Eco-friendly supermarkets - an overview

Report 2

SUPERSMART

Public report

for the project:

SuperSmart - Expertise hub for a market uptake of energy-efficient supermarkets by awareness raising, knowledge transfer and pre-preparation of an EU Ecolabel

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EXECUTIVE SUMMARY

This report reviews the technical characteristics of eco-friendly supermarkets. This has been fulfilled by presenting the conventional and eco-friendly cooling and heating systems available in the European supermarket sector.

The report is a deliverable for the H2020 project SuperSmart, which deals with the removal of non-technical barriers in commissioning of energy-efficient heating and cooling solutions in supermarkets. An introduction to the SuperSmart project and this set of training material is given in Chapter 1. The objectives and scope of this report are described in the same chapter.

Chapter 2 gives an overview over the supermarket sector in Europe. It is shown that the number of supermarkets and their total surface area has increased in the past decade. The increase includes all formats of the supermarkets, i.e., convenience stores, discounters, supermarkets and hypermarkets. The rate of increase is higher in Eastern-Southern Europe than in Northern and Western Europe grocery markets. It is also shown that the average share of “modern food retail markets” in the total food market of European countries has increased from 44 % in 2000 to 62 % in 2011.

Chapter 3 reviews the environmental impacts, which are associated with supermarket sector services. The focus is on the impact of cooling and heating systems. The two major factors, high energy use and significant consumption of refrigerants with high global warming potential (GWP) are elaborated in this chapter. It is shown that supermarkets have one of the highest annual specific energy consumptions among commercial buildings in Europe, typically in the range of 400-600 kWh/m^2.a. The largest energy consumer is the refrigeration system with a share of 35-50 % of the total energy use. Furthermore, it is indicated that supermarkets are the largest consumers and emitters of high-GWP HFC gases in Europe. The conventional refrigerant in European supermarkets is R404A with a GWP value of 3922. About one third of the total EU HFC consumption is used in supermarkets.

Chapter 4 reviews the technical aspects of energy systems in supermarkets. Cooling and heating systems are in the focus of this chapter. Both conventional and eco-friendly systems for refrigeration, heating, ventilation, air conditioning, dehumidification and lighting are introduced. As the refrigeration system has the largest carbon footprint, this system is discussed in more detail, both in chapters 4 and 5.

State-of-the-art supermarket refrigeration systems are discussed in chapter 5. The emphasis is on CO_2 transcritical booster refrigeration as the latest eco-friendly technology in the supermarket sector. It is shown that the CO_2 refrigeration system has been changed in the past few years from a single-functioning system to a multi-function integrated system providing refrigeration, heating and air conditioning in several European supermarkets. Furthermore, CO_2 transcritical booster systems with state-of-the-art features including usage of parallel compression, ejectors, thermal storage, mechanical sub-cooling and others are discussed in this chapter.

Best practices and case examples of eco-friendly systems installed in Europe and worldwide are introduced in chapter 6. The goal is to spread the knowledge and raise the awareness for faster uptake of these systems into the European market.

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1 INTRODUCTION

Efficient solutions for supermarket heating, cooling and refrigeration - such as integrated systems or the use of natural refrigerant-based equipment - are already available in the European market. However, their use is not yet widespread due to remaining non-technological barriers, including lack of knowledge and awareness, social, organizational and political barriers.

The European project SuperSmart aims at removing these barriers and additionally supports the introduction of the EU Ecolabel for food retail stores. The EU Ecolabel can encourage supermarket stakeholders to implement environmentally friendly and energy-efficient technologies and thus reduce the environmental impact of food retail stores.

Within the project several activities are carried out to remove the barriers: campaigns to raise the general awareness and spread the information about energy-efficient and eco-friendly supermarkets, as well as training activities within the following specific topics:

- Eco-friendly supermarkets – an overview
- How to build a new eco-friendly supermarket
- How to refurbish a supermarket
- Computational tools for supermarket planning
- Eco-friendly operation and maintenance of supermarkets
- EU Ecolabel for food retail stores

For each of the topics a set of training material is developed, which will be used in the training activities. The different kinds of training activities are:

- Conference related activities
- Dedicated training sessions
- Self-learning online activities

Dedicated training sessions are free-of-charge for the different stakeholders in the supermarket sector. This means that highly-qualified experts from the project consortium will carry out a training session on a specific topic at the premises of the stakeholder. If you are interested in receiving such a training regarding any of the above-mentioned topics, please contact the project partner via the project website: www.supersmart-supermarket.info.

The present report forms a part of the training material for the topic "Eco-friendly Supermarkets - an Overview". It can be used for self-studying and is freely available. There will be conferences, where this topic is included as a training activity. Information on conferences where members of the SuperSmart team will be present as well as the planned training activities can be found on the project website.

1.1 Introduction to "Eco-friendly supermarkets – an overview"

This report is the first of a series of training material aimed at raising awareness and transferring knowledge about eco-friendly solutions in supermarkets among different stakeholders of the supermarket sector. The report reviews both the conventional and eco-friendly supermarket energy systems, with emphasis on cooling and heating systems.

The content is balanced between general aspects of the supermarket sector and comprehensive technological information on the energy systems in supermarkets, making it instructive for many different stakeholders of supermarkets. These include:

- Supermarket chain managers
- Single supermarket /Shop owners or runners
- HVAC&R system contractors
- HVAC&R component providers
- HVAC&R service providers
- Engineering societies/studios
- Consultants/Energy consultants

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- Research Institutes/Universities
- Public bodies (legislative, e.g. the organization responsible for the EU-Ecolabel) and NGOs (e.g. associations of supermarket installers/maintenance companies)

The report explains the status of the European supermarket sector, its energy systems, state-of-the-art supermarket refrigeration systems and its best practices, including case studies of prominent supermarkets.

1.1.1 Objectives

The main objectives of this report are:

- Review the development of the supermarket sector in Europe.
- Review the major supermarket energy systems and their environmental impacts in Europe, including the conventional ones and the state-of-the-art eco-friendly ones. The major focus will be on refrigeration systems, which are the ones with the highest carbon footprint in supermarkets.
- Present the best eco-friendly practices of supermarkets installed and running across Europe and the world.
- Provide the baseline technological information for pre-preparation of a new European Ecolabel for food retail stores.
- Provide the basis for other reports in the series of training material.

1.1.2 Scope

The definition of supermarket[1] in the project is adapted from two existing European ecolabels for grocery stores. The term "supermarket" used in this report is corresponding to the term "grocery store" used in the following two national ecolabels:

- *Nordic Ecolabel*: Grocery stores in which groceries account for more than 50 % of turnover on an annual basis. The grocery store may be a single store, part of a larger chain or an internet store. Wholesalers are also in the scope. In this context, groceries are defined as goods that are expected to be consumed or used within a limited period, e.g. foodstuffs, sanitary products, household articles and cleaning agents (Nordic Ecolabel, 2016).
- *Blue Angel*: Grocery stores in the food retail sector include all store formats in the retail trade (self-service food stores and markets, food discounters, supermarkets, convenience stores, self-service warehouses, hypermarkets) whose product range consists primarily of food. The grocery stores must generate at least 50 % of their turnover through the sale of food (Blue Angel, 2013).

The scope of this report is predominantly the **cooling and heating systems in supermarkets**. It studies these energy systems in supermarkets/grocery stores where more than 50 % of the annual turnover is generated by sale of groceries, mainly food.

The fields, which are not in the scope of this report, are:

- Building envelope characteristics: it is reviewed in two other reports, section 2.1 of "D2.3: How to build a new eco-friendly supermarket" (Kauko et al., 2016) and section 2.2 of "D2.4: How to refurbish a supermarket" (CIRCE, 2016).
- Other eco-friendly aspects of the supermarkets including sales of eco-labelled food/non-food products, transportation & distribution carbon footprint, water and waste management, etc.
- Other type of food retail stores including cash-and-carry beverage stores, service station shops, cafeterias, caterers, restaurants and hotels, butcher shops and franchise outlets for meat products, bakeries and franchise bakery outlets, specialty food retailers and kiosks.

[1] **"Supermarket" in this report is an umbrella term covering different formats of food retail stores.**

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2 SUPERMARKET[2] SECTOR: AN OVERVIEW

Supermarkets have become a fundamental service facility of the modern European society and they have a vital role in the food cold chain. Supermarkets have shown a strong development in the recent decades and they are spreading across Europe. This can be verified in the following two figures. Figure 1 shows the evolution of the European food retail by number of outlets (left) and total surface area (right), comparing 2000 and 2011 (EY et al., 2014). The outlets are categorized as the three large sizes of grocery stores; "hypermarkets", "discount stores" and "supermarkets". A smaller format known as "convenience store" is not included in the figure but the growth rate for this format is even higher than the shown three formats. These different formats are defined later in this chapter. As shown in the figure, the numbers and total surface area of all formats have been increased over the past decade, despite the occurrence of 2007-2008 financial crisis.

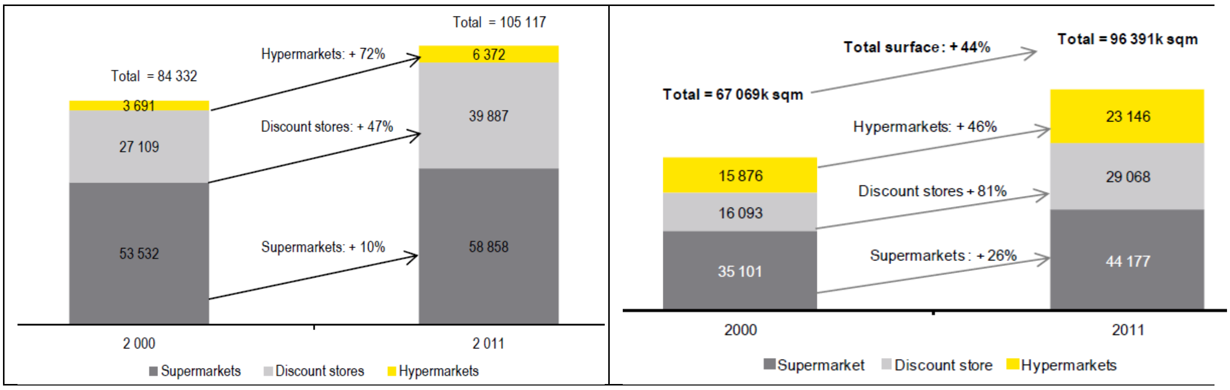

Figure 1: Increase in number of retail outlets (left) and total surface of retail [thousands m²] in Europe, comparing 2000 and 2011 (EY et al., 2014)

Figure 2 shows the share of modern food retail markets in the total food market of European countries, in 2000 and 2011. Modern food retail markets in the reference study are defined as hypermarkets, supermarkets and discounters[3]. What can be seen in the figure is that nearly all the European countries witness the increasing share of supermarkets and decreasing share of traditional local food markets in the food supply chain. As shown in the last column, while the EU average share was 44 % in 2000, it is increased to 62 % in 2011.

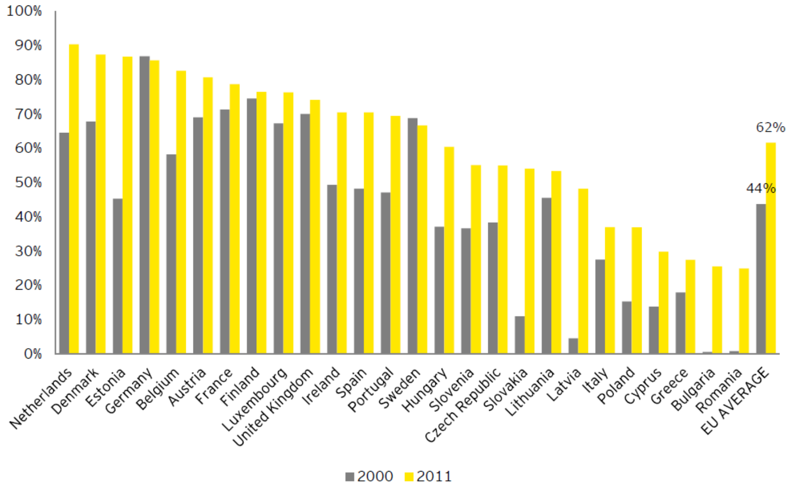

Figure 2: Supermarkets share of retail food market in European countries, 2000 and 2011 (EY et al., 2014)

[2] Unless mentioned as a specific format, "supermarket" is an umbrella term in this report covering different formats of food retail stores.
[3] Please refer to section 3.1.1 of EY et al. (2014) for the detailed discussion on this definition.

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The main reasons for growth in the number of supermarkets in the EU and around the world are (Traill, 2006):

- Urbanization: population shift from small cities and rural areas to big cities, spread and growth of cities.
- Emerging middle class: rising incomes, higher welfare levels, higher purchasing power.
- Globalization and taste convergence: globalization of media and advertising, well-developed international/intercontinental network of cold chain transportation, multi-national supermarket chains.
- More female labour in the market: less time spent on cooking at home, more purchase of prepared fresh and frozen food products.
- Openness to inward foreign investment (East Europe): liberalisation of trade and investment.
- Desire to emulate the western life style in Eastern Europe.

As shown in Figure 1, food retail stores are usually segmented into different format groups based on the size and the marketing strategy. The differences between these different formats have been highlighted in Table 1. It is worth mentioning that sometimes there is not a very clear distinction between some definitions. For example, a large supermarket in one European country can be accounted as a hypermarket in another country.

Table 1: Different formats of food retail stores (EY et al., 2014) (Schöenberger et al., 2013) [Wikipedia: Retail]

Format	Type of building	Products type	Products price	size	Notes
Hypermarket	stand-alone buildings, usually owned	- Food products - Non-food products - Large variety and huge volumes of products at low margins	Low-medium price	- larger than 4500 m^2 (EY et al., 2014)	Low refrigeration load share in total energy use, compared to supermarkets
Supermarket	stand-alone buildings (usually owned) or building units (usually rented)	- Mainly food products - limited non-food products	Medium price, comparing to other formats	- 400-2500 m^2 but can be as large as 4500 m^2 (EY et al., 2014) - 1000-3000 m^2 (Schöenberger et al., 2013)	High refrigeration load share in total energy use
Discounter	stand-alone buildings (usually owned) or building units (usually rented)	- Food products - less-fashionable non-food products	Low price	- similar to a small-medium size supermarket - less than 1000 m^2 (Schöenberger et al., 2013)	
Convenience store	building units (usually rented)	Limited number of products, predominantly food	More than other formats	- less than 400 m^2 (EY et al., 2014)	It can be a part of gas/petrol stations.

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The number of stores per million habitants for different European countries is shown in Figure 3. The breakdown of the total number indicates the numbers of small supermarkets (SSM) with sale surface 400-1000 m², large supermarkets (LSM) of 1000-2500 m² and hypermarkets over 2500 m². The difference between these numbers and the numbers in the previous paragraph originates from the fact that there is not a clear consensus about the differences between "large supermarkets" and "hypermarkets".

