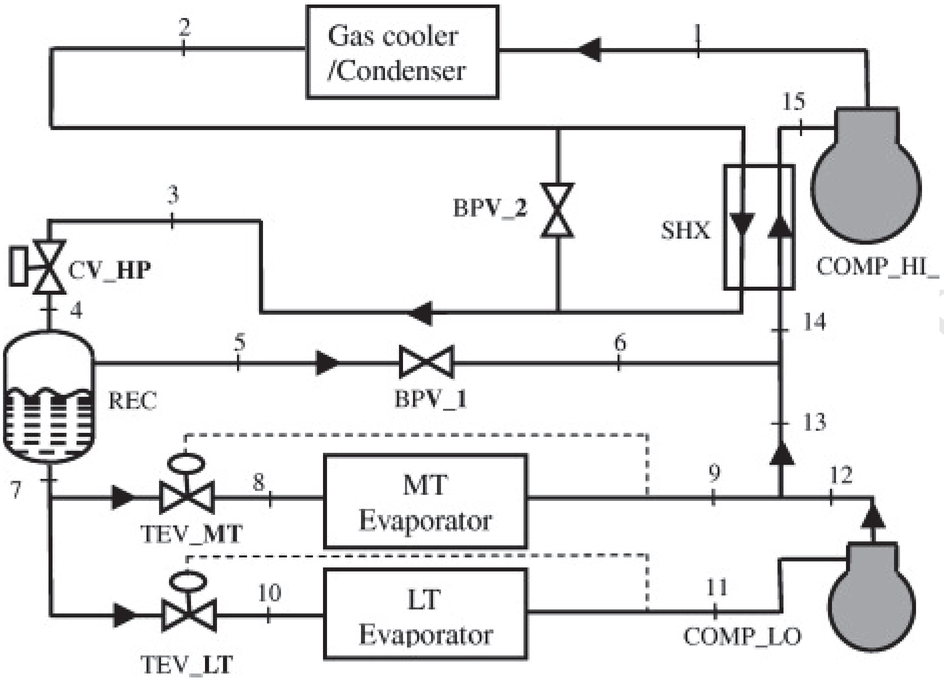


Figure 5. R744 booster system applied in supermarket refrigeration system [63].

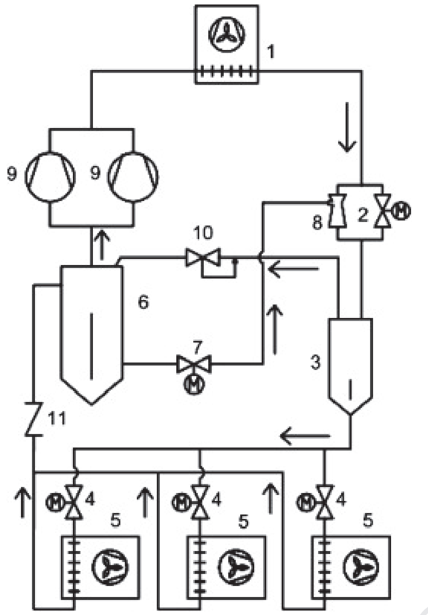


Figure 6. Schematic diagram of system proposed by Minetto et al. [68].

