How to build a new eco-friendly supermarket

Report 3

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 serves as a starting point material for training supermarket stakeholders in building new, eco-friendly supermarkets. The report covers building design, refrigeration, heating, ventilation and air conditioning (HVAC), as well as lighting, with the main focus being on the refrigeration and HVAC system. New, innovative and promising technologies and solutions are introduced, accompanied with case examples from different parts of Europe.

For the refrigeration system, the focus is on CO_2-only systems, as this is regarded as the most energy efficient and eco-friendly approach. State of the art CO_2 system layouts using ejectors for expansion work recovery, suitable for both warm and cold climates, are presented. An integrated system solution covering both the refrigeration and HVAC, allowing optimal heat recovery, is highly recommended, and a possible system layout for such an integrated approach is presented.

A prerequisite for energy efficient refrigeration are good components, including compressors, evaporators, condensers, and expansion devices, as well as a good cabinet design. Flooded direct expansion evaporators, enabled through the use of ejectors, are highly recommended. Such evaporators allow increased evaporation temperatures due to the improved heat transfer, and consequently also reduced demand for defrosting cycles, leading to a significantly higher overall system COP. Regarding cabinet design, having glass doors and lids is a crucial first step, allowing energy savings of 40 % or more. A detailed list of the design aspects leading to optimal cabinet energy efficiency is provided in the report.

Thermal energy storage is an important part of an energy efficient supermarket refrigeration system, allowing reduction in the peak cooling demand and thereby in the installed refrigeration capacity. Different thermal storage options suitable for supermarkets include energy wells as a seasonal storage, and hot water storage tanks and phase change materials (PCM) as a short-term thermal storage. The report presents an overview of these technologies, and how they can be or have been applied in supermarkets.

For lighting in supermarkets, LED lights both in- and outside the store, as well as inside the cabinets, should be used owing to the low electricity demand and low heat production. LEDs have the additional advantage that they consume less energy the cooler they are kept, opposite to fluorescent tubes. LED lights together with adapted utilization of daylight and intelligent control with respect to traffic and amount of daylight available can thus enable significant energy savings.

The most crucial measures for improving the supermarket energy efficiency are summarized as golden rules at the end of the report.

Apart from the technical aspects, the report discusses the non-technical barriers for the uptake of new eco-friendly supermarkets, as well as possible solutions to overcome these barriers. Increased investment costs are often regarded as the biggest non-technical barrier, and financing opportunities to overcome this barrier are therefore included for different European countries.

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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:

1. Eco-friendly supermarkets – an overview
2. How to build a new eco-friendly supermarket
3. How to refurbish a supermarket
4. Computational tools for supermarket planning
5. Eco friendly operation and maintenance of supermarkets
6. 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:

1. Conference related activities
2. Dedicated training sessions
3. 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 topic *How to build a new eco-friendly supermarket*. 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 How to build a new eco-friendly supermarket

New supermarkets are being built all the time. In the UK alone, supermarket chains are planning to open enough new stores in the years ahead to cover 500 football pitches (Neate 2011). At the same time, supermarkets consume huge amounts of energy. The annual energy use in supermarkets in for instance Germany is estimated to be 16 TWh, in Spain 6.8 TWh, in Italy 8.2 TWh, and in Norway about 1.5 TWh (Grocery Universe 2013). Moreover, supermarkets contribute to climate gas emissions both directly through leakage from the refrigeration system, as well as indirectly due to the energy consumption. Overall the cold chain is believed to be responsible for approximately 2.4 % of global greenhouse gas emissions (Foster and Evans 2015). The highest proportion – or all when natural refrigerants are used – of the climate gas emissions comes from emissions related to energy consumption (Kauffeld 2015). It is hence of utmost importance that new supermarkets should be built to be energy efficient, and based on utilization of natural refrigerants, primarily CO_2, i.e. refrigerant R744.

Nevertheless, many new energy efficient technologies for retail refrigeration based on CO_2 are not yet fully mature, and supermarket stakeholders are sceptical towards the commissioning of these technologies, in particular in warmer climates. In order to increase the confidence and thereby accelerate the uptake of new eco-friendly solutions, training campaigns dedicated to the supermarket stakeholders are urgently needed.

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The choice of the refrigeration and HVAC system to be installed in a new supermarket lies primarily in the hands of the supermarket chain and the shop owners, as well as in the hands of consultants and engineers designing the system. Hence these stakeholders need to be addressed, to raise their knowledge on existing eco-friendly technologies and their potential for reducing operational costs and total cost of ownership, as well as to inform about the different financing opportunities to cope with the increased initial costs. Furthermore, knowledge on CO_2 systems is required from the installers and technicians, in particular the refrigeration engineers and plumbers. To ensure correct dimensioning and successful, energy efficient operation of the refrigeration system, it is crucial to reach these stakeholders.

The objectives of this report are:

- To discuss optimal building design for supermarkets
- To present the state of the art and promising future technology for energy efficient and eco-friendly supermarket refrigeration and HVAC, including heat recovery and thermal storage and considering different climatic conditions
- To discuss the non-technological barriers and possible solutions for building new energy efficient supermarkets
- To present case examples of supermarkets with outstanding energy solutions from different parts of Europe

In addition, financing options for building new, energy efficient supermarket are given in appendix A for different European countries, including EU and partner countries, and more specifically Germany, Norway, Spain and Macedonia.

A supermarket is a complex energy system, having to satisfy chilling and freezing of valuable food at different temperature levels, and at the same time maintaining customer comfort in the sales area. The measures that can be taken to reduce the energy use are various, starting from an optimal building design, to correct dimensioning and operation of the refrigeration system and all its components. This chapter discusses the technical framework for building a new, energy efficient supermarket, starting with the building design and requirements in different parts of Europe, subsequently discussing the refrigeration and HVAC system, focusing on solutions based on CO_2 as the cooling medium, which is considered as the most eco-friendly and energy efficient solution. Other trends using natural refrigerants are discussed given in the SuperSmart project report D2.2, Eco-friendly supermarkets – an overview (Karampour, Sawalha et al. 2016). Finally, lighting and electrical equipment, as well as possibilities for local power generation in a supermarket will be discussed.

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2 BUILDING DESIGN

2.1 Size, shape and outer design

The size and shape of a supermarket is critical for highest possible energy efficiency, and regarding the customer experience. To minimize the heat losses or gains, the building should be as compact as practically possible. Regarding the size; a too high ceiling increases both the construction costs as well as the operation costs due to increased heating and cooling demand, while a too low ceiling creates a claustrophobic effect. The height should hence be designed for the minimum practical limit. The same applies for floor space, which should be designed based on the amount of traffic corresponding to 90 % of the busiest day (EPA 2010). Aisle widths should be varied based on traffic density.

Generally, the sunlight is a big heat load for the stores. In some countries this is a rare problem, but still creates high peak loads a few days a year. For a stand-alone store, sun shading is a simple but important measure to reduce this load. Reflecting walls (white or mirror) could also reduce the load. For supermarkets that are a part of a building complex, the placement of the store should be below or on the ground level, preventing the sun from reaching down to it. This is usually the case, and such stores have generally lower cooling loads than stand-alone stores. Having the supermarket as a part of a building complex is advantageous also in the sense that the condenser heat can be utilized to cover the heating demand in the other parts of the complex.

2.2 The building envelope

The building envelope – including walls, floor, roof, windows and doors – defines the heating and cooling demand of the building with respect to the ambient climate. It should be designed such that the heat load in the hot periods is minimized, and that a pleasant indoor climate is maintained in the colder periods. This section discusses suitable building materials for supermarkets and the prevailing requirements for the building envelope in the different parts of Europe. Novel ideas for increased energy efficiency for instance regarding fenestration and doors are included.

2.2.1 Floor, walls and roof

Proper insulation is crucial to reduce heat losses from the supermarkets in cold climates in the winter time, as well as to reduce overheating of the building in the summertime. A trade-off between space costs and investment costs for insulation of walls must be made, as the more space efficient insulation is, the more expensive it is as well. Exemplar values for normative heat transfer coefficients according to the newest building standards in the different parts of Europe are given in Table 2.1. It has to be pointed out that many of the values are aimed for commercial buildings in general, not particularly for supermarkets.

Table 2.1 Exemplar values for normative heat transfer coefficients for walls, roof and floor according to the building regulations in different parts of Europe.

	Heat transfer coefficient [W/m²K]		
	Walls	Roof	Floor
Norway (passive house/low-energy building) (Standard Norge 2012)	0.10-0.12/0.15-0.16	0.08-0.09/0.10-0.12	0.08/0.10-0.12
Sweden (for buildings with electric heating/heating method other than electric heating) (Boverket 2015)	0.10/0.18	0.08/0.13	0.10/0.15
Germany (for building projects from 2016 (EnEV 2014) / passive house criteria, depending on the climatic zone (Passivhaus Institut 2015))	0.28 / 0.09-0.50	0.28 / 0.09-0.50	0.28 / 0.09-0.50
Spain (the value depends on the climatic zone) (BOE 2013)	0.55-1.35	0.35-1.20	0.55-1.35/0.35-1.2 (in contact with ground/air)
Macedonia	0.35	0.2	0.4

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For the construction, materials with low CO_2 emissions throughout the life cycle should be chosen as far as possible, depending on the level of the environmental ambitions. As an example, a new, highly eco-friendly Kiwi-supermarket in Elverum, Norway, used near-produced wood as the main building material (KIWI 2016). Apart from the low environmental impact, it was pointed out that wooden wall constructions contribute to a good indoor climate and a reduced demand for ventilation.

2.2.2 Windows and doors

To reduce the cooling demand during warm periods, the thermal load from the sun through windows should be minimized. Therefore the window area in supermarket is generally low. The most energy efficient approach would be to have no windows at all, however a supermarket without any windows is not a very pleasant one. At the same time utilization of natural light should be maximized in order to reduce the electricity demand for lighting.

At REMA 1000 Kroppanmarka in Trondheim, Norway, this was accomplished such that parts of the north and west-facing walls as well as a small part of the roof were covered with translucent daylight panels, so-called Nordic Daylight Panels (Aerogel Norge 2016). These panels are filled with highly insulating porous silica aerogel (heat transfer coefficient 0.59 W/m²K), and spread the light diffusively into the room, preventing the creation of hot spots. The panels have a light transmission of 45 %. Daylight panels are employed also in a Kiwi-supermarket in Auli, Norway (KIWI 2015).

Table 2.2 Exemplar values for normative heat transfer coefficients for windows and doors.