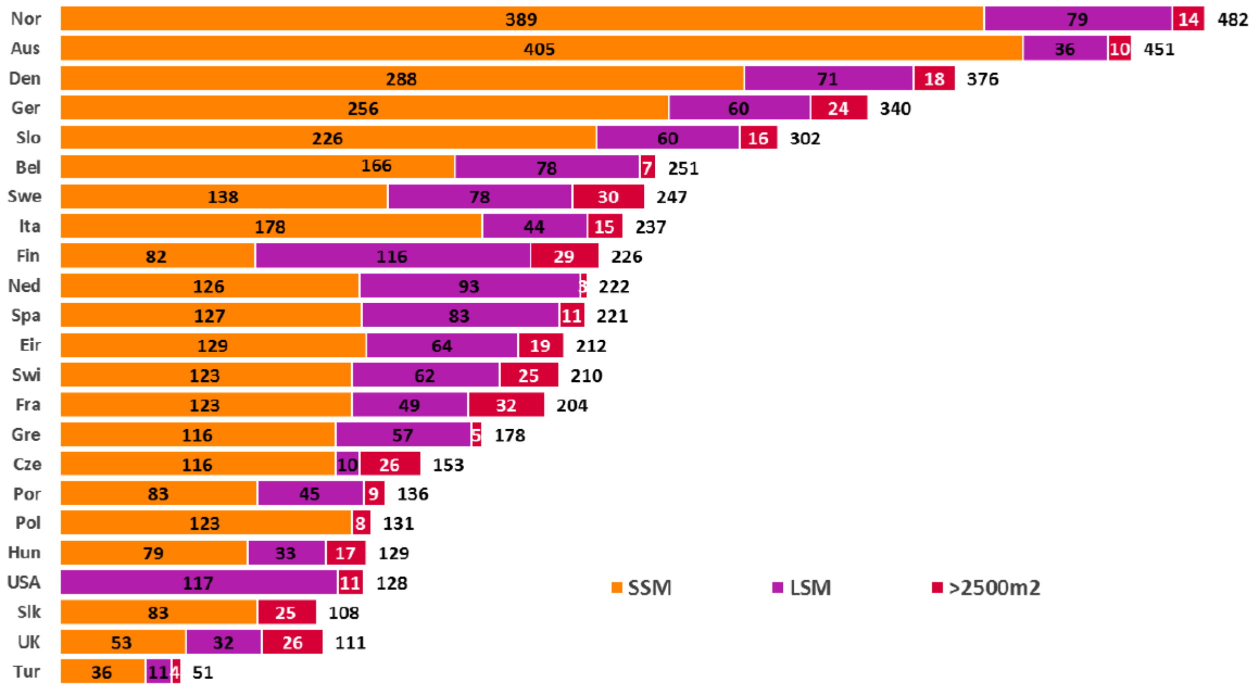

Figure 3: Number of supermarkets per million habitants of European and non-EU countries for small supermarkets [SSM], large supermarkets [LSM] and hypermarkets [>2500 m²] (Nielsen, 2014)

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3 ENVIRONMENTAL IMPACTS AND F-GAS REGULATION

The service which supermarkets provide is typically associated with significant environmental impacts. Focusing on the impacts of its energy systems, this chapter provides some facts highlighting the importance of implementing eco-friendly and energy-efficient solutions.

Firstly, supermarkets consume 3-4 % of the annual electricity production in industrialized countries. These have been reported in different countries including 3 % in Sweden (Sjöberg, 1997), 4 % in USA (Orphelin and Marchio, 1997), 3 % in UK (Tassou et al., 2011), 4 % in France (Orphelin and Marchio, 1997), and 4 % in Denmark (Reinholdt and Madsen, 2010).

Secondly, supermarkets are energy intensive buildings; they typically have one of the highest specific energy consumptions (energy consumption per sales or total area) among commercial buildings in European and developed countries around the world, where the majority of the food retail market is governed by supermarkets.

- Sweden: A survey carried out in 2010 compared the specific energy consumption of 130 buildings in Sweden with “retail” function. This includes 50 supermarkets, 30 shopping centres and 50 other types of shops. It has been found that the supermarkets’ average annual specific energy consumption is about 400 kWh/m^2·a while for other retail buildings, including shopping centres, the average is less than 265 kWh/ m^2·a (Energimydegheten, 2010).
- Norway: A report on energy use in Norwegian buildings shows that supermarkets’ average energy consumption is more than 500 kWh/ m^2·a, while it is about 280 kWh/m^2 for other type of commercial buildings (Enova, 2007). In a recent research work, the average specific energy consumption is reported to be 300 kWh/m^2 for shopping centres, 200-220 kWh/m^2 for other shop categories while it is 460 kWh/m^2 for Norwegian supermarkets (NVE, 2014).
- USA: The U.S. Environmental Protection Agency’s (EPA) ENERGY STAR Portfolio Manager is a tool to track and manage energy use in 260.000 commercial buildings across all the 50 states. The indicator used in the portfolio manager is called Energy Use Intensity (EUI). It has been shown that supermarkets have the highest EUI among all types of commercial buildings in the USA with about 600 kWh/m^2 annual specific energy consumption (Energy Star, 2014).
- UK: Tassou et al., (2011) studied the energy performance of several hundreds of stores in the UK (big hypermarkets, superstores, supermarkets and convenience stores) and found that the average total energy consumption of a store is about 1000 kWh/m^2·a. “This is significantly higher than the final energy demand of other commercial buildings, such as offices (100–200kWh/m^2.a) or hotels (100–300kWh/m^2.a), and much higher than that of residential buildings (50–150kWh/m^2.a)” (Galvez-Martos et al., 2013).
- Spain: The average specific energy consumption for large supermarkets and hypermarkets is reported to be 327 kWh/m^2·a while it is in the range of 118-333 kWh/m^2·a for shopping malls (CIRCE, 2015).

It should be noted that the values for supermarkets’ specific energy consumption in UK and Spain seems overestimated and slightly underestimated, respectively. The reasons for this are not clear to the authors.

Thirdly, refrigeration systems take a 35-50 % share of total energy use in supermarkets and they are typically the largest electricity consuming system in the supermarkets (Lundqvist, 2000). Figure 4 shows some examples of energy use breakdown in supermarkets in different countries. Some charts shown in the figure represent the breakdown of total energy use and some others indicate the electricity breakdown. In addition to refrigeration, lighting[4] and heating, ventilation and air conditioning (HVAC) systems are the other major energy consuming systems in supermarkets. As can be seen in Sweden and USA sample cases in Figure 4, supermarket’s largest share of primary energy use is in the form of electricity. This is the case for many European countries including Norway (NVE, 2014), Spain (CIRCE, 2015) and UK (Spyrou et al., 2014). The share of electricity use in total energy consumption is mainly dependent on the heating system in the supermarket.

[4] The power consumption related to lighting is nowadays much lower, when ordinary lighting is replaced by modern LED lights.

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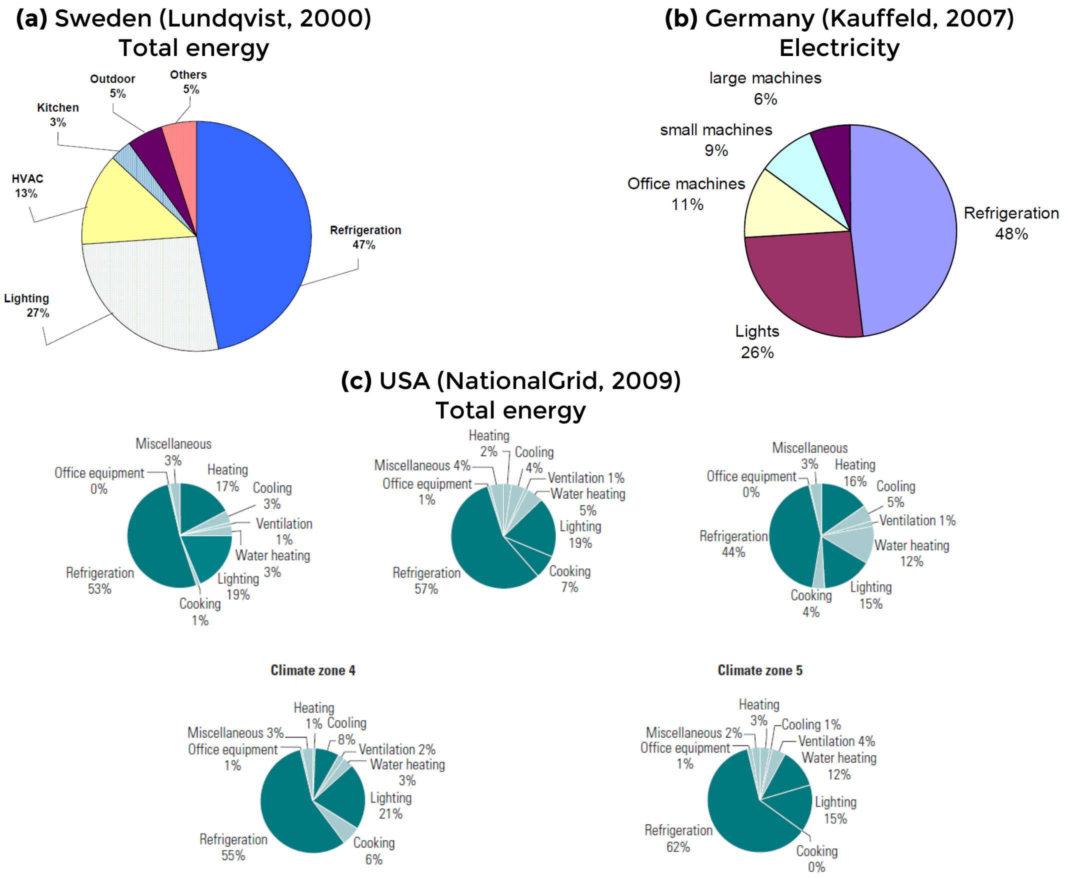

Figure 4: Energy use breakdown in supermarkets in (a) Sweden, (b) Germany and (c) the USA

To sum up, it has been shown that (I) supermarkets have a significant energy consumption, mainly in the form of electricity and (II) the refrigeration system is the largest consumer of this electricity. The supply of the needed electricity and heat is usually associated with CO_2 emissions to the atmosphere. This effect is typically known as “indirect” emission.

The supermarkets high energy use and high electricity consumption of their refrigeration systems is not the only environmental impact In addition, supermarkets use typically high GWP refrigerants. The conventional refrigeration system in European supermarkets consists of separate direct expansion HFC-based systems for medium and low temperature levels. The dominant refrigerant in European supermarkets is R404A with a GWP value of about 3922 (SKM Enviros, 2012). The amount of refrigerant charge in medium- and large-size supermarkets is in the range of hundreds to few thousands of kilograms. Due to the long pipe runs and numerous piping connections, the leakage rate is reported to be 3-22 % by different researchers (IPCC, 2005). The emission of high GWP refrigerants to the atmosphere is known as direct emission. In some countries, including Sweden and Switzerland, indirect systems have been installed to confine the HFC use in the machinery room and reduce the amount of refrigerant and thereby the total leakage.

One of the objectives of this report is to indicate how it is possible to reduce the direct and indirect emissions of supermarket refrigeration systems.

Figure 5 shows two charts which highlight the high HFC demand and consumption in the commercial refrigeration sector.

- Figure 5-a: “The commercial refrigeration sector represented 40 % of refrigerant [greenhouse gas] GHG consumption in 2010. The largest part of this consumption (85 %) is due to large refrigeration systems in supermarkets, most of which utilize the high GWP refrigerant R404A. The remaining consumption is split between small hermetic systems and single condensing unit systems (SKM Enviros, 2012). This implies that supermarkets are the largest consumers of HFCs in Europe, with a share of about one third.

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- Figure 5-b: The commercial refrigeration sector has the largest share of the market for HFC refrigerants among 8 different refrigeration, heat pump and air conditioning market sectors (EPEE, 2015). As mentioned before, supermarkets are the largest player in the commercial refrigeration sector.

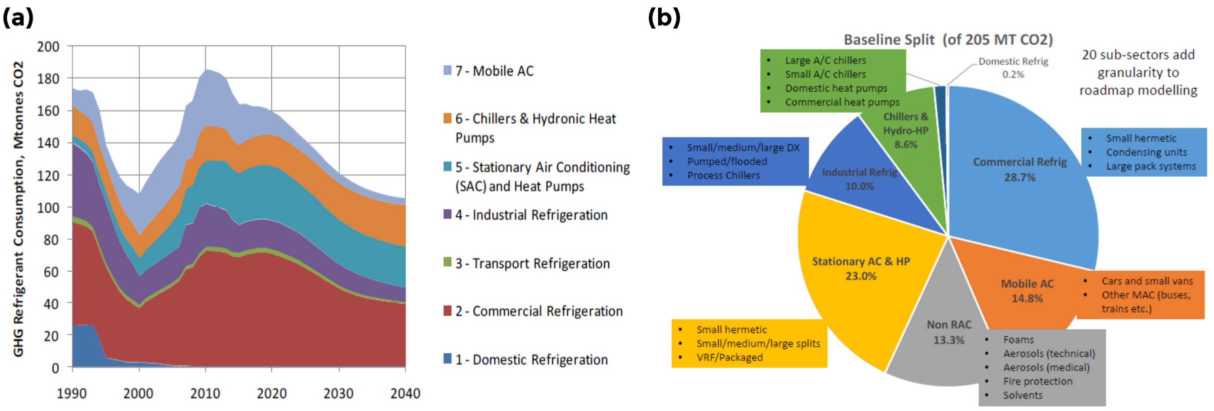

Figure 5: (a) GHG refrigerant consumption in EU countries (SKM Enviros, 2012) and (b) drivers of HFC demand: the 8 main market sectors (EPEE, 2015)

This high amount of HFC refrigerants consumption and emission in refrigeration systems reflects in the total carbon footprint of supermarkets. According to Carr-Shand et al. (2009), 18-30 % of annual equivalent carbon emissions in European supermarkets is due to their choice of refrigerants. The numbers can be slightly higher or lower than this range for different EU supermarkets depending on various factors including energy use, as well as refrigerant/refrigeration and transportation choices.

As an example, the carbon emissions distribution of the two largest Swedish supermarket chains is shown in Figure 6. As illustrated in the figure, the refrigerants are responsible for 31 % and 16,5 % (köldmedia: refrigerant) of their annual carbon emissions (ICA, 2015) (COOP, 2015).

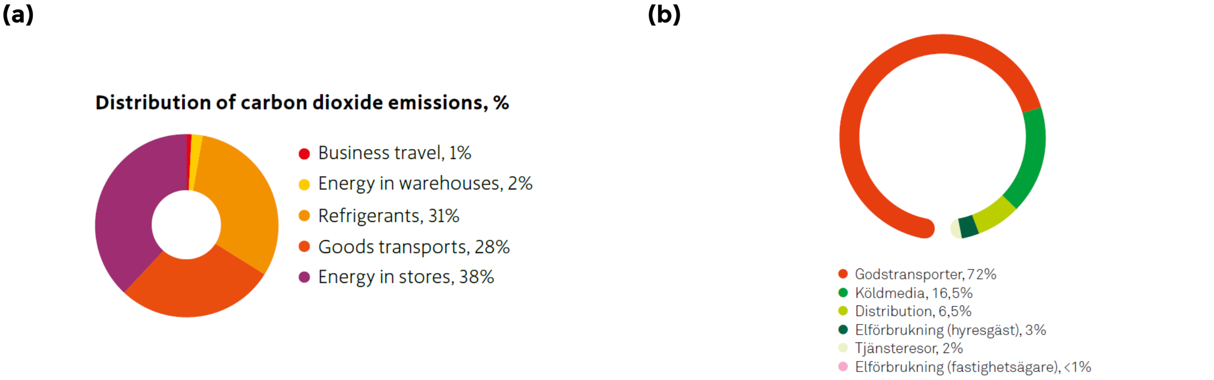

Figure 6: Distribution of carbon emissions of the two largest Swedish supermarket chains, (a) ICA (ICA, 2015) and (b) COOP (COOP, 2015)

According to a report from the European Environment Agency (European Environment Agency, 2012) comparing the greenhouse gas emissions in European countries between 1990 and 2012 "HFCs used in refrigeration and air conditioning were the **only** group of (**greenhouse**) gases for which emissions **increased** since 1990 and accounted for 2.1 % of total EU GHG emissions in 2012. The banning of CFCs by the Montreal-Protocol, both ozone-depleting substances and potent GHGs, led to new substitutes and their replacement with HFCs that are included in the Kyoto-Protocol." As mentioned earlier, supermarkets are one of the major contributors to this GHG emission increase.