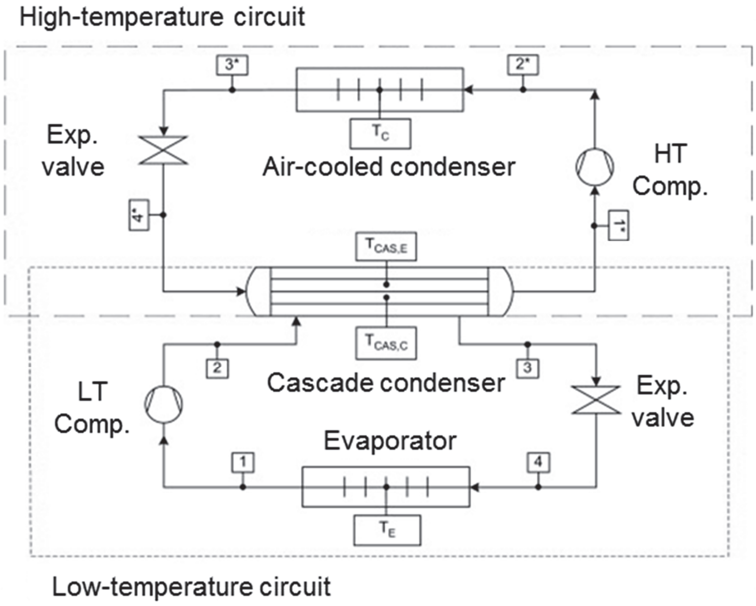


Figure 7. Schematic diagram of a two-stage cascade refrigeration system [70].

FIGURE CAPTIONS

Figure 1. Schematic of a vapor compression cycle with dedicated mechanical subcooling [30].

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Table 1. Placing on the market prohibitions by the EU Regulation No 517/2014 [13] that affects commercial refrigeration.

Products and equipment		**Date**[a]
Refrigerators and freezers for commercial use (hermetically sealed equipment) that contain HFCs with	GWP≥2500.	2020
	GWP≥150.	2022
Stationary refrigeration equipment, that contains, or whose functioning relies upon, HFCs with GWP≥2500 except equipment intended for application designed to cool products to temperatures below -50°C.		2020
Multipack centralised refrigeration systems for commercial use with a rated capacity≥40 kW that contain, or whose functioning relies upon, fluorinated greenhouse gases with GWP≥150, except in the primary refrigerant circuit of cascade systems where fluorinated greenhouse gases with a GWP<1500 may be used.		2022

[a] 1 January.

Table 2. Considerations about candidates to replace high-GWP refrigerants used in supermarkets.

Candidate		**Considerations**
Hydrocarbons		Efficient, flammable and non-toxic
Natural Refrigerants	Dioxide Carbone	Not enough efficient, non-flammable and non-toxic
	Ammonia	Very efficient, low flammable and toxic
Low-GWP HFC		Similar efficiency, low flammable and non-toxic
HFO		Less efficient, low flammable and non-toxic
HFO/HFC mixture		Similar efficiency. It can be low-GWP and low-flammable or medium-GWP and non-flammable, depending on the composition.

Table 3. HFC/HFO mixture alternatives to R404A.

Refrigerant	**Composition**	**(Mass%)**	**Security Class.**	**GWP$_{100\text{-yr}}$**
ARM-32a	R32/R125/R134a/R1234yf	(25/30/25/20)	A1	1577
DR-33 (R449)	R32/R125/R134a/R1234yf	(24/25/26/25)	A1	1410
N40 (R448A)	R32/R125/R134a/R1234yf/ R1234ze(E)	(26/26/20/21/7)	A1	1205
ARM-30a	R32/R1234yf	(29/71)	A2L	199
ARM-31a	R32/R134a/R1234yf	(28/21/51)	A2L	491
D2Y65	R32/R123yf	(35/65)	A2L	239
DR-7	R32/R123yf	(36/64)	A2L	246
L40	R32/R152a/R1234yf/ R1234ze(E)	(40/10/20/30)	A2L	285

Table 4. Summary of compressor calorimeter test.

Test	**Compressor capacity vs R404A**	**COP vs R404A**
DR-7 in a R404A Scroll Compressor [85]	90 to 110%	100 and 115%
DR-7 in a R-404A Reciprocating Compressor [86]	85 to 105%	100 and 110%
L-40 in a R-404A Scroll Compressor [87]	80 to 100%	95 and 120%
L-40 in a R-404A Reciprocating Compressor [88]	65 to 95%	90 and 115%

HIGHLIGHTS

- The recent investigations in commercial refrigeration are reviewed.
- Several energy saving methods are summarized.
- Additional subcooling or inclusion of ejectors can reduce energy consumption.
- Control improvements in supermarkets refrigeration systems are discussed.
- R744 is a very promising candidate to substitute R404A and R507A.