	Heat transfer coefficient [W/m²K]
Norway (passive house/low-energy building) (Standard Norge 2012)	≤0.80 / ≤1.2
Sweden (for buildings with electric heating/heating method other than electric heating) (Boverket 2015)	1.1/1.3
Germany (for building projects from 2016 (EnEV 2014) / passive house criteria, depending on the climatic zone (Passivhaus Institut 2015))	1.5 / 0.45-1.40
Spain (BOE 2013)	2.5-5.7
Macedonia	1.7

Infiltration through doors can be reduced by using double doors, i.e. having a vestibule (an entrance area) between the outer and the interior door. Adding a vestibule can provide energy savings of up to 6 % in warm climates (NREL 2012). The infiltration can be further reduced by operational changes (when and how long the doors are open) and changes in the effective door area. These measures may be applied to customer doors, or to shipping and receiving doors used by retailers and their product distributors.

Another energy efficiency measure for entrance doors is using an air curtain, i.e., a controlled stream of air across the opening (Figure 1). An air curtain provides energy savings by limiting the transfer of air between indoors and outdoors, and limits also the flow of insects, dust and humidity to the supermarket (Berner International 2014). It is however important that the air curtain is a part of the integrated refrigeration and HVAC system, hence utilizing excess heat from the refrigeration system. An air curtain utilizing electric heaters during winter time will have a negative impact on the total energy efficiency of the supermarket.

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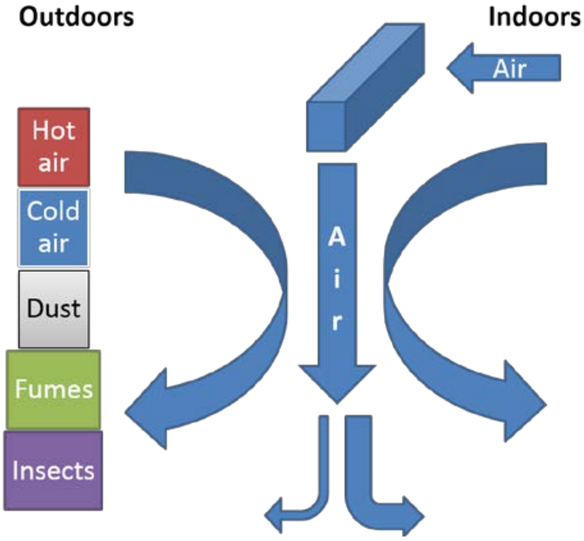

Figure 1 **Air curtain principle.**

2.3 Floor plan and interior design

To minimize thermal losses, the distribution of hot and cold zones within a store matters. Generally, products that are sold hot should be placed far away from the refrigerated products. Products that can be stored at normal room temperatures, but still not too high temperatures (fruit and vegetables) could be placed close to the cold room, so that the cold leakage is utilized. In this way, a temperature gradient, beneficial for the products and energy use is achieved.

An example of how climatic zones for lower heat losses can be arranged in a shop is shown in Figure 2. In this figure, the orange zone contains heated products and holds a generally high temperature all year, whereas there is an own room for chilled products displayed in cold cabinets in the light blue room. It is a good practice to have a cold storage room and space for inserting more products into the cold shelves from the backside of the cabinets for products with highest turnover rate, such as dairy products. Fruit and vegetables are placed in front of the cold disks, hence being cooled down by the cold air leaking from the disks. The shelves between the hot and cold zones will have an intermediate temperature. The entrance and payment area will be influenced, but not controlled, by the outdoor temperature.

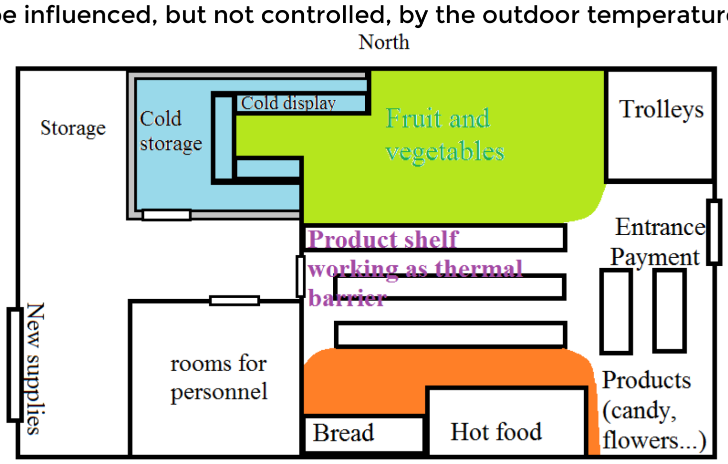

Figure 2 **Example of how different climatic zones can be achieved within a grocery store.**

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2.4 Lighting and electrical equipment

Lighting corresponds to approximately 20 % of the supermarket energy demand, hence an energy efficient lighting is crucial for an eco-friendly supermarket. At the same time, optimal lighting is important considering the sales: correct lighting for the different products will bring out the best of the products, and correct ambience will make the customers feel at ease (Philips Electronics 2012). LED-lights are the preferred type of lighting owing to the low electricity demand and low heat production, and the colour of LED lights can be optimized with respect to the different sales areas (Philips Electronics 2012).

Lighting energy consumption can be further reduced by using clever lighting control. This may include using less lights when enough daylight is available and using presence detection features to balance light levels according to the volume of store traffic. An automatic lighting control system which switches off the ceiling lights when sufficient daylight is available is employed for instance at the REMA 1000 supermarket at Kroppanmarka in Trondheim (Hafner and Tønseth 2014) and at KIWI Fjeldset in Elverum, Norway (KIWI 2016). Furthermore, room surfaces painted with matt colours with high reflectance should be used. Energy efficiency in lighting is further discussed in report D2.4. How to refurbish a supermarket CIRCE, 2016).

2.5 Local power generation

Supermarkets have a high specific power demand, which peaks in the summertime when the cooling load is the highest, and additionally usually a large roof area. This renders supermarkets suitable for local power production with solar PV, and this is already practiced in several supermarkets in Europe and Asia (Grovew 2014, Richardson 2015), including Northern countries such as Norway (KIWI 2015). Local power generation with renewable energy systems is discussed in more detail in the report D2.4, How to refurbish a supermarket (Mainar Toledo and García Peraire 2016).

Sun, or wind, are however not the only options for local power generation. Sainsbury's Cannock store in the UK will be powered using electricity generated using food waste from Sainsbury's stores across the UK (J Sainsbury 2014). The principle is to send zero operational waste to landfill. Any food waste that is unsuitable for charitable donations or animal feed is sent to anaerobic digestion and turned into bio-methane gas, which is then used to generate electricity. Sainsbury's is already the UK's largest retail user of anaerobic digestion, generating enough energy to power 2 500 homes each year.

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3 REFRIGERATION AND HVAC

There are two principal temperature levels in supermarkets: medium temperature (MT) for preservation of chilled food and low temperature (LT) for frozen products. In an integrated solution, the refrigeration system is also responsible for air conditioning (AC) of the store. The desired temperature levels for MT, LT and AC, as well as typical and ideal evaporation temperatures are given in Table 3.1. The measures for achieving higher evaporation temperatures for LT and MT are discussed in section 3.4.3. For AC, a typical evaporation temperature is +3 °C to provide chilled water at +7 °C. This is still a very low temperature to maintain an indoor temperature of 20 °C, owing to indirect system solutions used. In long-term one should aim for direct systems, allowing higher AC evaporation temperatures (see section 3.7).

Table 3.1 Temperature levels for refrigeration and AC in a supermarket.

	Desired temperature level [°C]	Typical evaporation temperature [°C]	Ideal/achievable evaporation temperature [°C]
Chilled food	1 to 14	-10 to -5	-2
Frozen food	-12 to -18 or lower	-35 to -30	-25
AC	~20	~3	12

Three main types of refrigeration systems are used in stores: stand-alone equipment, condensing units and centralised systems (UNEP 2002). A detailed explanation of these systems is given in the SuperSmart project report D2.2, Eco-friendly supermarkets – an overview (Karampour, Sawalha et al. 2016). For centralised system, there are two main types: direct (direct expansion, DX) and indirect system, also explained in the project report D2.2.

Indirect systems permit a lower refrigerant charge, and enables the use of flammable or toxic refrigerants when the refrigeration unit is located in a machinery room separated from the sales area. Indirect systems were hence previously recommended, in particular for hypermarkets where the distances are long. However, CO_2 has excellent transport properties – very low friction losses and low temperature drop per pressure drop – rendering direct systems with CO_2 feasible also for large supermarkets (R744.com 2015a). Direct systems offer better energy efficiency and more stable temperature levels in the refrigerated cabinets, and are additionally less complex to operate than indirect systems.

Ideally, most or all of the refrigeration demand should be covered by an integrated, central refrigeration system taking care of chilling and freezing the food stuff as well as AC, condenser heat being recovered for different heating purposes. The primary focus in this chapter is hence on the central refrigeration system, and direct systems, with CO_2 as the refrigerant of choice, covered in section 3.1. Refrigeration components, optimal cabinet design, air-handling unit, thermal storage and distribution of heat and cold in the supermarkets are discussed in sections 3.4-3.7. An example of an integrated system layout and strategies for optimal heat recovery are presented in section 3.8.

3.1 Central refrigeration system

For the central refrigeration system, a direct system based on CO_2 as the working fluid has become the preferred solution for European retailers. The first installation was made in 2004 by Linde, and by 2013 there were nearly 3000 installations in Europe (Shecco 2013). Figure 3 presents simplified system layouts for 1st, 2nd and 3rd generation CO_2 refrigeration systems. The pros and cons of these systems, and their suitability to different climates, is discussed in more detail below.

All figures in this section are highly simplified to clarify the principles. In reality, a number of compressors might be placed in parallel to match the varying capacity requirements, and in the same way one could include several evaporators and heaters. Missing in the figures is also the internal heat exchanger (IHX) between the point after the gas cooler and just before the LT compressor, which both ensures dry compression and provides subcooling, hence improving the process efficiency.

3.1.1 1st generation: The booster system

The 1st generation, i.e. the booster system (Figure 3 (a)), is the most widely applied solution. The system fits best to cold climates, where the demand for AC is low. In this system, the LT cabinets/evaporators are served by a separate, smaller booster compressor – hence the name booster system – which lifts the

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pressure to the medium temperature level. The discharge gas from the booster is then merged with the gas coming from MT evaporators. As the outlet temperature from the LT compressor is generally high, up to 90 °C, de-superheating recommended before mixing of the fluids. Heat from the de-superheater may also be utilized to different purposes, such as production of domestic hot water (DHW).