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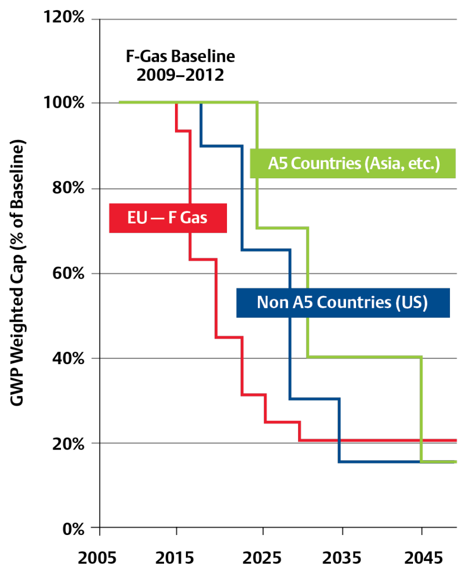
3.1 F-gas Regulation

The discussed significant environmental impacts of supermarkets resulted in some international and EU legislation to limit the amount of fluorinated greenhouse gases emitted to the atmosphere. The latest one is the EU F-gas Regulation on the use of F-gases (EU 517/2014, 2014). This regulation contains a ban to use any refrigerant with GWP higher than 150 for supermarkets centralized refrigeration systems larger than 40 kW from January 2022, with exception for primary cycle in cascade configurations, which are allowed to use refrigerants with GWP up to 1500.

A step-wise reduction plan in the F-gas Regulation is to decrease the GWP related emission, caused by the use of HFCs, by 79 % by 2030 with 2010 as the reference year. A summary of the F-gas Regulation showing this reduction plan is shown in Figure 7. What can be interpreted from the figure is that the present conventional supermarket refrigeration systems are not future long-term solutions.



Service and maintenance bans	GWP	Timing
HFC's	2,500	Jan. 2020
'Placing on the market' (new equipment) bans		
Domestic refrigerators and freezers	150	Jan. 2015
Refrigerators and freezers for commercial use (hermetically sealed systems)	2,500	Jan. 2020
Refrigerators and freezers for commercial use (hermetically sealed systems)	150	Jan. 2022
Stationary refrigeration equipment (except equipment for temperatures below -50 °C)	2,500	Jan. 2020
Multipack centralized refrigeration systems for commercial use with a capacity of $\geq$ 40 kW (140 kBTU/hr) (except in the primary refrigerant circuit of cascade systems, where fluorinated greenhouse gases with a GWP of less than 1,500 may be used)	150	Jan. 2022
Movable room air-conditioning appliances (hermetically sealed equipment which is movable between rooms by the end user)	150	Jan. 2020
Single split air-conditioning systems containing < 3 kg	770	Jan. 2025

Figure 7: An overview of THE EU F-gas Regulation (Emerson, 2015)

Supermarket stakeholders have three options to adapt their business to the recent F-gas Regulation:

- Business as usual, to continue using high GWP HFC refrigerants in their existing refrigeration systems until 2020 and use the reclaimed or recycled gas, if available, until 2030. The challenges/risks associated with this decision are:
  - Stricter leak detection requirements
  - Stricter, and in the near future banned service and maintenance of refrigeration units using HFCs with a GWP above 2500
  - Higher price and lower availability of HFC refrigerants with high GWP
  - Higher price and lower availability of equipment and components working with these fluids
  - Stricter refrigerant recovery and reclamation process

- To convert/retrofit their systems to other new synthetic refrigerants with lower GWP. The major serious risk accompanied by this decision is that these refrigerants can be subject to future environmental regulation, exactly as happened earlier to CFCs, HCFCs and now to HFCs. Examples for these R404A drop-in refrigerants are blends with non-saturated HFCs (also known as HFOs) R448A and R449A with GWP values 1387 and 1397, respectively, which have been introduced to the market in the past few years.

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- To replace their systems or orientation of their business to natural-refrigerant based (CO_2, HCs, NH_3 -cascade unit) refrigeration systems. The investment costs for using these systems are no longer higher than for conventional HFC systems in many Northern-Central European countries and the previously higher operational costs of CO_2 systems used in warm climates decreased or turned into energy savings thanks to the state-of-the-art innovations introduced in chapters 5 and 6. Considering the total cost of ownership and the challenges the other choices face, this option is considered as the only viable long-term solution.

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4 SUPERMARKETS ENERGY SYSTEMS

This chapter introduces the major energy systems in supermarkets. The focus is on cooling and heating systems; the other energy systems, including HVAC and lighting, have been discussed in brief.

4.1 Refrigeration

The purpose of refrigeration systems in supermarkets is to provide storage of and display of perishable food prior to sale. Food is stored in walk-in storages/cold rooms before the transfer to display cases in the sales area. There are two principal temperature levels in supermarkets: medium temperature (MT) for preservation of chilled food and low temperature (LT) for frozen products. Chilled food is maintained between 1°C and 14°C, while frozen food is kept at -12°C to -18°C, depending on the national and international food safety regulations. To provide the desired food temperatures, the refrigerant evaporation temperature range is typically between –15°C and 5°C for the MT level and between -30°C to -40°C for the LT level. Variations in temperature are dependent upon products, display cases and the chosen refrigeration system (IPCC, 2005). The modern refrigeration solutions are designed to keep the refrigeration temperatures as close as possible to the desired food temperatures.

There are typically three types of refrigeration systems in supermarkets, depending on the size of the supermarket and the quantity and type of fresh and/or frozen food products:

- Stand-alone: The other names for this unit are “self-contained” or “plug-in” system. Stand-alone equipment is often a display case where the refrigeration system is integrated into the cabinet and the condenser heat is rejected to the sales area of the supermarket. The function of plug-in equipment is usually to display products like ice cream or cold beverages such as beer or soft drinks. However, in some European discounter stores, all low temperature products are offered in these stand-alone units.

- Condensing units: These systems are small-size refrigeration equipment with one or two compressors and a condenser installed on the roof or in a small machine room. Condensing units provide refrigeration to a small group of cabinets installed in convenience stores and small supermarkets.

- Centralized: the other name for centralized systems is “multiplex”. Centralized systems consist of a central refrigeration unit located in a machine room. There are two types of centralized systems: direct and indirect systems. In a direct system (DX), racks of compressors in the machine room are connected to the evaporators in the display cases and to the condensers on the roof by long pipes containing the refrigerant. In an indirect system, the central refrigeration unit cools a fluid that circulates between the evaporator in the machine room and the display cases in the sales area. This fluid is known by different names, such as secondary refrigerant, secondary fluid, secondary coolant, heat transfer fluid, or brine. Secondary fluid is typically a solution of water with salts or alcohols, which decreases the freezing point of water well below zero.
  As mentioned in chapter 3, centralized systems are the largest consumers/emitters of HFC refrigerants in the EU. This is the reason why different configurations of centralized systems including the conventional and eco-friendly solutions are discussed in detail in section 4.1.1 and chapter 5.

The three types of supermarket refrigeration systems can be categorized as shown in Table 2. Needless to say, the numbers in the table are not exact and are dependent on many factors including country, system design evolution, regulations, etc.

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Table 2: Supermarket refrigeration systems (Kauffeld, 2007) (Kauffeld, 2012)

Type	Application	Capacity (kW)	Refrigerants	Refrigerant charge (kg)	Emission	Global numbers (millions)
Stand-alone	Shops, stores, petrol stations, offices, hotels, …	0,1-2	R22-R134a-R404A-R507A- R290-R600A-R744	0,05-1	Low	~ 50
Condensing unit	Shops, stores, petrol stations, offices, hotels, …	5- >25	R22-R134a-R404A-R507A-R744	1->5	Medium	~ 30
Centralized	Grocery retailers (discounters, supermarkets, hypermarkets, …)	20- >1000	R22-R134a-R404A-R507A- R744 - R290-(R717)	10->3000	High-medium	~ 0,5

4.1.1 Centralized refrigeration systems

The centralized supermarket refrigeration systems can be categorized into two groups based on the dominant refrigerants used in European system solutions. HFC systems can be considered as conventional solutions and CO_2 systems as the more eco-friendly and state-of-the-art ones.

4.1.1.1 HFC systems (Arias, 2005)

- **Direct systems**: The most traditional refrigeration system design in EU supermarkets is the direct system (Figure 8-a). This system comprises two completely separate MT and LT loops. In direct systems of medium-large size supermarkets, the refrigerant circulates in long pipe runs between the compressors in the machinery room, the display cases in the sales area and the condensers on the roof top. This implies very large refrigerant charges. The most common direct system in supermarkets is a centralized system and consists of two racks of compressors, each operating at the same saturated MT and LT suction temperatures. In each rack of compressors, the suction and discharge lines are common. The amount of refrigerant in a centralized direct system is typically 4-5 kg/kW of refrigeration capacity (Baxter, 2003).
Distributed system is another variation of the direct system (Figure 8-b). It is called distributed since there is no centralized compressor rack in the supermarket but several small compressor racks are distributed and located in boxes near the display cases. In such systems, the suction lines of the compressors are much shorter than in the conventional direct system. The discharge line of the compressors is typically connected to a separate rooftop air-cooled condenser. The refrigerant circuits in a distributed system are shorter and the total refrigerant charge will be about 75 % of multiplex systems (Bivens and Cage, 2004).

- **Indirect systems**: Indirect systems were the next generation of supermarket refrigeration systems aiming at decreasing the refrigerant charge and minimizing potential refrigerant leakage. One indirect solution with completely separate MT and LT loops is a "completely indirect system", as presented in Figure 8-c. In this system design, there are two primary and secondary refrigeration cycles with different temperature levels. The supply and return temperature in MT secondary loop is about -8 °C and -4 °C, respectively. Typical values of secondary refrigerant temperature supply and return in the freezers are about -32°C and -29°C. Secondary refrigerants based on potassium formate, potassium acetate, glycols, alcohols and chlorides are commonly used. CO_2 two-phase flow might be used as a secondary refrigerant in the low temperature system, as explained in section 4.1.1.2.

To decrease the usage and leakage of high GWP primary refrigerants, the condensers can be connected to rooftop dry coolers by secondary fluids as well. One or two other secondary loops (coolant fluids or dry cooler fluids) are used in the system to transport the heat rejected from the condensers, located in the machine room, to dry coolers.
Another configuration of indirect systems is the partially indirect system. The schematic of the system is shown in Figure 8-d. The heat from the condensers is rejected by a dry cooler on the roof of the supermarket to the ambient. The low temperature system has a direct system between the compressors and the freezers, and the medium temperature system has an indirect system between the cabinets and the chiller.

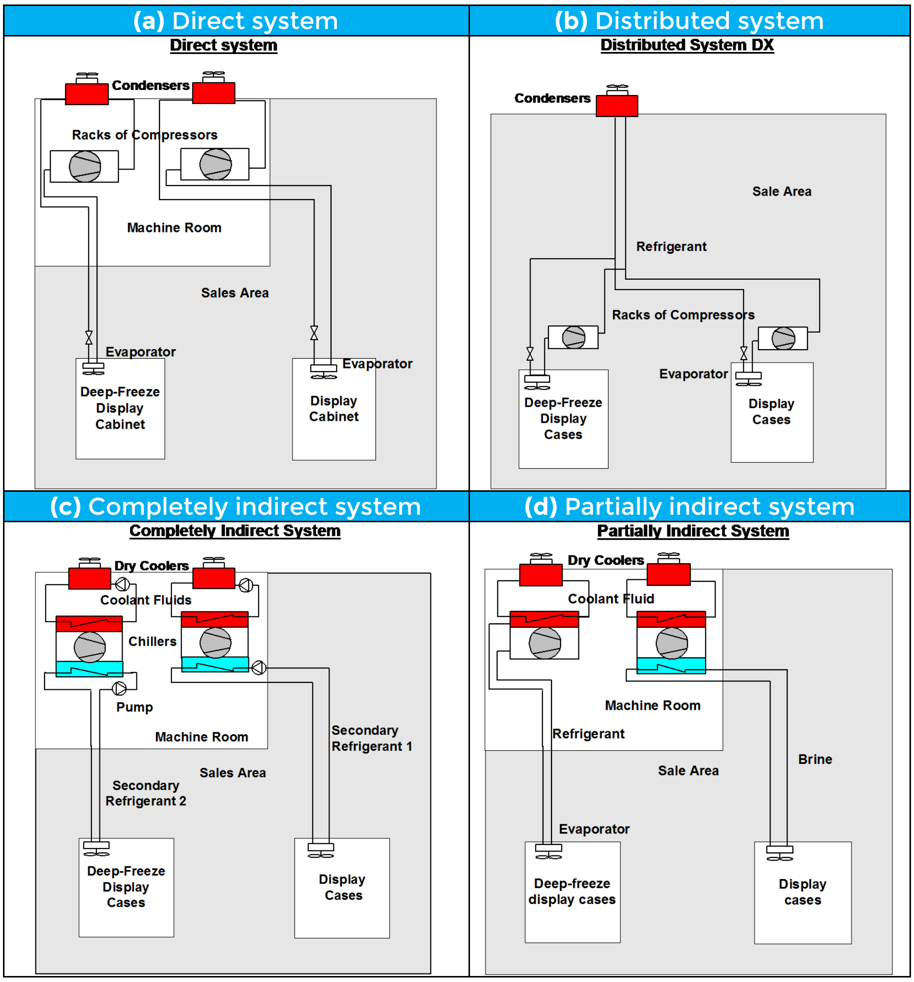

Figure 8: HFC direct and indirect systems (Arias, 2005)

A variation to the partially indirect system is shown in Figure 9. In this system, the MT secondary fluid sub-cools the low temperature loop to improve its poor efficiency. The poor efficiency is due to the high pressure lift of low temperature compressors.

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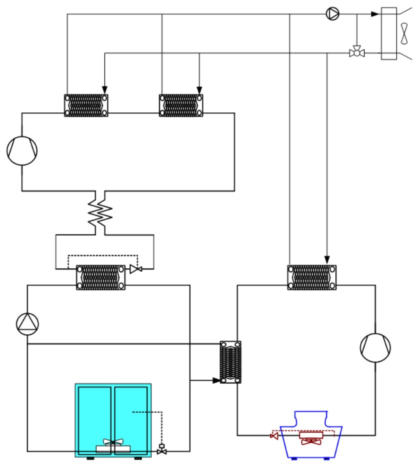

Figure 9: R404A indirect system in MT level and DX in LT level sub-cooled by MT secondary fluid (Karampour et al., 2013)

4.1.1.2 CO_2 systems

- **CO_2 Indirect systems**: as explained in the previous section, the first usage of CO_2 in supermarkets was as a secondary fluid. CO_2 has good heat transfer properties and lower viscosity than conventional secondary fluids. This makes the required pumping power considerably lower than in the conventional indirect systems. Corrosion has been another problem with some of the secondary fluids, which is not a problem in CO_2 indirect systems. CO_2 has been used mainly in LT circuits where pressure is low and suitable components were rather available in early 1990s, after the revival of CO_2 as refrigerant (Lorentzen, 1994). An example of a CO_2 indirect system is shown in Figure 10-a.
  There are several research works investigating the CO_2 indirect system performance and comparing it with traditional HFC solutions. Such studies include (Hinde et al., 2009), (Mikhailov and Matthiesen, 2010) and (Poland et al., 2010).

- **CO_2 Cascade systems**: the second generation of CO_2 systems were cascade systems. In this configuration CO_2 can be used in both MT and/or LT levels but the absorbed heat is rejected into an upper cycle. In the upper cycle, different types of refrigerants, which may have safety/environmental problems when used in the sales area, can be used. These include HFCs (leakage of high GWP refrigerant), ammonia (toxicity) and hydrocarbons (flammability). This system solution was the first one which gave the opportunity to install system solutions completely based on natural refrigerants. One drawback of cascade systems is the intermediate cascade heat exchanger and the temperature difference created by this heat exchanger. This "extra" heat exchange stage decreases the energy efficiency and the heat exchanger can be expensive. However, CO_2 cascade system can be a good solution for warm climates, **if** the safety regulations permit the use of HCs or NH_3 in the high-temperature stage. This way, CO_2 in the low stage for MT and LT refrigeration never operates in supercritical pressures.
  System description and performance analysis of various supermarket cascade configurations have been elaborated more by (da Silva et al., 2012) and (Sawalha, 2008).
  An example of a CO_2 cascade system is shown in Figure 10-b.

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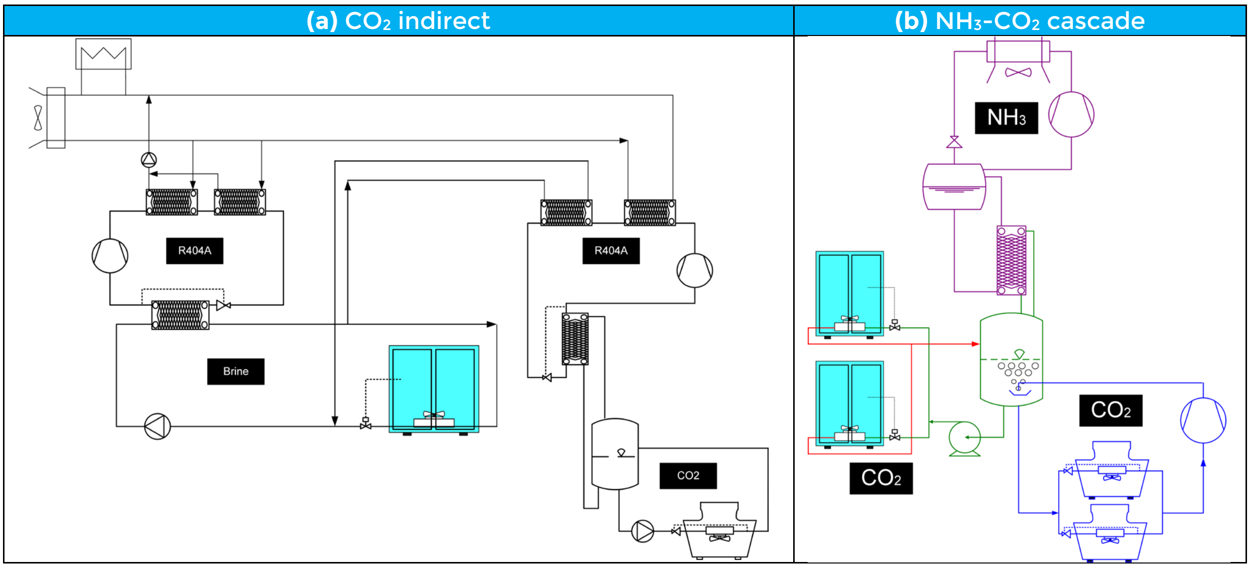

Figure 10: Examples of CO_2 indirect and cascade systems

- **CO_2 transcritical booster system**
  The latest refrigeration system using CO_2 as the refrigerant is the CO_2 transcritical booster system. A simple schematic of a CO_2 transcritical booster system and its pressure-enthalpy diagram is shown in Figure 11. This system is an only-CO_2 solution which provides cooling in the MT cabinets and LT freezers. The system is considered as one of latest developments towards using climate friendly refrigerants in European supermarkets. System's independency of using other refrigerants such as HFCs, ammonia or hydrocarbons in indirect or cascade configurations results in reduced negative environmental impact (compared to HFC-based solutions) and increased safety (compared to NH_3-HCs). The system which is described in this section is considered as the "standard" CO_2 transcritical booster system, however, there are several newer modifications and improvements on this system which are discussed in chapter 5 of this report. Newer generations of CO_2 system are presented in chapter 3 of the SuperSmart report D2.3 (Kauko et al., 2016).

  There are numerous research works based on computer modelling or real-world field measurement analysis which have shown that CO_2 transcritical booster systems have either higher or comparable COPs to conventional HFC systems in mild-cold climates:

  - Studies with computer modelling: the following research works show the privilege of using CO_2 systems over HFC ones in mild-cold ambient temperatures, typically lower than about 25 °C ambient temperature (Cecchinato et al., 2012) (Mikhailov and Matthiesen, 2013) (Sharma et al., 2014a).
  - Studies with analysis of field measurements:
    - Sweden: Performance comparison of five CO_2 and three advanced R404A systems revealed that modern CO_2 systems have higher or comparable total refrigeration COPs compared to HFC systems in Swedish climate conditions (Karampour et al., 2013). The details of CO_2 system evolution from older less efficient ones to newer more efficient ones have been discussed by Sawalha et al. (2015).
    - USA: the performance of the first CO_2 transcritical booster system in the USA was compared with a standard DX R407A solution. The two systems had identical boundary conditions including refrigeration loads and northeastern US climate conditions. The authors concluded that the two systems have nearly equal electricity use for refrigeration; the CO_2 system consumes up to 14 % more electricity in summer months, however, up to 18 % less in winter months (Weber and Horning, 2015).
    - Europe: Some researchers have compared the CO_2 and HFC system solutions based on specific (linear) energy use of the refrigeration system per meter of display case and year. In one of these studies, it was found that the average specific energy use value is

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about 5000 kWh/m·a for 103 European stores using HFC refrigerants, while it was about 3500-4000 kWh/m·a for 11 stores which use CO_2 as the refrigerant in the medium and low temperature levels. According to the EU "best environmental management practices in the retail sector", a benchmark of excellence is achievable for specific linear energy use of less than 3000 kWh/m·a (Galvez-Martos et al., 2013).

- Germany: a field measurement study showed that the CO_2 system has higher energy efficiency than standard and optimized R404A systems in ambient temperatures lower than 25 °C and 21 °C, respectively (Finckh et al., 2011).

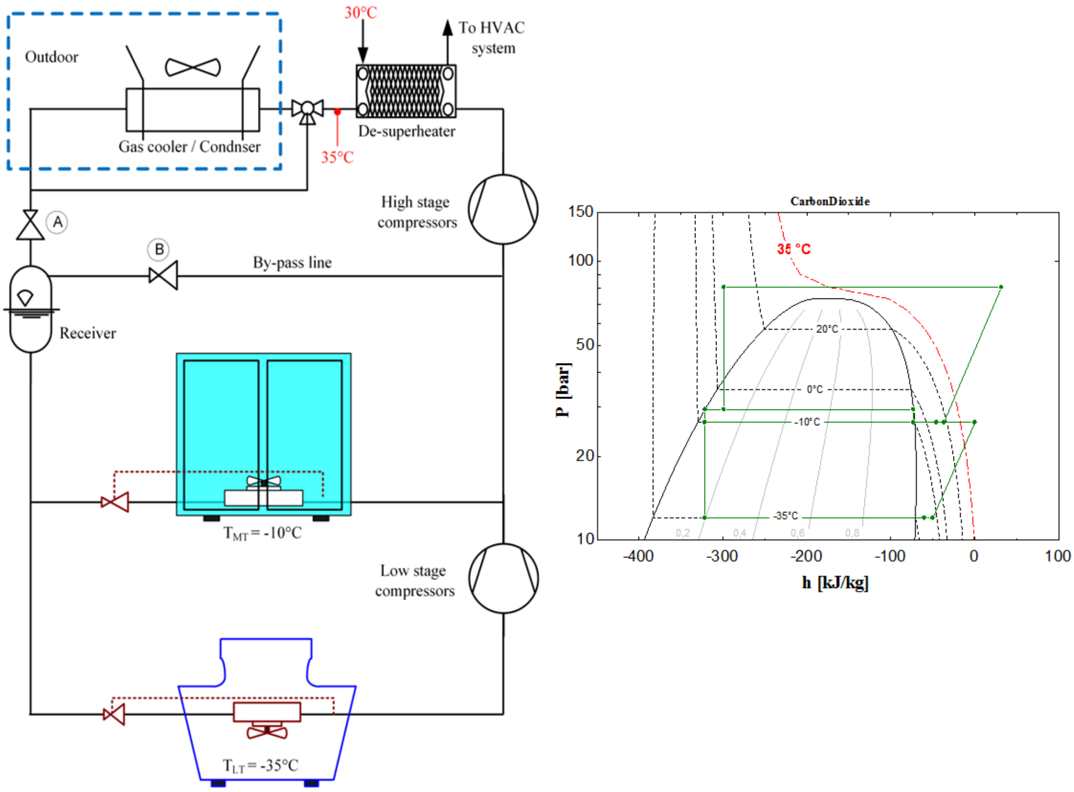

Figure 11: CO_2 transcritical booster system schematic and CO_2 transcritical booster P-h diagram

System refrigeration process

As shown in Figure 11, CO_2 enters a receiver after the gas cooler/condenser. The liquid and vapour streams are separated in the receiver. The liquid is fed to the MT and LT evaporators. CO_2 evaporation temperatures in medium temperature level and low temperature level are shown, as an example, to be -10 °C and -35 °C, but the state-of-the-art CO_2 booster systems have a few degrees higher evaporation temperatures.

The vapour from the LT evaporators is compressed by the LT "booster" compressors and mixed with vapour outlet from MT evaporators and vapour from the by-pass line of the receiver. The mixture of these three streams is compressed in the high stage compressors to the high pressure level.

The high pressure level is controlled by the high pressure expansion valve "A". The system can be run in subcritical or transcritical zones depending on ambient temperature and whether floating condensing pressure or heat recovery mode is used.

Heat can be recovered in the de-superheater which is a heat exchanger after the high stage compressors and before the condenser/gas cooler. There is, in this case, a loop transferring the heat from the de-superheater to the HVAC system. The return temperature of the heat transfer fluid, from HVAC to the de-superheater, is recommended to be as low as possible. The return temperature from

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the heating system is shown as 30 °C, a typical value for supermarkets working with low temperature heating radiators, and with 5 K approach temperature, CO_2 temperature after the de-superheater is about 35 °C. The function of the gas cooler by-pass line and the three-way valve before it is explained in section 4.2.4.

When the heating demand is low, for example in summer, the system runs in floating condensing mode. This means, the gas cooler pressure follows the ambient temperature in subcritical region. In the transcritical region, the system should be run based on an "optimum pressure algorithm" to maximize the COP of the refrigeration system. Such optimum pressure algorithms have been studied for instance by Liao et al. (2000), Sawalha (2008) and Chen and Gu (2005).

The CO_2 transcritical booster system is considered as the standard system solution for new supermarkets in some European countries, including Scandinavia. Figure 12 shows the status of the number of supermarkets in Europe and in the world using CO_2 transcritical booster systems. This is over 5500 stores in Europe and more than 7200 stores worldwide (Shecco, 2016). According to authors communication with natural refrigerants market analysers at Shecco company the numbers of stores in Europe is increased to 8700 stores, as of September 2016. The modifications and improvements in the standard system design including CO_2 integrated systems and warm climate solutions are discussed in chapter 5.

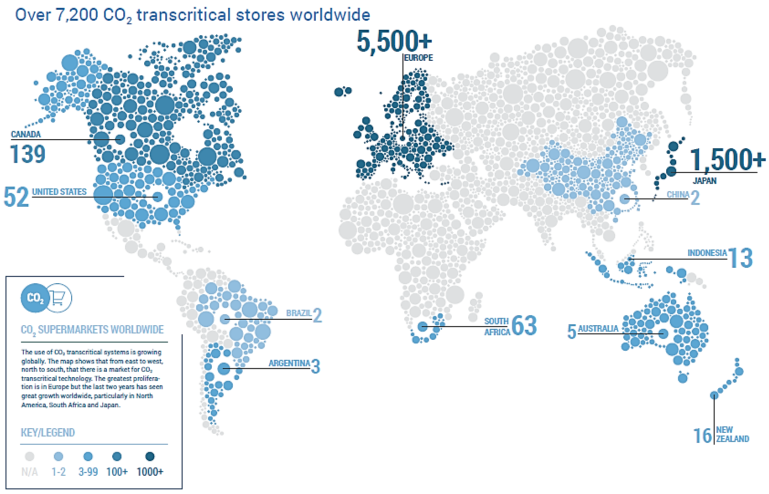

Figure 12: Worldwide map of the stores using CO_2 transcritical booster (Shecco, 2016)

4.2 Heating

4.2.1 Heating demand in supermarkets

Supermarkets have a rather wide range of heating demands, including space and tap water heating. Space heating is required in the sales area, offices and back rooms for customer and personnel thermal comfort. Tap water heating is required for early morning preparation of prepared meals and late night cleaning of the supermarket before closing. Another usage of heating in cold climate countries is to melt the snow and protect the soil/ground from freezing in the entrance zone or car parking area. The typical heating distribution systems and the delivery temperature are shown in Table 3.

Table 3: Typical delivery temperatures for various heating distribution systems (BRESEC, 2007)

Demand	Distribution system	Delivery temperature (°C)
Space heating	Water: Floor heating	30-45
Space heating	Water: Low temperature radiators	45-55
Space heating	Water: Conventional radiators	60-90
Space heating	Air: air handling units	30-50
Tap water heating	Water	55-65
Ground freeze protection/snow melting	Water/secondary fluids	10-20 [5]

4.2.2 Heating systems in supermarkets

Generally, and where needed, the sales area is heated by warm air provided by a centralized air handling unit (AHU). This is mainly the case for medium-large size supermarkets. Stand-alone or distributed smaller heating systems are used in smaller supermarkets. There are few examples of Nordic supermarkets using floor heating, but it is not installed in the refrigerated zone of the supermarket. The offices and back rooms can be heated by air or hydronic systems including radiators.

The heating can be provided by boiler/condensing boiler, electric heater or district heating but the most energy-efficient, cost effective and environmentally friendly method is to use primarily the waste heat rejected by the refrigeration system through the condenser and/or de-superheater (if available). The amount of heat pumped by the refrigeration system can cover a great share of the heating demand, sometimes even more than the supermarket needs. An example of proper heat recovery is the “open district heating” project running in Stockholm where a number of supermarkets and data centres recover and sell their excess heat to the city district heating network (Fortum, 2016). COOP Rådhuset supermarket in Stockholm is one of these supermarkets using a CO_2 booster system to provide supermarkets heating demand and sell the extra heat (COOP, 2016).

The conventional and more eco-friendly heating systems in supermarkets can be categorized as follow:

- Space Heating: conventional systems
    - Boiler/condensing boiler
    - District heating
    - Electric heating

- Space heating: more eco-friendly options
    - Refrigeration heat recovery
    - Heat pumps: ground source, air source, water source
    - Ventilation exhaust air heat recovery by heat recovery wheel
    - Co-generation/tri-generation of electricity, heating and cooling

[5] Added to the list by author.