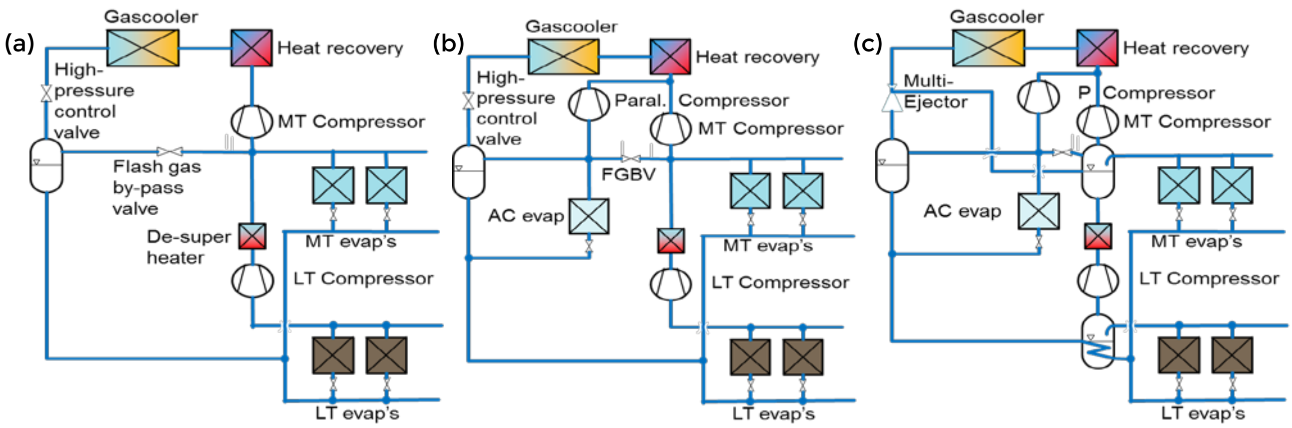

Figure 3 (a) 1st, (b) 2nd and (c) 3rd generation central CO_2 refrigeration systems for supermarkets.

After the gas cooler, CO_2 is throttled by the high-pressure control valve to the intermediate pressure receiver (separator). Liquid from this receiver is throttled further to either to LT or MT level, whereas flash gas is taken to the MT compressor through a flash gas by-pass valve (FGBV). The FGBV is crucial in controlling the pressure level in the separator, which enables a safe supply of liquid refrigerant to all evaporators.

The general booster system will have a slightly reduced energy efficiency in warm climates, where the gas cooler output temperature is high, due to higher expansion losses and increased heat rejection losses. A possible solution to this problem is using a mechanical subcooler, which cools down the CO_2 leaving the gas cooler, leading to reduction in the vapour fraction at the liquid receiver inlet, and consequently to a performance improvement (Hafner, Hemmingsen et al. 2014). Figure 4 shows the system layout with mechanical subcooling, as well as the *log(p)-h* diagram for the cycles with and without mechanical subcooling. A subcooling system will however increase the investments costs, and these systems have had reliability issues related to the subcooler heat exchanger as well. Alternatives for a subcooling unit are for instance an additional gas cooler with evaporative/wet cooling, or heat rejection to an energy well, providing a temperature level below ambient temperature during the warm season.

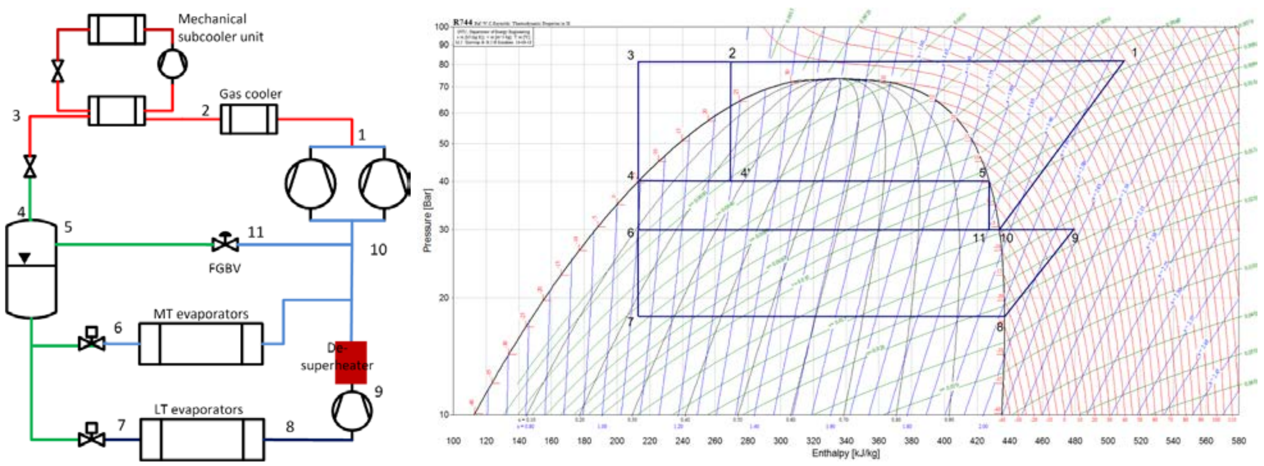

Figure 4 (a) CO_2 booster system with mechanical subcooling and (b) *log(p)-h* diagram for CO_2 booster system with (3-4) or without (2-4') mechanical subcooling.

On the other hand, too low gas cooler outlet temperatures are a challenge in cold climates during winter time. If the temperature at the inlet of the high-pressure control valve reduces below 5 °C, the pressure level in the separator drops below the level which is required to deliver liquid refrigerant to all the

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evaporators. This problem can be prevented with bypassing, or letting only a small portion of the working fluid through the external gas coolers and using only heat recovery (see Figure 6 (a)). Alternatively, a separate, significantly smaller gas cooler, dimensioned for winter conditions, may be used.

3.1.2 2nd generation: Booster system with parallel compression

The amount of vapour downstream of the high-pressure control valve increases as the external temperature rises. The reduced specific cooling capacity leads to an increment in the amount of refrigerant which has to be compressed from medium to high pressure, implying a growth in the energy consumption associated with the MT compressors, especially during summertime (Gullo, Elmegaard et al. 2016). A solution to this challenge is to adopt an auxiliary, parallel compressor on the purpose of sucking either a part or the entire amount of vapour from the separator and compress is directly to the gas cooler pressure. Such a system solution is called booster system with parallel compression, shown in Figure 3 (b). The corresponding *log(p)-h* diagram is shown in Figure 5.

Having an auxiliary compressor reduces the losses due to flashing. The auxiliary compressor is only operative if there is a sufficiently large amount of flash gas (otherwise the compressor would have a too poor operation). If the amount of flash gas is low, e.g. during winter time, it is throttled via the flash gas by-pass valve as in a standard booster system.

Furthermore, energy efficient integration of AC is possible with parallel compression. The AC evaporator outlet enters directly the separator (see the following section). In this case the AC cooling capacity is provided by the auxiliary compressor, determining the pressure level of the separator.

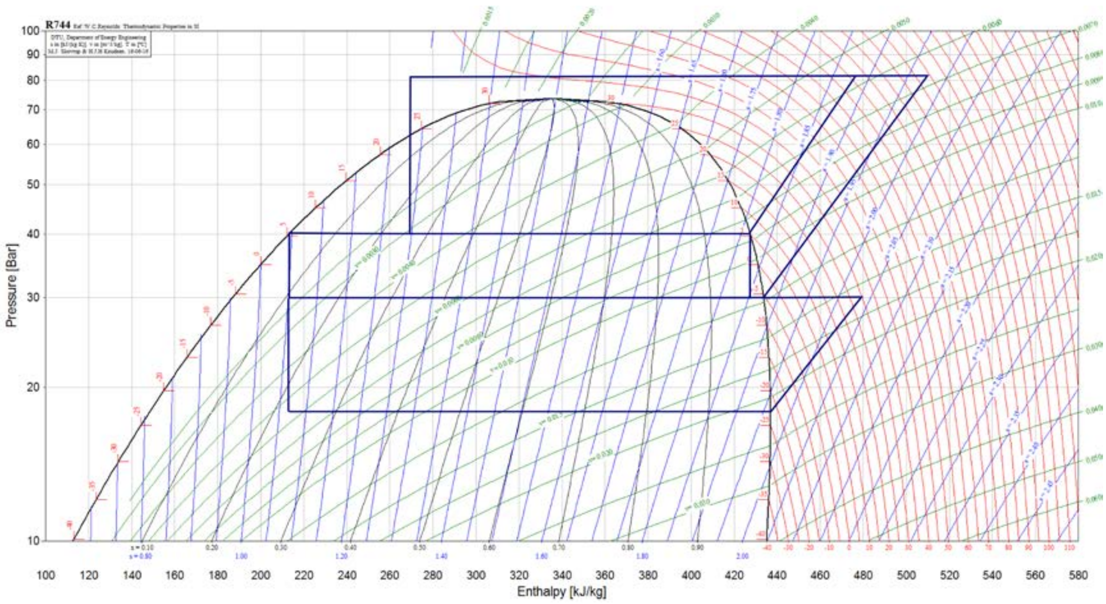

Figure 5 *Log(p)-h* **diagram for 2nd generation CO_2 system; booster system with parallel compression.**

3.1.3 3rd generation: The ejector system

The state of the art technology is to replace the high-pressure control valve with ejectors enabling for expansion work recovery, as illustrated in Figure 3 (c) and in more detail in Figure 6 (a). This is particularly important for CO_2 systems to be operated in warm climates, in which case the expansion losses are high, however, this ejector configuration can also be applied in cold climate locations. What an ejector does is that it entrains partly the low-pressure fluid downstream of the MT evaporators by means of high–pressure fluid coming from the gas cooler, accelerated in the motive nozzle of the ejector (Hafner, Försterling et al. 2014). Kinetic energy is converted into static energy, i.e. the pressure level between the suction nozzle and ejector discharge is equal to the pressure difference between the MT evaporators and the separator. The amount of vapour pre-compressed by the ejectors and discharged into the separator is determined by the available expansion work. The ejectors extend the operation time of the parallel compressors, by increasing the amount of vapour to be compressed. Ejectors hence shift a part of the MT compressor load to the

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parallel compressor which has to overcome a significantly lower pressure lift, hence reducing the total power demand.

When ejectors are used, some of the liquid from the low-pressure receiver is fed to liquid ejectors and vapour to vapour ejectors. The operation principle is as described above for both ejectors, but the dimensions of the internal flow channels are different. For active control of the discharge pressure at varying ambient (heat reclaim) conditions, a multi-ejector solution is necessary, where a number of ejectors are connected in parallel. To maintain a certain high side pressure, the requested effective flow area of the ejector rack is then varied through on-off operation of the individual ejectors. Other vendors have developed large variable capacity ejectors, in which case only one ejector is used to control the high side pressure by varying the effective flow area through flow restriction in the nozzle (R744.com 2016).