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- Tap water heating: conventional systems
    - Boiler/condensing boiler
    - Electric heater
    - District heating (depending on the delivered temperature)

- Tap water heating: more eco-friendly options
    - Refrigeration heat recovery: CO_2 and NH_3 systems with high discharge temperatures
    - High temperature heat pumps: ground source, air source, water source
    - Solar thermal panels

4.2.3 Heat recovery

Heat recovery from the refrigeration system is one of the most efficient ways to increase the total efficiency of the refrigeration system and to decrease the heating purchase demand. There are several methods available to reclaim the waste heat, depending on the system design and the refrigerant. Some examples of heat recovery systems are shown in Figure 13.

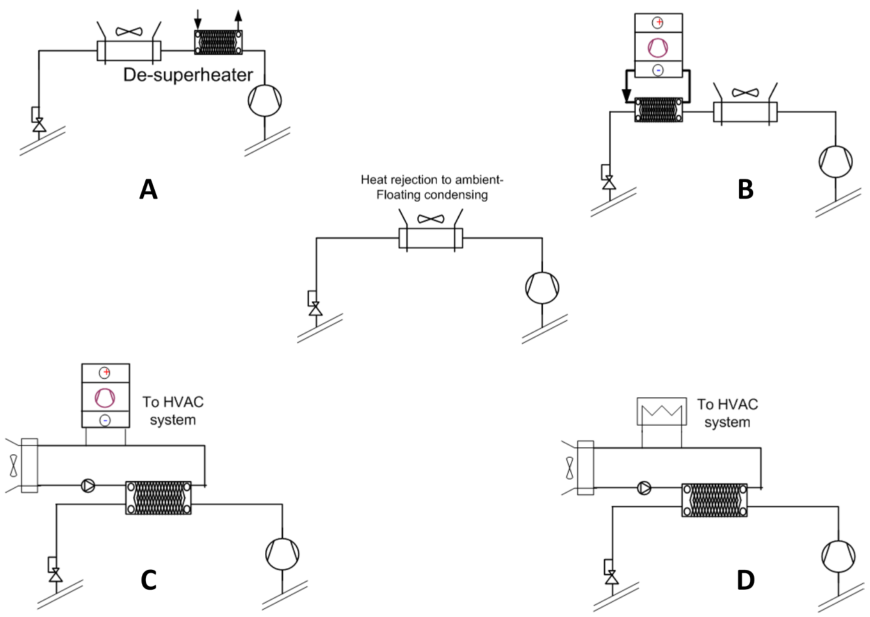

Figure 13: Configurations of heat rejection and heat recovery from a refrigeration system (Sawalha, 2013)

- **Middle layout-reference system**: No heat is recovered from the refrigeration system and the heat is rejected to the atmosphere. The running mode is called floating condensing as the condensation pressure follows the ambient temperature. The entire heating demand should be provided by a separate heating system including boiler/condensing boiler, district heating, electric heater, heat pump, etc.
- **Top-left layout (A):** heat is recovered in the de-superheater. This system is suitable when the discharge temperature is relatively high, for example in NH_3 or CO_2 refrigeration systems. The regulating valve after the condenser/gas cooler adjusts the discharge pressure and, consequently, the de-superheater heating capacity.
- **Top-right (B) and bottom-left (C) layouts:** these are two heat pump cascade solutions. In the C layout, heat is recovered from the condenser and delivered to a heat pump as low grade heat. This way, the refrigeration system is not required to run with high discharge pressures. Solution B (heat pump cascade for sub-cooling) is similar to the heat pump cascade but the heat is recovered in a sub-cooler after the condenser. This increases the efficiency of the refrigeration system simultaneously by decreasing the condenser/gas cooler outlet temperature.
- **Bottom-right layout (D)** is a fixed-head pressure heat recovery system. The discharge pressure is fixed according to the HVAC system supply temperature demand. There is a

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coolant/secondary fluid which transfers the heat from the condenser to the HVAC system (Sawalha, 2013).

4.2.4 Heat recovery in CO_2 transcritical booster system

CO_2 transcritical booster systems are one of the most energy-efficient systems in terms of heat recovery. The main reason for this fact is that by increasing the discharge pressure and switching from subcritical to transcritical zone, the amount of available heat increases considerably in CO_2 systems. To achieve an efficient heat recovery process and increase the heating capacity from the CO_2 booster system, a step-wise control of the refrigeration system is recommended. The steps are briefly described here but can be read more in detail in (Sawalha, 2013) and (Madsen and Bjerg, 2016):

- Step 1: Gas cooler should be run at full capacity to provide the highest sub-cooling possible[6] – discharge pressure should be regulated to be able to cover the heating demand.
- Step 2: Discharge pressure should be fixed to a "max optimum" value and gas cooler capacity should be decreased by the following steps:
    - Step 2-1: Fan speed should be slowed down.
    - Step 2-2: Fans should be switched off.
    - Step 2-3: Gas cooler should be by-passed, via the three-way valve and the gas cooler by-pass line shown in Figure 11.

The "max optimum" discharge pressure value which is mentioned in step 2 is found based on the optimum discharge pressure algorithm mentioned in section 4.1.1.2 but instead of using gas cooler exit temperature for the regulation, de-superheater exit temperature should be used (Sawalha, 2013).

There have been several studies highlighting the importance and advantages of heat recovery in increasing the total efficiency of CO_2 transcritical booster system:

- **Studies with computer modelling:**
    - Reinholdt and Madsen used computer simulation to investigate the heat recovery strategies from a CO_2 booster system (Reinholdt and Madsen, 2010). Maximization of refrigeration COP or the amount of recovered heat are used as two strategies to optimize the energy efficiency and to cover the supermarket heating demands including traditional space heating, domestic hot water heating, hot water for hygienic cleaning and floor heating. They concluded that heat recovery is an appealing choice to increase the total efficiency of the CO_2 system.
    - Tambovtsev et al. developed a bin temperature analysis method to compare the heat recovery from CO_2 booster system and traditional electric heating in supermarkets (Tambovtsev et al., 2010). The study showed significant savings in the supplied heating energy if a high efficient integrated CO_2 system, using gas cooler by-pass and optimally tuned control algorithms, is implemented. (Tambovtsev et al., 2011).
    - Sawalha used computer simulation to investigate the performance of a CO_2 transcritical system with heat recovery from de-superheater (Sawalha, 2013). As mentioned earlier, a multi-step control strategy is recommended to maximize the total COP of the CO_2 system. The study showed that the CO_2 transcritical booster system with heat recovery has lower annual energy consumption in an average size Swedish supermarket compared to a conventional R404A refrigeration system with separate heat pump for heating needs. Karampour and Sawalha simulated the hourly performance of a CO_2 transcritical booster system over a year, following the recommended heat recovery control strategy (Karampour and Sawalha, 2014). It has been shown that a seasonal performance factor (SPF) of four can be achieved; a number comparable with the majority of the available commercial heat pumps in the market.
    - Nöding et al. highlighted the importance of thermal storage (hot water tank) in heat recovery control by adapting an "optimal operation strategy" (Nöding et al., 2016). It has been concluded that using thermal storage will help in time-wise decoupling of the

[6] Minimum gas cooler exit temperature must not fall below +5 °C, otherwise the required receiver pressure cannot be maintained.

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heating demand and heat production. This implies that the system can be run with highest heat recovery COPs/minimum specific heating cost and the stored heat can be used when necessary. Savings of 8.5 % and 13.1 % comparing to a reference mode were reported when adapting this strategy for a typical and a cold January day in Braunschweig, Germany. The reference mode is defined as the case where heat recovery and heat demand are equal in every point of time.

- **Studies with analysis of field measurements:**
  - Tambovtsev et al. examined a heat recovery strategy focusing on gas cooler by-pass in a German supermarket (Tambovtsev et al., 2011). It has been indicated that using the gas cooler by-pass can increase the total COP of the CO_2 system by 20 %.
  - Rehault and Kalz analysed the heat recovery from a CO_2 refrigeration system in another supermarket in Germany (Rehault and Kalz, 2012). The CO_2 system used a parallel compressor connected to a ground thermal storage as the auxiliary heater in parallel with heat recovery from the refrigeration system. It was shown that up to 50 % of the heat rejected by the de-superheater was recovered in the cold months.
  - Funder-Kristensen et al. presented a case study of a supermarket replacing the gas heating system with heat recovery from CO_2 transcritical booster system (Funder-Kristensen et al., 2013). It was shown that the CO_2 system was able to provide the entire heating demand of the supermarket.

Some examples and cases of supermarket refrigeration system with heat recovery are presented in chapter 6.

4.3 Ventilation

A ventilation system distributes and provides outdoor air to the customers and personnel of the supermarket. It is also essential for maintaining the quality of the products. Furthermore, it provides the required air change rate to limit the concentration of pollutants, smell, mould, fog and bacteria.

Supermarkets have a unique mix of several different thermal zones under one roof. Each of the zones have unique thermal and air flow demands. Simultaneously, most of the thermal zones are not isolated and interact and affect each other. This makes the design of the ventilation system a complex task. The supply of the required air with a proper temperature level and flow rate is not the only complex part of the design. The zones which are supplied more with the outdoor fresh air, such as the sales area, should be pressurized to force the air to migrate to the zones which produce exhaust gases, such as the supermarket kitchen or bakery.

High volume flow rate of outdoor air intake means both high fan power consumption and more need for pre-treatment of the outdoor air, such as higher need for heating the air in winter time. This is the reason why it is recommended to minimize the air intake. A minimum air intake flow rate ranges between 0.3-1 cfm/ft^2 [1.5-5 $lit./s{\cdot}m^2$] (Clark, 2015).

The conventional ventilation systems are constant volume air distribution systems, which have generally high energy consumption. There are some options to make ventilation systems more energy-efficient and, consequently, eco-friendly:

- Demand control ventilation, for example based on CO_2 PPM (parts per million) level
- Minimum air intake and maximum reuse of exhaust air in winter
- Air curtain at the entrance
- Exhaust air thermal/heat recovery wheel
- Clark (2015) conducted a comprehensive modelling study on supermarket HVAC Energy Efficiency Measures (EEMs) and identified the three best ones as (I) reduction of exhaust requirements, (II) improvement of outdoor air delivery method and (III) improved dehumidification system. Dehumidification has been elaborated in section 4.5 of this report.

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4.4 Air conditioning

Air Conditioning (AC) cools and controls the temperature level in supermarkets. The size and type of this system is dependent on the supermarket size; it ranges from small units, for example moveable plug-in ones, to large stationary central AC systems. Two major categories of AC systems in the supermarkets are "packaged systems" where all components are built into a single casing and "split systems" where essential components are built into several casings. Split systems can be ducted or non-ducted. Some AC systems are reversible; this means they have the possibility to reverse the cycle flow direction and can hence be converted into a heat pump during cold months (Gschrey and Zeiger, 2015).

Stationary air conditioners are also large consumers of HFC refrigerants in Europe (Figure 5) and they will be affected by the EU F-gas Regulation as shown in Figure 7. R134a, R410A and R407C are the dominant refrigerants used in European AC systems. A recent trend is to use R32 as a refrigerant with a lower GWP value.

In addition to the traditional HFC-based AC solutions, natural refrigerant based systems are also available in the market. Many good case studies and examples of NH_3 or hydrocarbon chillers can be found in http://www.hydrocarbons21.com/ and http://www.ammonia21.com/. Furthermore, there are a few studies of CO_2 air conditioners (reversible heat pump) (Girotto, 2016), (Minetto et al., 2016).

Another interesting AC system solution introduced to the market a few years ago is integration of AC into the CO_2 booster refrigeration system. This is a very recent technology, and there are research works ongoing to investigate whether the AC function of this integrated solution is more efficient than an isolated HFC-based AC system or not. Karampour and Sawalha (2015) have found that the COP of air conditioning in an integrated CO_2 system is higher than in an isolated HFC-based AC system for ambient temperatures lower than 25 °C. This integrated system is described more in detail in chapter 5. Examples and performance analysis of commercial systems using this CO_2 integrated solution for AC have been presented in different studies including (Kallesoe, 2013), (Hafner et al., 2016) and (Karampour and Sawalha, 2016a).

4.5 Dehumidification

High humidity in supermarkets has several disadvantages. These include:

- Frost formation on the evaporator coils, less efficient heat transfer process, demand for lower evaporation temperatures, higher compressors power consumption
- Higher de-frost demand, more de-frost cycle tripping, more energy consumption for de-frosting and loss of products quality due to frequent de-frosting cycles
- More formation of condensate/ice on the cabinets' glass lids, higher anti-sweat heating demand, and higher energy consumption. Glass lid invisibility can affect the sales, as well.
- More formation of condensate or ice on products, product quality loss

However, despite all these mentioned disadvantages, a surprising fact is that the majority of supermarkets is not supplied with a dehumidification system of any kind. The humidity control is usually done by introducing excess dry outdoor air, or the open cabinets/freezers play the role of the dehumidification system. Neither of these methods can be considered as energy-efficient solutions.

As pointed out by Arias (2005) "many research works have tried to quantify the effect of reduced space humidity on refrigeration energy use". Kosar and Dumitrescu (2005) have summarized some of these research works, providing measured ranges of 3–21 % reduction in compressor energy use with a 20 % relative humidity (RH) reduction in the space, a 4–6 % reduction in defrost energy, and a 15-25 % reduction in anti-sweat heater energy.

To dehumidify the air, two primary solutions are available. The first one is to cool the humid air below its dew point. This leads to condensation of a part of the water content. For cooling the air, a branch of cold refrigerant/brine stream from the refrigeration system or a separate refrigeration system can be

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used. This dehumidification process is illustrated in Figure 14-a. Dehumidification by condensation can be integrated with the ventilation or refrigeration system.

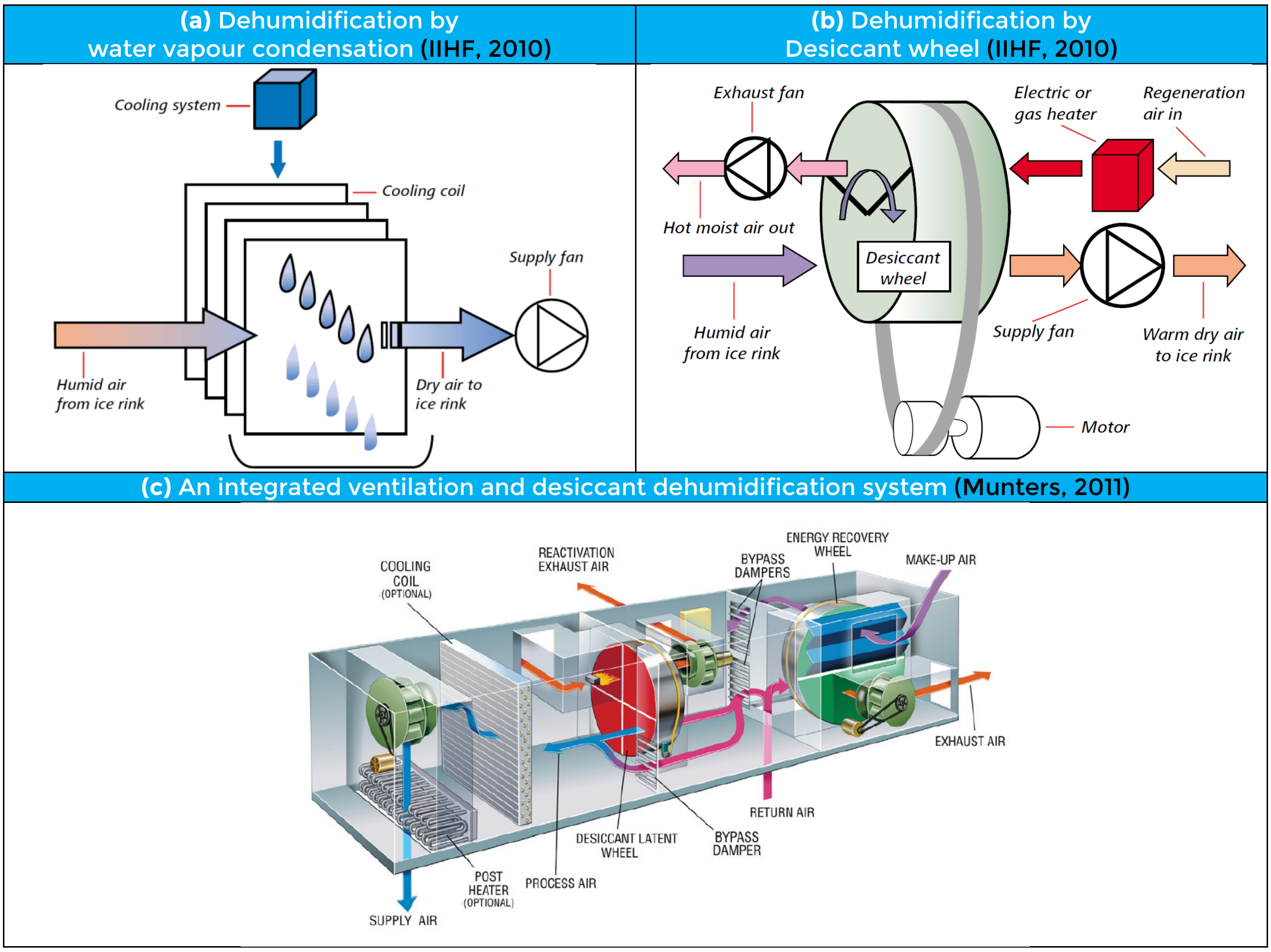

Figure 14: Commercial dehumidification systems (shown for ice rink application)

The second method is to use water absorbing materials like silica gel. The most well-known equipment which uses this technique is called desiccant wheel, shown in Figure 14-b. Desiccant wheel is the major component in a desiccant dehumidification system. It is a slow rotating wheel containing some absorbent chemicals, normally silica gel. When moist air passes one portion of the wheel, the moisture is absorbed. While it is rotating, in other portion of the wheel a hot drying air is blown to the wet absorbent to dry and "regenerate" it. In this system, the desiccant wheel plays the role of a "moisture transporter"; extracts the moisture out from the supply air and transports it to the exhaust air.

The hot drying air can be produced by different heating systems mentioned in section 4.2 but the most eco-friendly solution is to use refrigeration heat recovery, for example by CO_2 systems which can provide the high temperature demand for the regeneration. Such a system with CO_2 heat recovery for regeneration has been studied through computer modelling by Sharma et al. (2014b).

A simple desiccant dehumidification system is shown in Figure 14-c. Desiccant dehumidification systems can be integrated with an air handling unit (AHU) of the ventilation system.

4.6 Lighting

Lighting is not in the scope of this report, but as it is one of the important energy systems in the supermarkets, some good references for further reading are given:

- "Key opportunities for energy saving" (Carbon Trust, 2013).
- Efficient lighting has been discussed in section 2.1.6.7 in (Schöenberger et al., 2013).
- Some technical recommendations on the use of natural and artificial lighting have been presented in a document by the US Environmental Protection Agency (Energy Star, 2008).
- Spanish Research Centre for Energy Resources and Consumption (CIRCE) has studied some energy efficiency measures and discussed the pros and cons of using LED lighting (CIRCE, 2015).
- In another deliverable of the SuperSmart training series (D2.3: How to build a new energy-efficient supermarket, section 2.3), LED lighting has been discussed in more detail (Kauko et al., 2016).

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5 STATE-OF-THE-ART SUPERMARKET REFRIGERATION SYSTEMS

This chapter expands the introduction to supermarket refrigeration systems given in section 4.1, and it will elaborate more on state-of-the-art innovative and eco-friendly refrigeration systems. The focus will be on the CO_2 transcritical booster system since it is considered as the latest eco-friendly and energy-efficient system.

The standard CO_2 transcritical booster system described in chapter 4 is experiencing two major trends aiming at spreading and accelerating the usage of this system across Europe.

The first trend is to integrate heating and air conditioning systems into the CO_2 refrigeration system. This system is an integrated, all-in-one environmentally friendly and compact solution. However, as the single-purpose system is converted into a multi-function system, the fine-tuning of the control system becomes more important. The system has been reported to be able supplying the entire or a great share of heating (space heating and tap water heating) and AC demands, to be shown in the case studies and examples of chapter 6.

Heat recovery from this system has been discussed in section 4.2.4. AC is the latest function added to the CO_2 refrigeration system. This is done by adding a heat exchanger before the receiver, as shown in Figure 15 or by adding a heat exchanger connected to the liquid compartment/exit liquid line of the receiver, as shown in figure 6 of D2.3 (Kauko et al., 2016). The forward and return temperatures of the water or secondary fluid in this AC heat exchanger are typically about 7 and 12 °C, respectively. Proper control of the receiver pressure guarantees a stable CO_2 evaporation temperature in the AC heat exchanger. Examples of such an integrated system are presented in chapter 6.

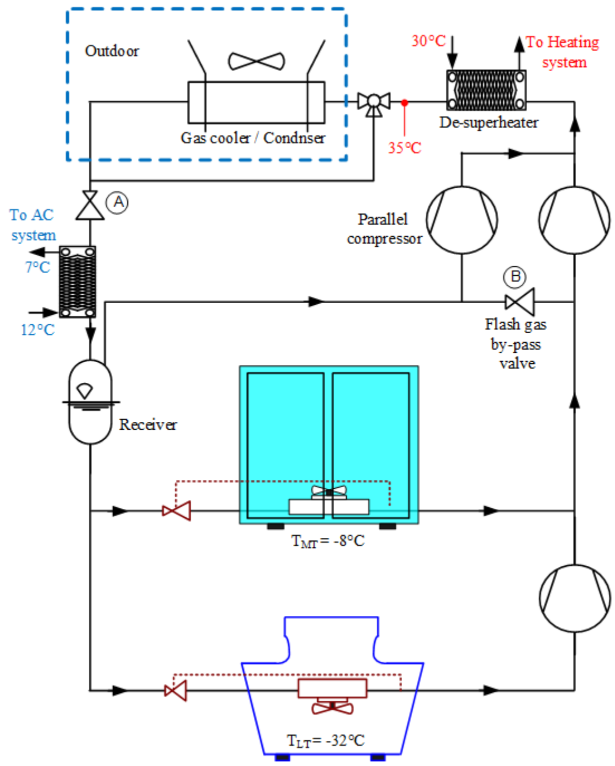

Figure 15: Schematic of an integrated CO_2 refrigeration system with heat recovery, AC and parallel compression

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The second trend in this field is the advent of innovative solutions to improve the performance of standard CO_2 transcritical booster system, mainly in warm climates. Some methods to increase the energy efficiency of the system CO_2 are as follows:

- **Parallel compression:** Parallel compression (PC) is used to compress the flash gas vapour directly from the receiver to the high pressure side, instead of the less efficient expansion to MT pressure level. A parallel compressor is shown in Figure 15. Different research works based on computer modelling have concluded that parallel compression can improve the energy efficiency of CO_2 booster systems significantly (by 10-15 %) (Javerschek, 2015), (Karampour and Sawalha, 2015), (Hafner et al., 2014c), (Minetto et al., 2014b).
  Integration of AC to CO_2 systems is generally recommended to be accompanied by PC. In a field measurement analysis, it has been shown that AC delivery is 25 % more efficient when using parallel compression instead of standard flash gas by-pass (Karampour and Sawalha, 2016a).

- **Ejector:** A drawback of using CO_2 systems in warm climates (transcritical operation) is high throttling losses in high pressure expansion valves. Ejectors are used to recover part of the expansion losses and convert it to work for pre-compressing CO_2 before the compressors suction line (vapour ejectors) or to allow higher evaporation pressures in flooded evaporators (liquid ejectors). Ejector systems are explained more in detail in the SuperSmart report D2.3, in section 2.2.1 (Kauko et al., 2016). Various computer simulation and field measurement analyses show that a multi-ejector device can improve the system efficiency up to 20 % (Hafner et al., 2014a), (Schönenberger et al., 2014), (Hafner et al., 2014b). Some experts in the field believe that ejector technology is the solution to remove the "CO_2 efficiency equator", the term used to point out the climate conditions at equal energy efficiency of CO_2 systems compared to conventional units.

- **Flooded evaporators:** A direct result of using liquid ejectors is to make the system able to operate its evaporators with no superheating. This means better usage of the evaporator heat transfer area, and as a consequence, higher evaporation temperatures. A rough estimation for energy efficiency is 2-3 % increase in COP for each degree of higher evaporation temperature. Minetto et al. (2014a) reported a 13 % decrease in compressor power consumption by over-feeding an evaporator with the help of an ejector.

- **Mechanical sub-cooling:** Sub-cooling has a significant positive impact on refrigeration COP in CO_2 systems. But it is a challenge to provide enough sub-cooling by the gas cooler in warm summer days. One technique applied in some southern European supermarkets is to install a separate refrigeration system for sub-cooling the CO_2 cycle. This technique is known as mechanical sub-cooling and HCs or NH_3 can be used in the sub-cooler to have an eco-friendly solution. Mechanical sub-cooling can be set to be activated only in warm climate conditions. Different research works reported significant COP improvements for CO_2 systems applying mechanical sub-cooling in warm conditions. These include computer modelling works (Hafner et al., 2014b), (Gullo et al., 2016), laboratory tests (Llopis et al., 2016) and field measurements (see section 6.6). However, the energy efficiency gains versus the expenses of using an extra unit for sub-cooling should be investigated in the design stage.

- **Evaporative cooling:** Another method for warm climates, to avoid operating the refrigeration system at elevated transcritical discharge pressures, is to spray water in the inlet air stream to the gas cooler. This way the system gets less affected by the peak outdoor temperatures. The evaporative cooling is activated when the outdoor temperature is higher than 30-35 °C. More on the use of evaporative cooling can be read in articles by (Girotto and Minetto, 2008) and (Lozza et al., 2007). This technique is not applied widely due to water availability, water treatment, scaling and corrosion issues.

- **Thermal storage:** long-term seasonal storage (summer-winter) has been used in several Northern and Western European supermarkets in the past few years. Comparing with ambient temperature, ground temperature is rather constant throughout the entire year. Therefore, it can be used as a heat sink for sub-cooling in summer time and as a heat source for heat pumping in winter time.
  Short-term thermal storage (day-night) is mainly used in the heat recovery side of CO_2 systems where heat is stored in hot water tanks. Thermal storage in the cold side of the refrigeration cycle is less developed in supermarket refrigeration. Using phase change materials (PCM), water

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or ice-water have been studied widely (Heerup and Green, 2014), (Fidorra et al., 2015), (Abdi and Ohannessian, 2014); however, large storage volumes comparing with marginal energy-saving has been a hinder for large-scale commissioning of short-term thermal storage in the cold side. More on thermal storage can be read in section 3.6 of "D2.3: How to build a new eco-friendly supermarket" (Kauko et al., 2016).

Figure 16 shows some examples of the above-mentioned state-of-the-art features: the heat discharged in the high stage compressors is recovered for tap water heating and space heating in two de-superheaters. The gas cooler has an evaporative cooling option for very warm summer days. The sub-cooler after the gas cooler is connected to a ground thermal storage. The heat stored in the ground can be extracted and upgraded by the parallel compressor or a separate heat pump. The high pressure fluid after the sub-cooler is the driving/motive force for the liquid ejector. The suction side of the ejector is connected to a liquid accumulator which allows the MT evaporators running in flooded condition. A heat exchanger after the ejector is connected to the HVAC system to provide the AC demand. The AC evaporation temperature corresponds to the receiver pressure which is controlled by parallel compressors or the flash gas by-pass valve. The last component added to the standard system is an LT de-superheater after booster compressors to recover heat in winter and/or de-superheat LT discharge gas in summer.

It is necessary to mention that this system is not necessarily the ultimate energy-efficient solution and many parameters influence the choice of the best energy efficiency measures. These influencing parameters include interactions between these innovative solutions, climatic conditions and the magnitude of the system cooling/heating loads.

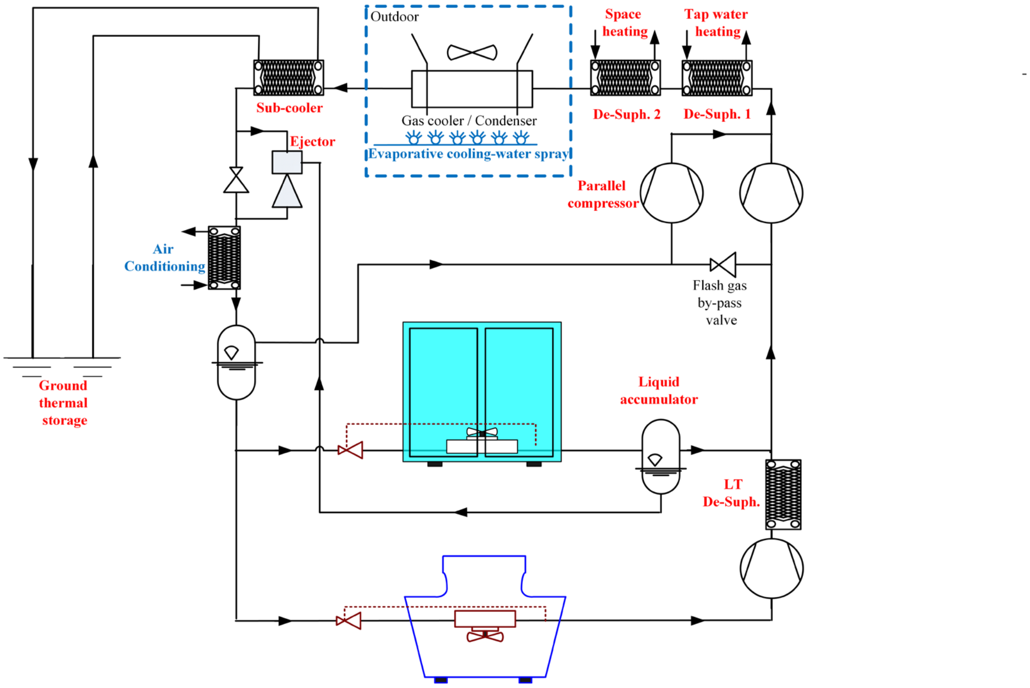

Figure 16: Schematic of a CO_2 transcritical booster system with some state-of-the-art features

5.1 Other trends in using solutions based on natural refrigerants

In addition to the improvements in central CO_2 transcritical systems, there are some other less wide spread but innovative solutions available in the market:

- CO_2 condensing units for convenience stores: Convenience stores are one of the fastest growing food retail store formats. These stores require smaller CO_2 systems with lower capacities, fewer compressors and more compactness. In the past few years, a range of CO_2 condensing units (see section 4.1) have been introduced to the market to alleviate this shortage. A successful example of installing these systems is the Japanese supermarket branch Lawson which installed its 1500th CO_2 condensing unit in August 2016 (R744.com, 2016a).