Moreover, using ejectors enables to operate the evaporators without any superheat, i.e. in flooded mode. In standard DX evaporators, part of the evaporator has to provide superheating of the refrigerant, reducing the heat transfer rate. In flooded direct expansion evaporators, the vapour fraction of the refrigerant downstream of the MT evaporators can be continuously kept at around 100 %. This leads to increased heat transfer rate and better utilization of heat exchanger area, allowing significantly higher evaporation temperatures (around -2 °C with optimal design of the display cabinets) and hence increased overall energy efficiency for the system.

Figure 6 (a) presents also an innovative approach for integrating AC capacity in the circuit, without a separate AC compressor. The AC loop is cooled down by evaporating CO_2 in natural circulation from the separator, and is activated with an on/off valve. The evaporated CO_2 is returned to the upper part of the separator, from where also the parallel compressors get their suction flow. With this approach, control and regulation becomes easier as there are only two evaporation pressure levels. The pressure level in the receiver (around 40 bar, corresponding to an evaporations temperature of ca. 5 °C) is low enough to allow sufficient cooling for the AC loop. The system costs are lower as no extra compressor, condenser, control, etc. is required for AC.

Depending on the design of the HVAC unit, direct expansion of CO_2 in the ventilation air stream could be applied to further reduce the total installation cost, avoiding the entire chilled water loop. This would additionally enable a further raise in the separator pressure level, since the required evaporation temperature for direct air cooling is in the range of +10 °C (corresponds to ~45 bar separator pressure).

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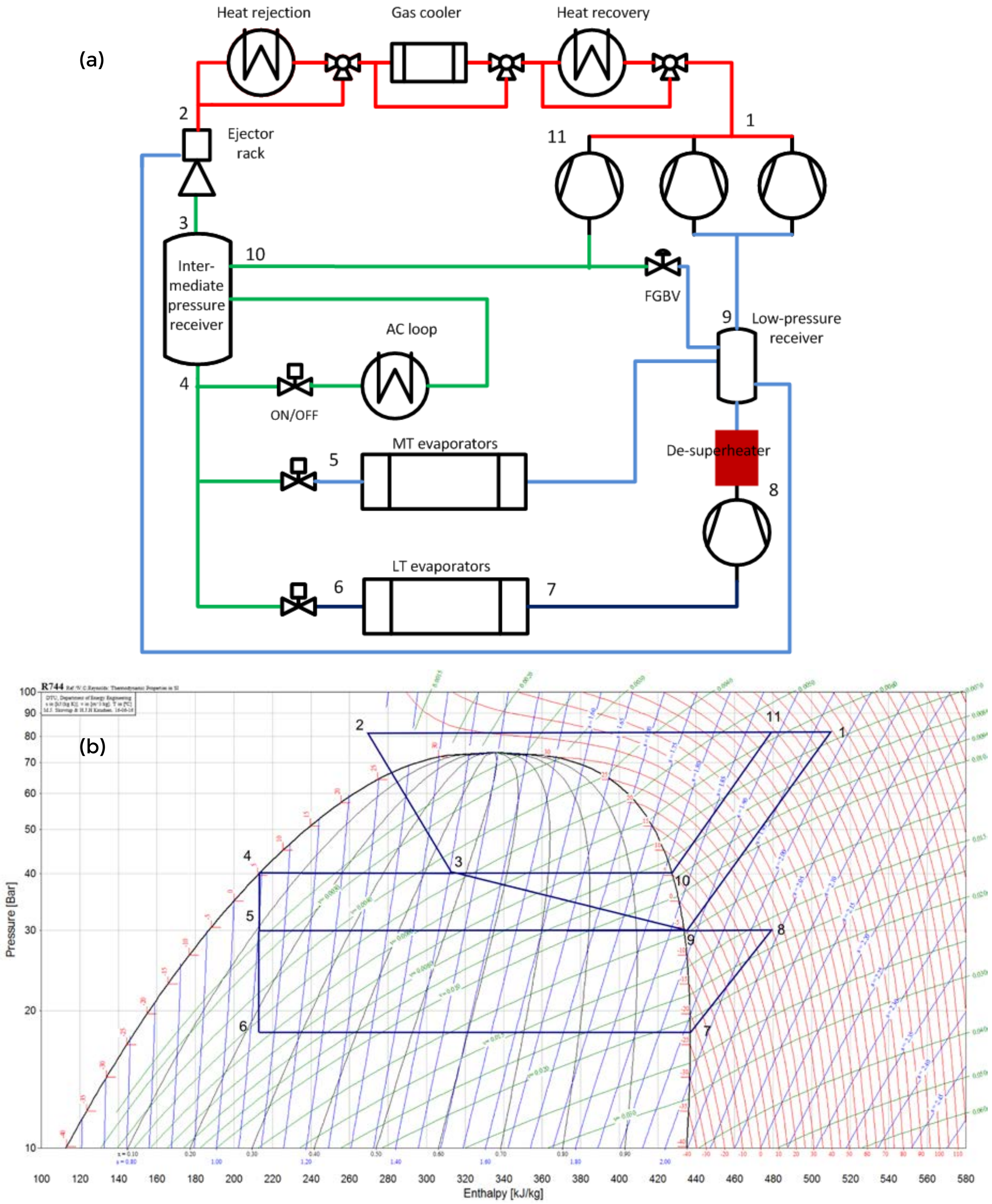

Figure 6 **(a) Principle scheme for supermarket refrigeration system with ejector and (b) the corresponding *log(p)-h* diagram.**

3.2 Condensing units

The typical refrigeration capacity of a condensing unit is in the range of 1 to 20 kW. Several display cabinets and/or indoor AC units can be connected to these units, which explains their global popularity for small shops and convenience stores. Currently H(C)FC refrigerants are dominating this market segment, supported by Asian manufacturers. There are however no technical barriers which would prevent CO_2 refrigeration units from becoming an alternative working fluid for condensing units. In Japan, more than

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1000 small supermarkets have been successfully converted from HFCs to CO_2 during the past years, as described by Uto (2016). Energy savings up to 27 % are reported by the end-users.

A successful transfer of this technology from Japan to Indonesia has also taken place (Santoso 2016, Uto 2016). 12 pilot stores in Indonesia are equipped with the same CO_2 technology as in Japan. Despite being located close to the equator, energy savings of around 20 % as compared to conventional HFC systems used previously and additionally a 15 % higher turnover due to increased customer comfort have been reported for the stores in Indonesia (Santoso 2016).

All these new Asian CO_2 units are integrated systems, i.e. the AC unit (and space/hot water heating where needed) is a part of the refrigeration unit. The systems are operated without ejector technology, hence their energy efficiency could still be improved. Nevertheless, in the South East Asian countries the investment costs for the new CO_2 units are still relatively high as compared to traditional H(C)FC units, which hinders large-scale commissioning of the technology.

3.3 Plug-in units

Plug-in units have the advantage of having a relatively small refrigerant charge and very leak tight circuits, since the refrigeration system is finished when the product leaves the factory. They are a tempting option, as the specific investment costs are extremely low as compared to a central refrigeration system, and they are also cheap and easy to replace upon failure. The main disadvantage is that the condenser heat is released directly to the sales area, creating an additional heat load to the supermarket and hence increasing the energy costs (AC requirement). Moreover, still non-natural refrigerants are often utilized, even if more energy efficient options with natural working fluids are available. In general, in larger stores, having a centralised refrigeration unit, plug-in units should be avoided as far as possible. If still some plug-in units have to be installed, those utilizing natural refrigerants (hydrocarbons), available from most suppliers, should be chosen.

Plug-ins utilizing CO_2 are also available from ISA (ISA 2016) and SANDEN/Hauser (R744.com 2015b). In tests by ISA comparing plug-in units utilizing R404A, propane and CO_2, 14 % lower energy consumption was obtained with the propane unit and 16 % reduced energy usage was measured with the CO_2 unit as compared to the R404A unit (Menghini 2016). The initial system cost was however 8 % higher for both the propane and CO_2 unit as compared to the R404A unit, owing to the double compressor in the case of the propane unit and heat exchanger costs in the case of the CO_2 unit. SANDEN reports 21 % reduced energy use and 15 % higher initial costs when comparing CO_2 plug-in unit with an HFC unit (Gillaux 2016).

3.4 Refrigeration components: design and operation

3.4.1 Compressors

Frequency control/variable speed drive compressors enable to adjust the cooling performance of the refrigeration system to the demand. This has earlier been done by on/off control of individual compressors owing to high costs of frequency converters; however the prices are lower now. Frequency control may allow energy savings of up to 25 %, improved performance at part load and increased working life (Bouchareb, Gibson et al. 2003), as well as a reduction in the total number of installed compressors.

For CO_2 compressors, many different suppliers, and all capacity ranges (from small stores to hypermarket scale) are nowadays available. Reciprocating compressors are the dominating technology, due to the strongly varying heat rejection conditions (condensing pressure). A reciprocating compressor is able to adapt to the varying conditions better, with less variation in efficiency, than other compressor designs. For LT, the pressure ratio is however more constant (between LT and MT) and other compressor types may be applied as well.

3.4.2 Expansion device

Use of electronic expansion valves instead of thermostatic expansion valves allows an adaptive adjustment of the control characteristics during operation. Electronic expansion valves are also able to operate with a lower pressure difference, allowing a more radical decrease in condensation temperature. In a large Italian supermarket, energy savings of between 20 % (summer) and 35 % (winter) were achieved by using

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electronic expansion valves for the MT and LT evaporators, as compared with a similar supermarket using thermostatic expansion valves (Bobbo, Camporese et al. 2005). For future CO_2 refrigeration systems, the individual local expansion valves of the cooling and freezing equipment attached to the centralised unit should also be able to handle flooded operation.

3.4.3 Evaporators/condensers

An evaporation temperature increase by 3 K reduces the energy use by approximately 3 %. Lowered evaporation temperature can be achieved by increased evaporator area, and by using an IHX installed after the evaporator. An IHX allows transferring superheat, only required to safeguard the compressors, into the refrigerant leaving the evaporator from the refrigerant leaving the gas cooler, which is then simultaneously subcooled. This increases the overall energy efficiency.

Increased evaporation temperature is also facilitated by using flooded direct expansion evaporators, enabled through the use of ejectors, as was discussed in section 3.1.3. For flooded evaporators, the evaporation temperature should ideally be -2 °C for MT chillers and -25 °C for LT freezers. These temperature levels are the highest that can be achieved today in pilot supermarkets.