- Hydrocarbon and CO_2 plug-in units, roll-out of compact and safe systems: Similar to condensing units, there is a new trend in Europe and the world for using HFC-free cabinets/freezers and vending machines for ice cream and soft drinks sale (see section 4.1). There are more than 2 million plug-in units using HCs, mainly propane, and CO_2 across Europe followed by 1.35 million units in Japan and 300.000 units in North America (Masson, 2016).
  The wide usage of these low-capacity systems proves the availability of natural refrigerant solutions, not only in large commercial systems but also in light commercial ones. Availability of the components and safety were two major issues linked to the HC and CO_2 plug-in units in the past, but have been overcome in the recent few years.
  Research on the development of natural-refrigerant based plug-in units is a hot topic in the present time and there are some pilot projects in the market which will widen the scope of using these systems. For example, a supermarket in Belgium started to use a set of propane plug-in units which are connected on the condenser side. The heat is rejected to a common water-propylene loop connected to a dry cooler (Hydrocarbons21.com, 2016). No need for a central system (machinery room space saving) and no need for propane rooftop air cooler (safety issues) are advantages of the system comparing with the disadvantage of high pressure side indirect loop.

- Usage of HCs in large central systems: An example of this system is an “integral propane indirect system” installed in a number of German Lidl discounters. The system supplies MT refrigeration, heating and AC (Proklima, 2012). The system consists of a compact plant for outdoor installation with indirect cooling (MT and AC) and a heating system, using R290 in the primary circuit and potassium formate brine in the secondary circuit. An additional LT stage uses R744 direct expansion, or can also be installed using a secondary circuit with brine. Another example of large-capacity HC units is a system installed in Belgium where it uses propane and propylene glycol as primary and secondary refrigerants in MT cabinets and cold rooms. Freezers are stand-alone units using propane as the refrigerant. A description of the system is to be published in the autumn 2016 edition of Accelerate Europe magazine.

- NH_3-CO_2 cascade systems: usage of ammonia in supermarkets hasn’t been initiated/spread in Europe but there are examples of usage of NH_3-CO_2 cascade systems in the U.S. supermarkets (R744.com, 2016b). Two of these supermarkets received the GreenChill Award 2016 for “Best of the Best” certified stores from the U.S. Environmental Protection Agency’s GreenChill Partnership (R744.com, 2016c).
  Furthermore, cold stores are not defined within the supermarket sector scope but they have the important role of distributors and suppliers for supermarkets. There have been several successful installations of NH_3-CO_2 cascade systems for cold storage facilities across Europe (Shecco, 2013).

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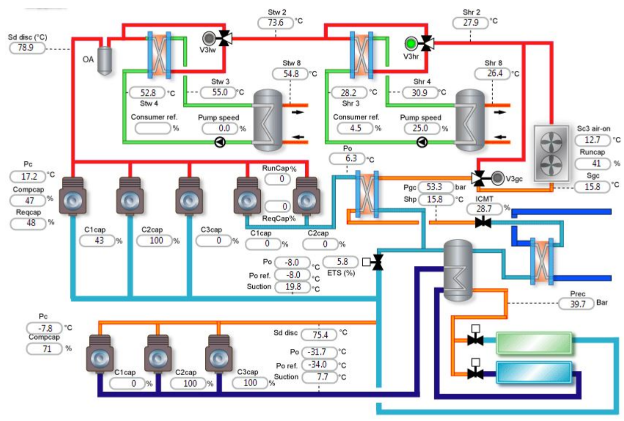
6 BEST PRACTICES AND CASE EXAMPLES

This chapter presents some best practices and case examples of eco-friendly supermarkets installed in Europe and worldwide. The main objective of this chapter is to show the spread and availability of eco-friendly and energy-efficient cooling and heating systems. The introduced systems in this chapter are mainly all-CO_2 systems, as the dominant trend in the market. However, as mentioned in section 5.1, there are other eco-friendly solutions available in the market.
It is necessary to mention that some of the cases are adapted from two other SuperSmart reports:

- D2.3: How to build a new eco-friendly supermarket (Kauko et al., 2016)
- D2.4: How to refurbish a supermarket (CIRCE, 2016)

6.1 Sweden

ICA Kvantum Sollefteå	
	
Opening year	2013
Location, country	Sollefteå, Sweden
Size [m²]	
Type	Stand-alone
Energy efficiency measures implemented	• CO_2 integrated refrigeration + heating + AC • Parallel compressor • Intercooler inside receiver • Suction liquid heat exchanger (IHX) in parallel compressors suction line • Glass doors on cabinets and freezers • Heating for radiators, air handling units, floor heating, entrance air curtain and snow melting • Real-time energy measurements monitoring
Reduction in energy demand and CO_2 emissions (when applicable)	25 % reduction in AC energy demand and 8 % reduction in total electricity demand by using parallel compression instead of flash gas by-pass in AC running mode
Energy use [kWh/m².a]	
Total investment and payback (when applicable)	
Financing solution (when applicable)	
Link for more information	(Karampour and Sawalha, 2016b)

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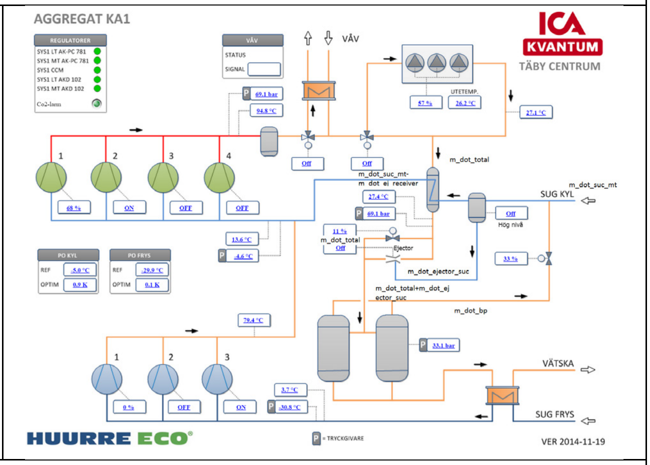
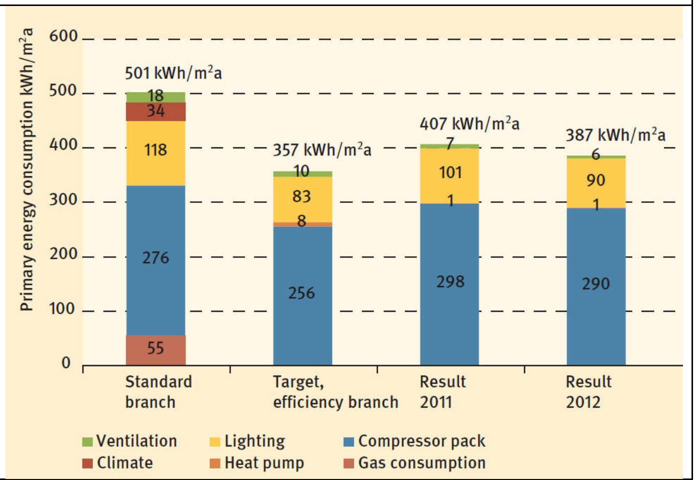
ICA Kvantum Täby	
	
Opening year	2013
Location, country	Täby, Stockholm, Sweden
Size [m²]	
Type	Part of a large shopping centre
Energy efficiency measures implemented	• First ejector-based system in Sweden • One liquid ejector • Glass doors on cabinets and freezers • Real-time energy measurements monitoring • 4 K higher MT evaporation temperature by using ejector
Reduction in energy demand and CO_2 emissions (when applicable)	19 % less energy consumption by using ejector, comparing Oct. 2014-May 2015 (non-activated ejector) and Oct. 2015-May 2016 (activated ejector)
Energy use [kWh/m².a]	
Total investment and payback (when applicable)	
Financing solution (when applicable)	
Link for more information	No public access

The research leading to these results has received funding from the European Union/EASME H2020 Programme under Grant Agreement No 696076.

6.2 Germany

Aldi Süd Rastatt	
	
Opening year	2010
Location, country	Rastatt, Germany
Size [m²]	1 675 (useful area)
Type	Stand-alone
Energy efficiency measures implemented	• Efficient refrigeration and HVAC with an integrated CO_2 system • Good insulation, a very air tight construction • Utilization of daylight through 28 skylights in the ceiling, with triple glazing. Lighting controlled depending on the amount of daylight. • Controlled ventilation with heat recovery • Geothermal storage and thermally activated concrete (floor heating integrated in the bottom concrete slab) for storing heat/cold. An array of 6 boreholes 100m deep is used for ground thermal storage. • Use of surplus heat from cooling – possible to use the refrigeration system as a heat pump • Energy flow monitoring • Automatic system control • Regenerative and passive cooling • Demand controlled ventilation by CO_2 censors, 1600 ppm CO_2 set-point • Heat recovery in ventilation system via rotary heat exchanger
Reduction in energy demand and CO_2 emissions (when applicable)	23 % reduction in energy demand, compared with standard specific energy consumption of Aldi supermarkets
Energy use [kWh/m².a]	387 (primary energy use in 2012)
Total investment and payback (when applicable)	Construction 718 (€/m²) Technical system 332 (€/m²)
Financing solution	
Link for more information	http://www.bine.info/en/topics/industrial-and-commercial/refrigeration-cooling/publikation/supermarkt-der-zukunft-spart-energie/ (Rehault and Kalz, 2012) http://www.enob.info/fileadmin/media/Projektbilder/EnBau/Aldi_R

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Tegut supermarket, Marburg-Cappel

Opening year	2014
Location, country	Marburg-Cappel , Germany
Size [m^2]	
Type	Part of a shopping centre
Energy efficiency measures implemented	• The first supermarket to receive the German ecolabel Blue Angel, in 2015 • Integrated CO_2 refrigeration + heating system • Photovoltaic (PV) panels on the roof, 90 kW capacity • Glass doors, LED lighting and EC fans in the cabinets • LED lighting • Energy management system according to DIN EN ISO 50001
Reduction in energy demand and CO_2 emissions (when applicable)	Overall estimated energy saving of 30 % comparing to conventional supermarkets
Energy use [kWh/m^2.a]	122 (Günther, 2016)
Total investment and payback (when applicable)	
Financing solution (when applicable)	
Link for more information	http://www.coolingpost.com/features/co2-system-helps-tegut-to-eco-award/ http://www.carrier.com/carrier/en/us/news/news-article/carrier_equips_the_first_blue_angel_ecolabel_supermarket_in_germany.aspx

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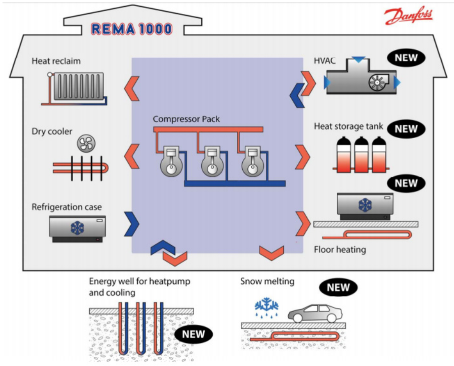
6.3 Norway

REMA 1000 Kroppanmarka		
		
Opening year	2013	
Location, country	Trondheim, Norway	
Size [m²]	Ca. 1000	
Type	Stand-alone	
Energy efficiency measures implemented	• Energy-efficient shop (measured in kWh/m²·a). Won the Energy Saving Prize in Trondheim (Energisspareprisen) in 2014. • Integrated refrigeration system with heat recovery at multiple temperature levels, CO_2 as the refrigerant • Doors/lids in all refrigerated cabinets • Controlling technologies for optimized, easier operation • Aerogel facades, and demand controlled lighting based on amount of daylight available • Energy wells for storage of heat and cold, four 170 m deep boreholes (energy wells) • AHU unit adapted to supermarkets using the most efficient solutions available today • All waste is sorted and recycled, and customers may also return several types of waste for recycling at the entrance	
Reduction in energy demand and CO_2 emissions (when applicable)	Reduction in annual energy demand 30 %, in comparison with a standard Norwegian supermarket	Reduction in CO_2 emissions ~30 %
Total investment and payback (when applicable)		
Financing solution (when applicable)	The project received 1 million NOK from Enova	
Link for more information	http://gemini.no/en/2014/06/drastic-cut-in-electricity-bill-for-supermarket/ https://issuu.com/simplymarcomms/docs/atmosphere_303_2_kristensen_danfoss	

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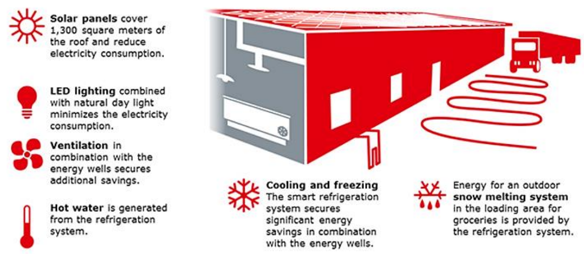
NorgesGruppen – KIWI Auli	
	
Opening year	2014
Location, country	Auli, Norway
Size [m^2]	
Type	Stand-alone
Energy efficiency measures implemented	• Built in passive house standard • Integrated refrigeration system with heat recovery, based on CO_2 as refrigerant • Covers for all refrigerated cabinets • LED lights in the cabinets as well as in the store • Aerogel facades, and demand controlled lighting based on amount of daylight available • Five 200 m deep energy wells for thermal storage • 1300 m^2 solar panels on the roof, which should give ~150 kW • Extra heat exchanger before compressor to ensure dry inlet • Eco-friendly building materials, such as wood produced in Norway
Reduction in energy demand and CO_2 emissions (when applicable)	Expected 50 % reduction in energy use compared with a similar sized store
Total investment and payback (when applicable)	7.8 million NOK (additional costs due to energy efficiency measures)
Financing solution (when applicable)	The project received 3.7 million NOK from Enova
Link for more information	https://kiwi.no/Informasjon/Fremtidsbutikken/ http://food-retail.danfoss.com/technicalarticles/rc/new-100-percent-green-kiwi-store-follows-the-norwegian-co2-trend/

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6.4 UK

Olympic Way, Wembley solution, Sainsbury's		
		
Opening year	2015	
Location, country	London, UK	
Size [m^2]	252	
Type	Part of a building (convenience store)	
Energy efficiency measures implemented	• Booster CO_2 refrigeration + heat recovery + AC system • Intercooler (internal gas cooler) • Heat recovery to water, utilized for domestic hot water (DHW), heating of ventilation air and air curtain • De-stratification (mixing) fans	
Reduction in energy demand and CO_2 emissions (when applicable)	55 % reduction in average weekly energy use comparing with 6 other similar stores	Total annual carbon saving (kg CO_2) 70, 503
Total investment and payback (when applicable)	14.15 months payback	
Financing solution (when applicable)		
Link for more information	http://www.atmo.org/media.presentation.php?id=764 http://www.r744.com/articles/1047/sainsbury_s_using_green_cool_co_sub_2_sub_systems	

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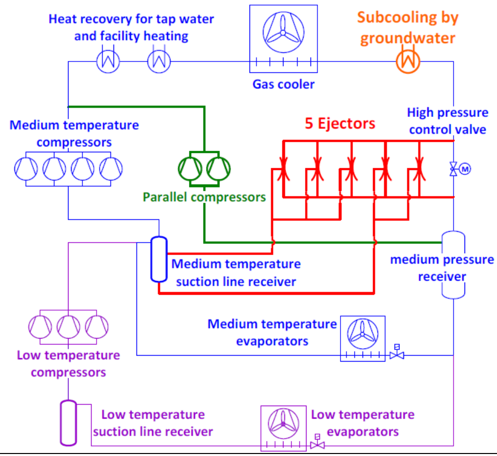
6.5 Switzerland