As the energy use of the compressor is dependent on the lowest evaporation temperature, it is of utmost importance that all cabinets connected to the same compressor are designed for the same evaporation temperature.

Evaporators are often defrosted by means of a time shift, even if defrosting is often not necessary at the time pre-set by the timer. In new CO_2 refrigeration systems using flooded evaporators with elevated evaporation temperatures, defrosting once a week is sufficient! Alternatively, defrost on demand can be performed by observing the evaporation temperature (the evaporator temperature drops upon defrosting) (Kauffeld 2015). Furthermore, adequate defrosting flaps or socks, controlled by motors, can be used to interrupt the air exchange with the refrigeration room during defrosting.

For condensers, condensation temperature/high-side pressure should be lowered as far as possible. In CO_2 systems, gas cooler outlet temperatures can be lowered by using evaporative condenser/gas cooler cooling. Serial arrangement of gas coolers should be applied with respect to heat recovery and rejection to different heat sinks (see section 3.8).

Air-cooled heat exchangers, in particular condensers in the plug-in units, are prone to contamination. Periodical cleaning of any heat exchanger surface improves the heat exchange and hence reduces the energy consumption.

3.4.4 Cabinet design

Figure 7 illustrates the cooling load for an open multi-deck refrigeration cabinet. There are several ways to reduce the cooling load through improved cabinet design, the single most important of them being the use of glass doors or lids. As shown in Figure 7, approximately 75 % of the cooling load is due to air infiltration. With cabinets covered by a glass door or lid, the refrigeration capacity of the supermarkets can be reduced by up to 40 % (Kauffeld, Harnisch et al. 2008). In a laboratory study, 60 % reduction in daytime energy use was obtained, while the interior storage temperature of the goods was reduced by up to 4 K in the daytime and 5 K in the night time (Lindberg, Axell et al. 2010). Measurements at a cash-and-carry market in Austria, comparing the cooling load of open refrigerated multi-decks with those retrofitted with sliding glass doors, resulted in energy savings of 86 % (KWN Engineering 2004).

Besides the reduced cooling load, the energy consumption for defrosting will be reduced as less ambient air and hence less humidity will enter the cabinet. Single, double or triple glazing of low emissivity may be used. If possible, the glass doors/lids should be coated with a thin metal layer to reflect heat (infra-red) radiation, further reducing the energy consumption.

Many retailers are concerned that introduction of glass doors will result in reduction in sales. There are no studies on the influence of glass doors on the supermarket turnover, however based on observations from retailers, no losses in sales were documented after retrofitting of individual supermarkets (Kauffeld 2015). Furthermore, with glass doors, the air temperature in the aisle in front of the cabinets will be higher. The customers hence tend to spend a longer time in front of the cabinets, increasing the sales.

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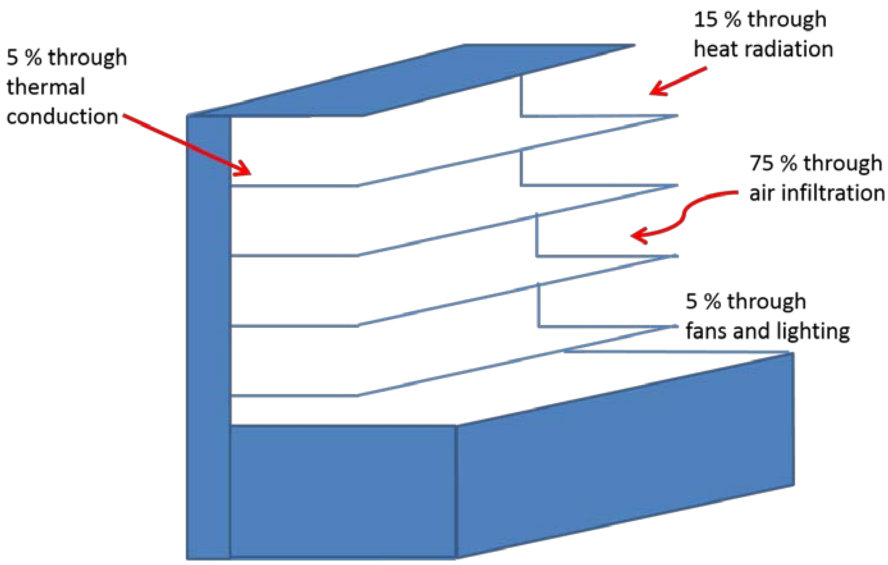

Figure 7 Approximate cooling load for an open refrigerated multi-deck cabinet (Kauffeld 2015).

Further measures for improved energy efficiency in refrigerated cabinets (Laguerre 2015):

- **High-efficiency fan motors and fan power adjustment:** By using energy-saving (PM) motors and aerodynamic optimization of the fan blades, the energy consumption of the fans can be reduced considerably, by up to 70 % when compared to conventional fans (Goetjes 2007).
- **Evaporator fan outside the cabinet:** By placing the fan motor outside the part of the refrigeration unit to be cooled, only a small part of the propeller fan mechanical power is fed to the air to be cooled (Kauffeld 2015).
- **Anti-condensate heaters on the display doors.** The design of the anti-condensate heaters depends on the door characteristics, cabinet configuration, ambient conditions (dehumidification by the AC unit) and frequency of the door opening.
- **Use of LEDs for lighting inside the cabinet.** LED lights consume approximately half of the lighting energy compared with fluorescent tubes while maintaining adequate product lighting. Lighting power reduction serves the additional benefit of reducing the heat load into the cabinet. LEDs have the additional advantage that they consume less energy the cooler they are kept, opposite to fluorescent tubes. Use of LED lights may hence reduce the energy use by a factor of 60-70 % as compared with the use of fluorescent lamps (Raghavan and Narendran 2002). Apart from using energy efficient lights, it may also be possible to place the lighting outside of the refrigerated zone, or one may install reflectors or light conductors (Kauffeld 2015).
- **Improvement of insulation materials.** Thermal conduction through walls is responsible for approximately 5 % of the cooling load, as shown in Figure 7. This load can be significantly reduced by improved thermal insulation, such as PU-foam (Kauffeld 2015).
- **Infrared reflecting shades and baldachins.** Approximately 15 % of the cooling load of an open multi-deck cabinet results from heat radiation exchange with the surrounding air, as shown in Figure 7, and the share is even larger for open chest freezers (Kauffeld 2015). This impact can be efficiently reduced by using infra-red reflecting shades or baldachins/canopies mounted at the top of the cabinet.
- **Use of night covers.** Energy savings of 25-40 % have been reported through the use of night covers (Axell and Fahlen 1995, Axell and Fahlen 1998).
- **Improved anti-sweat heaters, edge/rim heating, dew point control.** Rim heating for chest freezers prevents condensation from ambient air, and improves customer safety/comfort through increased edge temperature. A portion of this heat is conducted to the refrigeration unit and creates hence an additional cooling load. By demand-controlled edge heating, i.e. adjusting the surface temperature slightly above the dew point temperature of surrounding ambient air, a reduction in this cooling load by 5 % is possible (Faramarzi 2004).
- **Correct product loading of the refrigeration/freezer units:** Overfilled open refrigerated multi-decks consume up to 6 % more energy, while the temperature of the warmest products increases by 6 K (Faramarzi 2004).

3.5 Air-handling unit

The purpose of an air-handling unit (AHU) is to maintain a satisfactory indoor climate, considering the temperature, relative humidity and the air composition (CO_2 concentration, pollutants, moisture etc.). Basics of supermarket ventilation, AC and dehumidification are given in given in the report D2.2, Eco-friendly supermarkets – an overview (Karampour, Sawalha et al. 2016).

Humidity is of particular concern due to possible condensation problems in the refrigerated cases; although open displayed food may lose weight when exposed to dry air. Using dehumidification in the AC system increases the energy consumption of the AHU, however, the water contained in the air is only condensed in the evaporator of the AC unit instead of building up frost in the refrigeration units. Consequently, the number of defrost cycles can be significantly reduced resulting in a higher overall COP.

In today's supermarkets, AHU units designed for office buildings are often used (Hafner 2013). These use normally rotating heat recovery wheels, resulting in unnecessary large fan power consumption due to the high pressure losses through the wheel and filters. Auxiliary (electric) heating of the supply air is often utilized, rendering heat recovery from the refrigeration system difficult. Furthermore, including dehumidification in these systems may be difficult.

In Kroppanmarka supermarket in Norway, an AHU by Systemair designed particularly for supermarkets (Figure 8) was chosen (Hafner 2013). The system includes the following features:

- Heating of supply air by hot water from thermal storage tanks (water heated only with surplus heat from the refrigeration system)
- Re-use of indoor air based on exhaust air CO_2 levels (shop air quality). Outdoor air added only according to the demand, reducing the electricity use and supply air humidity.
- Possibility for dehumidification with a chilled water circuit
- Bypass of components not in use (heat recovery wheel and heat exchangers)
- Free cooling from energy wells (heat rejection)
- Permanent magnet (PM) electrical motor with 90 % efficiency, low vibration and noise

In addition, floor heating is used in the building, reducing the required heat supply covered by the AHU unit and hence the required air flow rates.

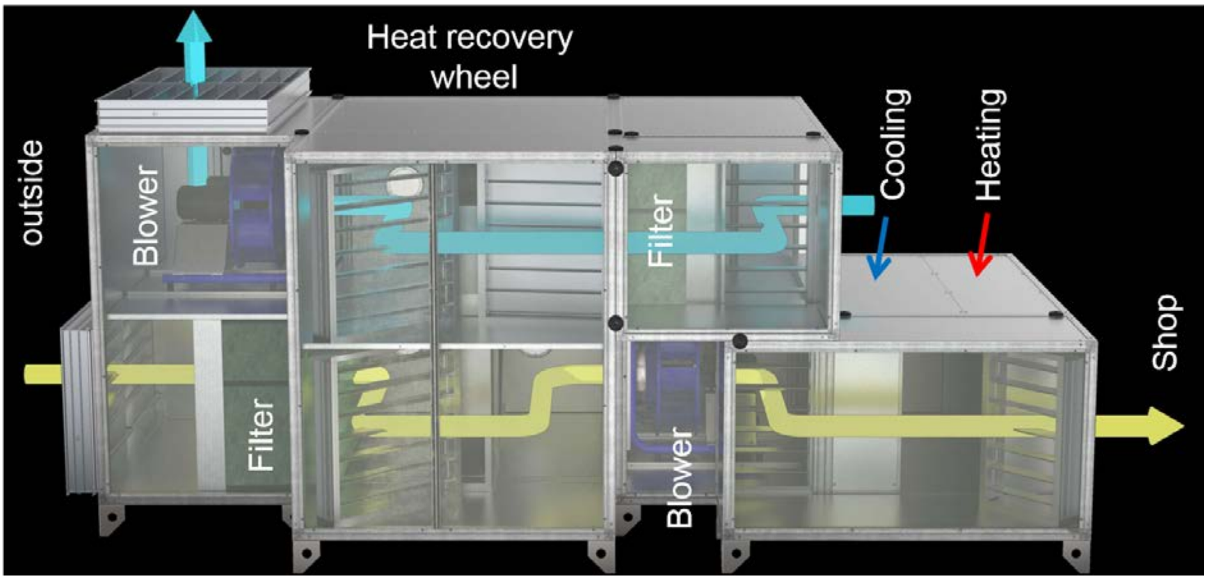

Figure 8 Supermarket AHU unit by Systemair, employed in REMA 1000 Kroppanmarka in Trondheim. Here the venting (free air cooling mode) is shown (Hafner 2013).

3.6 Thermal storage

Any material has a thermal capacity, an ability to store heat, but the amount of heat and the rate at which it can be stored varies. A material with high thermal capacity can be used for shifting heating or cooling loads from times of high demand to times with lower demand and, normally, lower prices. Peaks and net demands for heating and cooling can hence be reduced, allowing a reduction in the installed heating and cooling capacity. The challenge is good heat transfer and the appropriate choice and dimensioning of the thermal storage.

In supermarkets, special peaks of cooling load arise in the morning when new, partially warm goods are delivered and reloaded in the cabinets, and in the afternoon during the busiest hours of sale (Kauffeld 2015). The refrigeration system must be dimensioned to cover these peaks, and most of the day it operates in the part-load mode, which is generally not the most efficient mode of operation. With thermal storage, a large part of the refrigeration load can be shifted to the night hours when ambient temperatures are lower, allowing reduction in both the energy demand as well as the installed capacity of the compressor racks. Similarly, the highest cooling loads occur in the summertime, and with appropriate seasonal thermal storage even these peaks can be reduced. Types of thermal storage applied in supermarkets are water tanks, energy wells, and phase change materials (PCMs). The applications, temperature range and time scale of these storage options are summarized in Table 2.3, and discussed in more detail below.

Table 3.2 Summary of different thermal storage options suitable for supermarkets.

Type of thermal storage	Temperature range [°C]	Time scale	Suitable for
Geothermal storage/energy wells	2-20	Seasonal	Condenser heat sink and free cooling (summer); heat source for heat pumps for space heating and hot water production, as well as snow melting (winter).
PCM	Practically all; depends on the choice of the PCM.	Diurnal	Peak shaving of demand for AC and cooling in all refrigerated disks (including plug-ins); shifting load to the night, extra security at shorter power breakdowns.
Water tanks	0-100	Diurnal	Utilization of condenser heat for space heating and hot water production, peak shaving of cooling or heating needs.

3.6.1 Geothermal storage: energy wells

For stand-alone supermarkets, geothermal storage for accumulating and extracting heat and cold have been successfully implemented (GI Energy 2014, Hafner and Tønseth 2014). There are two main types of geothermal storage: aquifer thermal energy storage (ATES), involving direct use of ground water, and borehole thermal energy storage (BTES), involving the use of a well filled with water or bauxite for thermal contact where no water exists. ATES is the cheapest alternative but can only be applied in places where there are aquifers (IFTech 2005-2016). BTES can be applied in any type of ground, but the investment costs are high, depending on the ground type (Båsum 2012-2015). Several holes of normally 50-250 m are drilled down into the bedrock and an ethanol based fluid is circulated up and down in two or four hoses installed in each well. It is important not to build the wells too short, as they then cannot cover demands, and extending them afterwards is difficult. Appropriate spacing between the wells is also important.

Energy wells are a seasonal thermal storage. They serve as a heat sink, storing the heat in the summer or whenever excess heat is available, and provide a heat source in periods with high (auxiliary) heat demand. The ground temperature is fairly stable and uniform below 15 m (Burkhard 2013). Energy wells, wherever applicable and legal to implement, hence provide a heat sink independent of the ambient temperature, allowing stable operation conditions for the refrigeration system. The temperature of the heat stored in the ground should however not be too high, the normal range being around 2-20 °C (Burkhard 2013). In warm climates, in order to prevent an increase in the ground temperature, the stored heat has to be removed during the winter and utilized for heating purposes. Similarly, in cold climates where a lot of heat is extracted from the wells in the wintertime, the ground has to be recharged during the summertime.

The stored thermal energy can seldom be used directly for heating or cooling, however, it is a valuable heat source or sink in combination with a heat pump, or in the case of a supermarket, the central refrigeration unit. At REMA 1000 Kroppanmarka supermarket in Norway, four 170 m deep energy wells have been drilled, acting as a heat sink for the AHU and dehumidifier units in summer, and as additional heat source during the winter months (Hafner and Tønseth 2014). At Sainsbury's East Kilbride, 14 boreholes are employed as a

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heat sink to improve the system operation during summer, and provide heat source for hot water supply through a heat pump (GI Energy 2014).

3.6.2 Water tanks

Water tanks can store heat at a wide range of temperatures, from 0 up to 100°C. Water has a very high thermal capacity and is a very good thermal storage material with regards to volume, price, environmental concerns and ease of use. Hot water tanks with a volume up to approximately 1000 l are commonly used as a diurnal thermal storage, also in supermarkets in areas with high heat demand (see section 3.8), or when DHW is needed.

In warmer climates, it is possible to use larger water tanks to accumulate chilled water for cooling purposes. DN Tanks provides water thermal reservoirs made of concrete, with a volume ranging from 300 to 200 000 m^3 (DNTanks 2015). The reservoir provides chilled water to nearby buildings during the day. Hot water is returned to the tank, while cold water sinks to the bottom and thus makes it possible to continue cooling by extracting water from the bottom. At night, a refrigeration unit cools the now hot water in the tank and the return water from the buildings, thus covering the cooling demand and recharging the tank simultaneously. An opposite solution for heating is possible in colder climates.

3.6.3 Phase change materials

While energy wells and water tanks store heat as sensible heat of water, PCMs store it as latent heat. The energy of phase change (latent heat) is much larger than that of temperature change alone, resulting in a higher energy density and reduced demand for heat storing material, and space. Furthermore, as the phase change takes place at a constant temperature (or nearly constant for mixtures), the temperature around the PCM will be very stable. In most processes, the PCM alters between solid and liquid phase when used for thermal storage (due to the large expansion upon phase change from liquid to gas). The PCM is typically enclosed into capsules or in a container, and a secondary fluid is transferring heat in and out of the PCM storage and towards the heat exchangers.

PCM has shown to be a potential approach for improving the efficiency of buildings AC (Etheridge 2006). The savings that can be achieved depend on the temperature of the fluid with respect to the temperature that needs to be maintained. In a simulation study of domestic cooling, a PCM with a melting temperature of 4°C gave 4 % savings; 10°C gave 14 % savings whereas 0°C increased the energy demand (Bruno 2014). Use of solid CO_2 as a cold storage system in large-scale freezing applications has been suggested by Hafner, Nordtvedt et al. (2011). In this study, calculations showed up to 30 % lower electricity demand for equal freezing capacity, when the cold TES was applied to prevent inefficient part load operation of a large ammonia refrigeration plant.

In supermarkets, placing PCM units inside the refrigerated cabinets is a promising alternative (Foster, Campbell et al. 2013, Lu and Tassou 2013). As the PCM will retain the cold for some time even with insufficient cooling from the refrigeration system, such an approach could reduce the peak cooling loads during warm periods. This would allow a refrigeration system with lower installed capacity and investment, and shift parts of the cooling load to the night when electricity prices (and temperatures) are lower. Such a solution gives also an extra operational security, maintaining a stable temperature in the cabinet upon defrosting or if a system failure should occur. A suitable PCM for supermarkets is water/ice; for MT cabinets, an ice bank or ice slurry system can be used (Kauffeld 2015).

Having PCM integrated in the cabinets could also serve as a smart energy storage for supermarkets with local production of renewable electricity by wind turbines or solar photovoltaics (PV). During periods with high electricity production, the refrigeration system can produce excess cold that is stored in the PCM units, and utilized during periods of low electricity production and high cooling demand.

3.7 Heat and cold distribution

For distribution of heat and cold inside the sales area, ventilation or floor heating system may be used. In cold climates, floor heating is the preferred approach for heat distribution. For customer comfort, higher temperature close to the floor and lower close to the ceiling is the preferred condition, and this will be achieved if heat is supplied through the floor and cooling from the ceiling (Zijdemans 2012). Floor heating produces also an even temperature distribution inside the store, utilizing the natural flow direction of the

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air, as hot air rises and cold air sinks. Furthermore, with floor heating, ventilation is no longer necessary for space heating. Consequently, the air circulation rate can be reduced significantly, reducing pressure losses and the entrainment of cold outdoor air, and hence the energy use. Floor heating is also a very good way to utilize medium temperature heat rejected by the condensers of the refrigeration system (see section 3.8).

When designing a floor heating system, the thermal conductivity, and thickness of pipes and floor must be taken into account. The floor, in particular concrete floor, has also a significant thermal capacity, hence acting as a thermal storage. Floor heating is therefore slower than ventilation in responding to changes in heating and cooling demand. Floor heating system is controlled through adjusting the supply temperature level and the mass flow rates, which also allows maintaining zones with different temperature levels inside the store. The supply temperature for floor heating is normally 35-40 °C, but the system should be designed such that the floor temperature does not exceed 29 °C (Zijdemans 2012).

In hot climates, cooling should be provided not only through the central AHU (limited amount of air circulation), but also by several air coolers, placed underneath the ceiling in the sales area. Even distribution of such units ensures a uniform temperature throughout the store. Enex has developed local space heating and cooling units utilizing CO_2 directly from the central refrigeration system as the heating/cooling medium, shown in Figure 9 (Girotto 2016), avoiding the secondary fluid circulation system. Such a direct heating/cooling solution could be particularly suitable for small shops, enabling cost reductions and energy savings as only one system is needed for refrigeration/freezing appliances, and space heating and cooling. The beneficial transport properties of CO_2 enable reduced pumping power, and lower temperature lift that needs to be generated by the refrigeration system, enhancing the system COP.

Figure 9 Local direct CO_2 heating/cooling unit by Enex (Girotto 2016).