Migros Ibach



Opening year	2014 (refurbished)
Location, country	Ibach, Switzerland
Size [m²]	3900 (sales area)
Type	Part of a shopping centre.
Energy efficiency measures implemented	• CO_2 refrigeration system using multi-ejector technology • Parallel compression • Partially flooded evaporators • Tap water heating and facility heating • Sub-cooling by ground water in summer • MT and LT evap. temp. could be raised to -2 °C and -25 °C, respectively, thanks to five vapour and liquid ejectors. The conventional evaporation temperatures without ejectors would have been -8°C and -33°C.
Reduction in energy demand and CO2 emissions	Expected energy savings: at least 25 %
Total investment and payback	
Financing solution	
Link for more information	http://www.frigoconsulting.ch/en/news/new_bench_mark_in_co2_technology.htmlhttp://www.r744.com/articles/6921/migros_putting_co_sub_2_sub_refrigeration_technology_at_heart_of_climate_strategy http://www.atmo.org/presentations/files/571_CaseStudy_Presentation_Wiedenmann_v13_150312.pdf

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6.6 Spain

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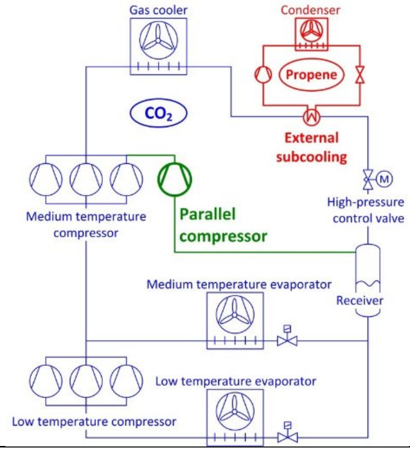
<tr><td colspan="2"></td><td>
</td></tr>
<tr><td>Opening year</td><td colspan="2">2013</td></tr>
<tr><td>Location, country</td><td colspan="2">Alzira, Valencia, Spain</td></tr>
<tr><td>Size [m^2]</td><td colspan="2"></td></tr>
<tr><td>Type</td><td colspan="2">Hypermarket</td></tr>
<tr><td>Energy efficiency measures implemented</td><td colspan="2">• CO_2-booster system with integrated parallel compression and external subcooler using propane, enabling constant gas-cooler output temperature of 26 °C all year long
• Heat recovery for DHW (5000 l every day)</td></tr>
<tr><td>Reduction in energy demand and CO_2 emissions</td><td>35 % more energy-efficient than the previous installed system.</td><td>90 % reduction in CO_2 emissions compared to cooling systems using synthetic refrigerants.</td></tr>
<tr><td>Total investment and payback</td><td colspan="2"></td></tr>
<tr><td>Financing solution</td><td colspan="2"></td></tr>
<tr><td>Link for more information</td><td colspan="2">http://www.frigoconsulting.ch/en/news/most_southerl_co2-refrigeration_system_in_spanien.html
http://www.carrier.com/commercial-refrigeration/en/eu/news/news-article/southern_most_carrier_co2oltec__refrigeration_system_installed_in_valencia.aspx
http://www.r744.com/articles/5074/span_style_color_rgb_255_0_0_update_span_part_1_first_100_co_sub_2_sub_cooling_installation_in_southern_spain_carrefour_alzira_achieves_10_energy_savings
http://www.r744.com/articles/5071/part_2_first_100_co_sub_2_sub_cooling_installation_in_southern_spain_promising_outlook_for_co_sub_2_sub</td></tr>
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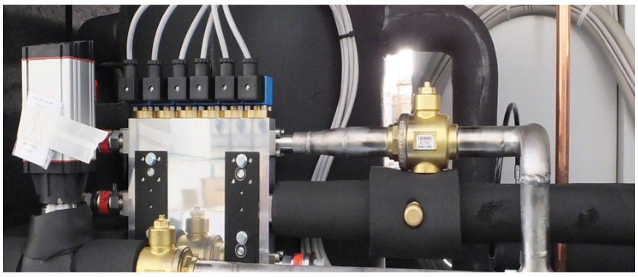
6.7 Italy

Iper Hypermarket Milan	
	
Opening year	2016
Location, country	Milan, Italy
Size [m^2]	10 000
Type	Italy's largest hypermarket. A part of a large (92 000 m^2) shopping centre.
Energy efficiency measures implemented	• CO_2 refrigeration system using multi-ejector technology, designed for energy-efficient operation at ambient temperatures up to 38 °C • Heat recovery for DHW production • Integrated control of light, HVAC and refrigeration; control system designed by Danfoss • The centre is LEED Gold certified, designed and constructed to use less water and energy and reduce greenhouse gas emissions
Reduction in energy demand and CO_2 emissions	Energy savings of up to 50 % are expected.
Total investment and payback	
Financing solution	
Link for more information	http://www.danfoss.com/newsstories/rc/italy-largest-hypermarket-opts-for-co2-refrigeration/?ref=17179879870

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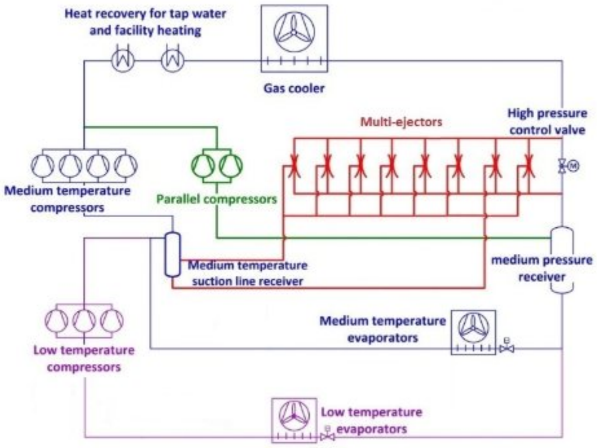
6.8 Romania

Carrefour Timisoara	
	
Opening year	2015
Location, country	Timisoara, Romania
Size [m²]	
Type	Hypermarket
Energy efficiency measures implemented	• First CO_2 refrigeration system with parallel compression and multi-ejector technology in Romania • Increased evaporation temperature, from -7 °C up to -2 °C depending on the evaporator performance, enabled by the ejector technology • Heat recovery for DHW and for facility heating that covers offices and parts of the sales area • LED lighting
Reduction in energy demand and CO_2 emissions	Energy savings up to 13 % compared to a transcritical CO_2 system with parallel compression are expected. LED lighting reduces lighting electricity consumption by 35 %.
Total investment and payback	
Financing solution	
Link for more information	http://www.frigoconsulting.ch/en/news/carrefour_timisoara_ejector.html https://www.carrefour.ro/magazine/timisoara/carrefour-timisoara/ http://www.r744.com/articles/6801/carrefour_timisoara_new_r744_multi-ejector_refrigeration_system_is_major_success http://www.daas.ro/en/daas-successfully-implemented-a-new-project-using-the-latest-refrigeration-technology-for-carrefour-timisoara/#news-modal

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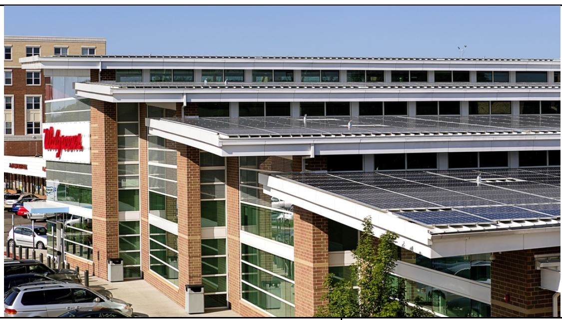
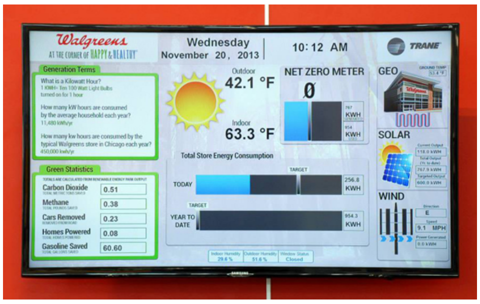
6.9 USA

Walgreens store, Evanston	
	
Opening year	2013
Location, country	Evanston, Illinois, U.S.
Size [m²]	14 460
Type	Stand-alone
Energy efficiency measures implemented	Net-zero energy retail store. The store received the Illinois Chapter of ASHRAE Excellence in Engineering Award, U.S. EPA Green Chill Platinum Certification and 1st Place Tech Award for New Commercial Buildings of ASHRAE. **Sustainable construction:** • Automatic shade control of the curtain-wall reacts automatically to solar flux. • Highly insulating walls, roof and windows prevent heat/cold loss. • Window glass with light redirecting film technology redirects 80 % of the direct solar radiation to the ceiling reducing glare and enhancing natural daylight penetration **Renewable energy sources:** • 256 kW solar PV installation covering the entire roof area with an annual production of 212 300 kWh • Two 2 kW wind turbines with an annual production of 7200 kWh • Power measurement and visualization **Energy efficiency measures** **Refrigeration** • CO_2 refrigeration system with heat recovery for the ventilation air heating and DHW pre-heating • AC + parallel compression + sub-cooling using a ground thermal storage (energy wells) • Seasonal storage with energy wells to reject the excess heat and use it during heating season (eight 150 m deep boreholes) • “False load” heat exchanger in gas cooler for extra heat recovery (heat recovery from the warm exiting the gas cooler) • Power measurement and visualization **Lighting** • LED technology installation with an automatic light control system with daylight sensing zone • Energized control of power and lighting systems based on time of day schedule for reducing the parasitic loads for HVAC systems

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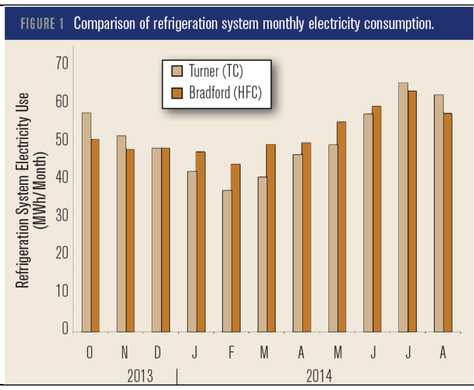
	Indoor air quality • Motorized aperture in the roof controls natural ventilation for pre-conditioning • Centralized, demand controlled ventilation system based on CO_2 levels in retails space with single-zone air handling units for local temperature control.
Reduction in energy demand and CO_2 emissions (when applicable)	60 % saving in energy consumption
Total investment and payback (when applicable)	
Financing solution (when applicable)	
Link for more information	http://www.cyclone.energy/portfolio/walgreens-net-zero-store-opens/

Hannaford supermarket, Turner	
	
Opening year	2013
Location, country	Turner, U.S.
Size [m²]	3252
Type	Stand-alone
Energy efficiency measures implemented	• Pilot project: the first CO_2 booster system installed in the U.S. • Integrated CO_2 refrigeration system with heat recovery at multiple temperature levels • Real-time energy measurements monitoring
Reduction in energy demand and CO_2 emissions (when applicable)	Similar energy consumption (Conventional HFC-based system with similar layout and climate as baseline) Reduction in CO_2 emissions ~15 %
Total investment and payback (when applicable)	
Financing solution (when applicable)	
Link for more information	ASHRAE Journal Oct. 2015 (Weber and Horning, 2015) http://betterbuildingssolutioncenter.energy.gov/ http://www.achrnews.com/articles/130514-transcritical-co2-one-year-of-lessons-learned

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6.10 Japan

Lawson Convenience stores	
	
Opening year	
Location, country	Japan
Size [m²]	
Type	Convenience store

Energy efficiency measures implemented	• Lawson is the operator of more than 1500 stores using natural refrigerant in Japan
	• One of Lawson's most efficient systems in Toyohashi city, opened 2014, features:
	  • Double-skin façade with insulation function
	  • Ground source heat pump
	  • 60 % energy reduction comparing to 2010 consumption levels of Lawson standard convenience stores

Reduction in energy demand and CO_2 emissions	• Standard Panasonic CO_2 systems are on average 27 % more efficient than the conventional HFC solutions in Lawson convenience stores • 21 % energy saving in an Okinawa Lawson supermarket (hot and humid climate), comparing CO_2 and R404A convenience store solutions
Total investment and payback	
Financing solution	
Link for more information	Shecco Japan guide (Shecco, 2016) http://www.atmo.org/media.presentation.php?id=506

6.11 Other countries

There are other sources which are recommended for reading about best practices and case examples from different countries around the world:

- SHECCO publications
  - CO_2: http://www.r744.com/
  - HCs: http://www.hydrocarbons21.com/
  - NH3: http://www.ammonia21.com/
  - Shecco Accelerate magazines and Shecco guides: http://publication.shecco.com/publications/lists

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- The presentations of Shecco ATMOsphere conferences and events: http://www.atmo.org/events.php

- Companies detailed case studies including CO_2 integrated systems, ejector and parallel compression:
- Frigo-Consulting LTD: http://www.frigoconsulting.ch/en/news.html
- Danfoss: http://refrigerationandairconditioning.danfoss.com/news/case-studies/

- Environmental organizations case studies:
- UNEP (2016): 11 case studies for commercial refrigeration: http://www.unep.org/ozonaction/Portals/105/Publications/CCAC_case_studies_2016_final.pdf
- UNEP (2014): http://www.pnuma.org/ozono/publicaciones/7686-e-Low_GWP_Alternatives_in_Commercial_Refrigeration.pdf
- Danish Environmental Ministry: https://www.thepmr.org/system/files/documents/low%20GWP%20alternatives%20final%20.pdf
- GIZ-Proklima Germany-Hydrocarbons-chapter 7: https://www.giz.de/expertise/downloads/giz2010-en-guidelines-safe-use-of-hydrocarbon.pdf
- EIA (Environmental Investigation Agency): http://eia-global.org/images/uploads/Putting_the_Freeze.pdf https://eia-international.org/report/supermarkets-shift-hfc-free-commercial-refrigeration-worldwide
- Cool technologies-Interactive online **database** of HFC-free technologies-sponsored by Green Peace and EIA: http://cooltechnologies.org/refrigeration/commercial

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7 CONCLUSION

The objective of the series of training material in the SuperSmart project is to raise the awareness and transfer the knowledge for a faster uptake of eco-friendly and energy-efficient technologies in supermarkets. Following this objective, this report has given an overview of eco-friendly supermarket concepts. The main concentration and scope of the report has been on refrigeration, heating and air conditioning systems. Other energy systems in supermarkets including ventilation, lighting and dehumidification have been discussed in brief.

A concise overview of the supermarket sector status in Europe has been presented in the report. It was shown that the total number of supermarkets and total share of modern food retail in European food retail markets have increased in the past decade.

The negative environmental impacts associated with its growth have been discussed, and are largely attributed to the refrigeration systems in supermarkets. High energy consumption, as well as large consumption and emission of high GWP refrigerants are the factors that render the refrigeration system the most environmentally harmful energy system in supermarkets.

A comprehensive review of available conventional and modern eco-friendly energy systems in supermarkets has been included in the report. Different configurations of refrigeration, heating and air conditioning systems, as well as their energy efficiency and eco-friendliness have been discussed.

With emphasis on state-of-the-art CO_2 transcritical booster systems, two major trends in supermarket refrigeration technology have been described in the report. These trends are CO_2 integrated systems and innovative solutions for energy efficiency improvement of CO_2 systems for warm climates. Presented in the report are also case examples of operative installations of such systems worldwide.

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