3.8 Heat recovery

The condenser/gas cooler heat from the refrigeration system can be recovered and utilized to several different purposes. Potential uses and their minimum temperature requirements, as well as common heat recovery strategies are presented in the report D2.2, Eco-friendly supermarkets – an overview (Karampour 2016).

CO_2 systems are particularly well suited for heat recovery owing to the high compressor discharge temperatures and gliding temperatures in the heat rejection in the transcritical cycle. Figure 10 shows an

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example of an integrated system layout from REMA 1000 Kroppanmarka, where heat from a central CO_2 booster system is recovered at three temperature levels.

Heat from the first gas cooler, downstream of the compressors, is stored in the hot storage tanks (HST, red cycle in Figure 10), from where heat is supplied primarily to heat ventilation air in the AHU. The heat can also be utilized towards an air curtain at the entrance or the villa vent unit, which supplies heat to the social rooms in the shop. Three HSTs with a total volume of 2.7 m^3 are utilized. The HSTs also include spiral heat exchangers connected to the floor heating loop, in case of increased floor heating supply temperature requirements. There is also an electric backup heater included in the system, in case of a major failure in the refrigeration system. (Jorschick 2014).

The heat from the second gas cooler, which has a CO_2 inlet temperature of about 30 °C depending on the temperature distribution in the HSTs, is rejected to the floor heating loop (blue). A mixture of water and a propylene glycol-based fluid is used as heat transfer fluid. Two snow melting circuits that keep the entrance and service ramp free for snow and ice are additionally connected to this loop. If not all the heat can be applied inside the shop, excess heat is rejected to the environment by dry coolers. (Jorschick 2014)

The third gas cooler rejects heat towards the cold fluid of the energy well (EW) loop (purple). The loop consists of four vertical energy wells with a depth of 170 m each, with approximately 8 m spacing in between. A water-alcohol mixture is used as a secondary fluid. During the summer, when there is no heat demand in the shop, the EWs are charged by providing free cooling of the ventilation air and at the same time contributing to reduce the CO_2 return temperature upstream of the high side pressure control valve, improving the COP of the refrigeration system. If the temperature level of the secondary fluid from the energy well is too high to provide AC, a CO_2 evaporator is be applied to adjust the temperature (preferably coupled to the parallel compressor, or even to the MT compressor when there are only a few annual operating hours and if only a simple booster system is installed). During the winter, the EWs can be used as a heat source, through an auxiliary evaporator at MT pressure level. (Jorschick 2014)

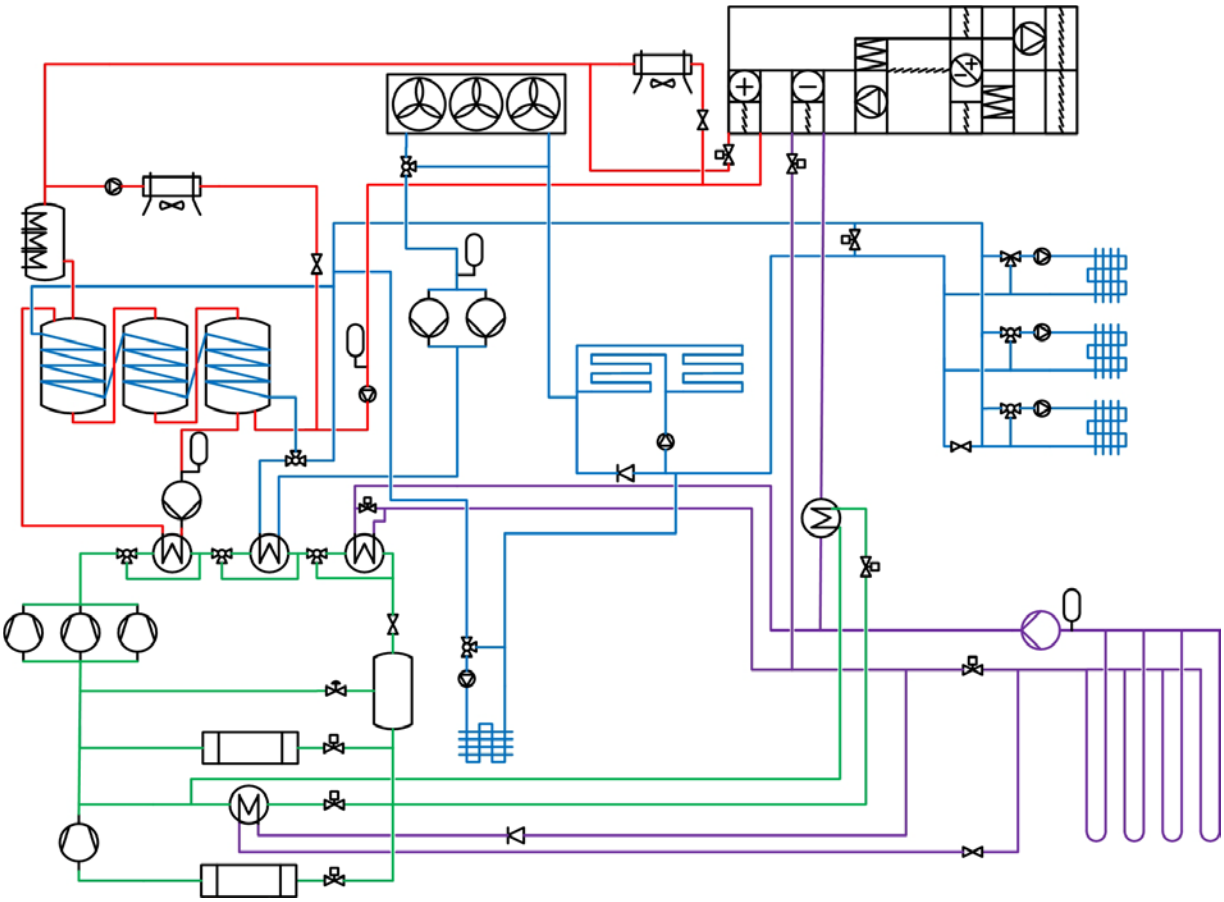

Figure 10 Integrated refrigeration and HVAC solution for REMA 1000 Kroppanmarka supermarket, Trondheim, with CO_2 as the refrigerant (Hafner 2013).

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Figure 11 and Figure 12 illustrate possible strategies for the gas cooler heat recovery on a T-s diagram for cold and hot climate, respectively. The overlap is a region that could belong to either the category above or the one below, depending on the demand. For cold climates, on a hot day, the situation could be much like the one in the hot climate, but the internal heat exchanger should be placed before the exchange with the ground (energy wells), as the ground would hold a much lower temperature in colder climates. On a cold day, it is important to note that the return temperature from snow melting should not be too low (≥ +5 °C), such that the state after throttling is within the vapour dome.

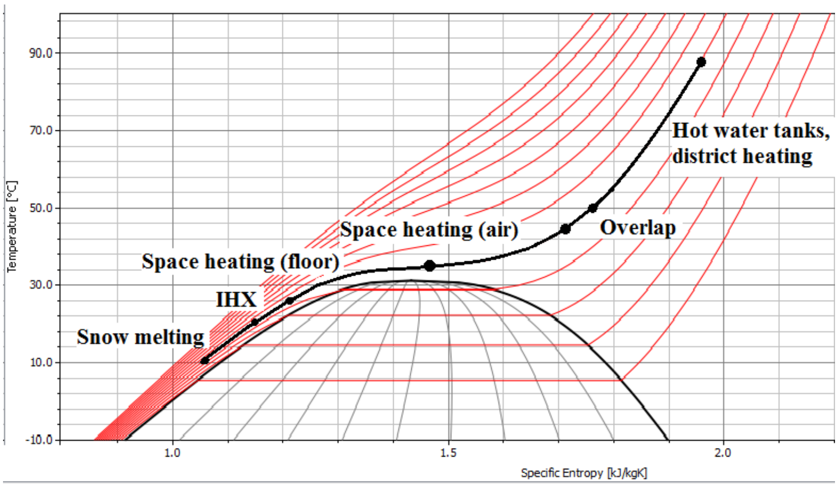

Figure 11 **CO_2 gas cooler heat recovery in a cold climate (with high external heating demand), shown in a temperature-entropy (T-s) diagram.**

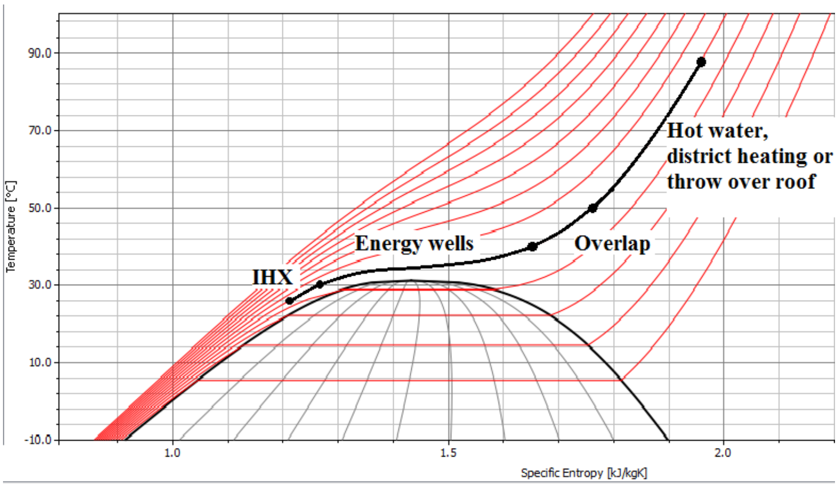

Figure 12 **CO_2 gas cooler heat recovery in a hot climate, shown in a temperature-entropy (T-s) diagram.**

The centralised refrigeration unit of a supermarket is a capital intensive part of the building and should be integrated with other energy systems in its surroundings. Excess cooling capacity and the surplus heat can be utilized to different purposes outside the supermarket, depending on if the supermarket is a stand-alone building, a part of a larger building complex, or placed in the ground floor of a block of flats. REMA 1000 supermarket in Trondheim, Norway, residing at the ground floor of an office block is one example. The supermarket provides AC (chilled water) and heating for the entire building with its CO_2 parallel compression system, and excess heat is also utilized for snow melting (Herdlitschka 2016).

3.9 Control and monitoring

A good control system and energy monitoring system are crucial for successful operation of the supermarket. By means of computer-aided control systems, many of the measures described in this report

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can be adequately integrated into one multifunctional system controller. This topic is discussed in detail in a dedicated report, D2.6 Eco-friendly operation and maintenance of supermarkets (Ciconkov and Ciconkov 2016).

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4 NON-TECHNICAL BARRIERS

Lack of awareness	
Barrier	**Solution**
Lack of awareness on available new solutions, in particular regarding only-CO_2 systems for warm climates.	Demonstrating and documenting the reliability of new solutions with direct reference to existing/running systems.
The initial costs for CO_2-based systems are still high compared to conventional systems based on H(C)FCs. Lacking awareness on financial support.	Informing about financing possibilities (see appendix A)
The savings in operational costs of new solutions are not well-known. For many supermarkets, the installation costs are more visible than the operation costs, thus the savings on operation are less important.	Documenting and demonstrating annual savings in operational costs, and the reduced total cost of ownership. Success stories from new eco-friendly supermarkets are important, but the savings can also be demonstrated by numerical tools.
Lack of knowledge	
Barrier	**Solution**
Lack of training material and programs, adapted to the level of expertise of the different stakeholders, available in different languages and at a reasonable cost.	Visit the website of SuperSmart! http://www.supersmart-supermarket.info/
Lack of knowledge to operate novel efficient heating and cooling solutions in the best way.	Increasing the availability for training programs.
Lack of experienced trainers	Visit the website of SuperSmart! http://www.supersmart-supermarket.info/
Social barriers	
Barrier	**Solution**
Concern about increase in investment costs and long payback time.	Demonstrating and disseminating success stories on new eco-friendly supermarkets with decreased operating costs and increased revenue.
Fear for new solutions bringing about too many technical changes at the same time.	Increasing the level of confidence in new solutions by showcasing that technical changes are supported by training programs and technical sessions. Promoting interaction amongst stakeholders for mutual support.
Fear for new systems being less reliable than the old H(C)FC ones.	Demonstrating and disseminating success stories on new eco-friendly supermarkets and solutions with CO_2.
Fear for energy efficient systems not performing as promised.	Registering and disseminating energy consumption of new systems vs old ones using well-known performance indicators (e.g. kWh/m^2) and clear figures.
Increase in the required effort for new solutions or increased installation time.	- Increasing the availability for training programs and technical support - Increasing stakeholder awareness on the support available from suppliers and technical and research organisations to cope with the first installation and learn from it
Concerns about availability of trained technicians for installation/maintenance of the new systems.	As above, and promoting networking among stakeholders.
Concerns about consumers not appreciating and valorising improved environmental impact of supermarkets.	- Disseminating the negative environmental impact of H(C)FC-based solutions to a wider audience - Disseminating success stories on energy-efficient supermarkets where the improved food safety and consumer comfort has led to increased revenue - Making consumers aware and responsible for the environmental footprint deriving from their shopping habits, using mass media

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Organizational barriers	
Barrier	**Solution**
Conflicting interests of stakeholders involved in planning or operation of a supermarket. A problem in particular for heat recovery when a supermarket is a part of a building complex.	- Legislation on building integration and waste heat recovery. - Possibility for supermarket owner to sell the heat, for nearby buildings/users and to the DH grid ("prosumer" schemes in DH). - Promoting the concept that energy systems can be a part of the contractual obligations amongst the involved stakeholders
Lack of distributed responsibility chain for setting up an "integrated, efficient solution"	SuperSmart – to bring all parts of the chain together to create holistic, integrated solutions.
Lack of an energy rewarding/payback scheme between system owner and system operator	Set-up proposal for valorising energy solutions and make them a part of contractual obligations (e.g. rental fee, etc).
Short term view for energy efficiency investments	- Documenting reduced total cost of ownership in new energy-efficient supermarkets - Increasing awareness on financing possibilities - Legislation regarding energy efficiency
Legislative barriers	
Lack of legislation considering the supermarket system as a whole	New EU Ecolabel on supermarkets may eventually lead to such legislation.

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5 BEST PRACTICES AND CASE EXAMPLES

5.1 Germany

Aldi Süd Rastatt	
Opening year	2010
Location, country	Rastatt, Germany
Size [m²]	1 675 (useful area)
Type	Stand-alone
Energy efficiency measures implemented	• Good insulation, a very air tight construction • Utilization of daylight through glass cases in the ceiling, with three layers of glass. Lighting controlled depending on amount of daylight. • Controlled ventilation with heat recovery • Efficient refrigeration and HVAC with an integrated CO_2 system • Geothermal storage and thermally activated concrete (floor heating integrated in the bottom concrete slab) for storing heat/cold • use of surplus heat from cooling – possible to use the heat system as a heat pump • Energy flow monitoring • Automatically controlled systems • Regenerative and passive cooling
Reduction in energy demand and CO_2 emissions[1]	23 % reduction in energy demand
Energy use [kWh/m²a]	387 (primary energy use in 2012)
Total investment and payback	Construction 718 (€/m²) Technical system 332 (€/m²)
Financing solution	
Link for more information	(Fiksen, Grøndahl et al. 2012)(EnOB 2013) http://www.enob.info/de/sanierung/projekt/details/energieeffizienter-supermarkt-nutzt-tageslicht-und-erdreichkaelte/

EDEKA Center Wucherpfennig	
Opening year	2014
Location, country	Hannover, Germany
Size [m²]	3 312 (sales area)
Type	Stand-alone
Energy efficiency measures implemented	• Built in passive house standard • Integrated CO_2 refrigeration with heat recovery • Delivers heating and cooling to nearby buildings • LED lighting • PV installation of 120 kW_p
Reduction in energy demand and CO_2 emissions[1]	
Total investment and payback	
Financing solution	Received 50 000 € funding from proKlima
Link for more information	http://www.zvkkw.de/uploads/media/03_ZVKKW-Supermarktsymposium2016_Wohlfahrt.pdf

[1] As compared to similar supermarkets in the same region

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Lidl Germany	
Opening year	Several high efficiency stores with integrated units using propane. By the beginning of April 2012 Lidl had already opened 109 stores with the new integral units.
Location, country	Germany
Size [m²]	Different sizes
Type	Mostly stand-alone
Energy efficiency measures implemented	• Integrated system for refrigeration with heat recovery for heating • Refrigeration system uses propane (R290) in the primary circuit and potassium formate brine in the secondary circuit. The LT stage uses R744 direct expansion or also a secondary circuit with brine. The LT stage is built in as cascade in the MT stage. • Activated concrete core for heating and cooling • Central ventilation system with heat recovery • LED lighting • Conversion to (deep) cabinets with semiautomatic defrosting
Reduction in energy demand and CO_2 emissions[1]	• 100 % reduction in heating energy • 47 % reduction in energy use, and 30 % reduction in energy costs • 43 % reduction in CO_2 emissions
Total investment and payback	Investment: 19.5 mill. € Reduction in energy costs: 3.95 mill. €/year (47 %) Return on capital: 20 %
Financing solution	
Link for more information	(Proklima International 2010, hydrocarbons21.com 2013, Deutsche Energie-Agentur 2015)

5.2 Great Britain

Olympic Way, Wembley solution, Sainsbury's		
Opening year	2014	
Location, country	London, UK	
Size [m²]	252	
Type	Part of a building (convenience store)	
Energy efficiency measures implemented	• Booster CO_2 system • Intercooler (internal gas cooler) • Heat recovery to water, utilized for DHW production, heating of ventilation air and over door heater • Destratification fans	
Reduction in energy demand and CO_2 emissions[1]	**Reduction in average weekly energy use** 56.8 %	**Total annual carbon saving (kg CO_2)** 70, 503
Total investment and payback	14.15 months payback	
Financing solution		
Link for more information	http://www.atmo.org/media.presentation.php?id=764	

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5.3 Norway

NorgesGruppen – KIWI Auli	
Opening year	2014
Location, country	Auli, Norway
Size [m²]	
Type	Stand-alone
Energy efficiency measures implemented	• 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[1]	40 % reduction in energy use the first year (Halstensen 2016).
Total investment and payback	7.8 million NOK (additional costs due to energy efficiency measures)
Financing solution	The project received 3.7 million NOK from Enova
Link for more information	(Granås 2013), (KIWI 2015), http://www.tekniskenyheter.no/index.php/artikler/energieffektivisering/9-energieffektivisering/332-kiwi-butikk-med-hurtigladestasjon-for-elbiler

NorgesGruppen – KIWI Fjeldset	
Opening year	2016
Location, country	Elverum, Norway
Size [m²]	1300
Type	Stand-alone
Energy efficiency measures implemented	• Integrated refrigeration system with heat recovery • Approximately 35 % of the building's energy consumption will be covered by the recovered energy. • LED-lights for all lighting inside and outside the store • Solar panels with an estimated annual energy production of 70 000 kWh • Demand controlled lighting based on amount of daylight available • Near-produced wood as the main building material
Reduction in energy demand and CO_2 emissions[1]	Goal is 50 % reduction in both energy use and CO_2 emissions
Total investment and payback	7.5 million NOK (additional costs due to energy efficiency measures)
Financing solution	The project received 1.9 million NOK from Enova
Link for more information	(KIWI 2016), http://www.bygg.no/article/1266692

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REMA 1000 Kroppanmarka Norway's most energy efficient shop (measured in kWh/m^2/yr). Won the Price for Energy Saving in Trondheim (Energisparepisen) in 2014.		
Opening year	2013	
Location, country	Trondheim, Norway	
Size [m^2]	Ca. 1000	
Type	Stand-alone	
Energy efficiency measures implemented	• Integrated refrigeration system with heat recovery at multiple temperature levels, CO_2 as the refrigerant (see section 3.8) • Doors/lids in all refrigerated cabinets • Controlling technologies for optimized, easier operation • Aerogel facades, and demand controlled lighting based on amount of daylight available (see section 2.2.2) • Energy wells for storage of heat and cold • AHU unit adapted to supermarket using today's most efficient solutions (see section 3.5) • 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[1]	Reduction in annual energy demand 30 %	Reduction in CO_2 emissions ~30 %
Total investment and payback		
Financing solution	The project received 1 million NOK from Enova	
Link for more information	(Hafner and Tønseth 2014) (Trondheim Kommune 2014)	

5.4 Romania

Carrefour Timisoara	
Opening year	2015
Location, country	Timisoara, Romania
Size [m^2]	
Type	Hypermarket
Energy efficiency measures implemented	• CO_2 refrigeration system with parallel compression and multi-ejector technology • 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 heating facilities, including offices and parts of the sales area • LED lighting
Reduction in energy demand and CO_2 emissions[1]	Energy savings up to 13 % compared to a transcritical CO_2 system with parallel compression are expected. LED lighting reduces power 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

5.5 Spain

Carrefour Alzira	
Opening year	2013
Location, country	Alzira, Spain
Size [m^2]	

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Type	Hypermarket	
Energy efficiency measures implemented	• 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 heating for domestic use (5000 l every day)	
Reduction in energy demand and CO_2 emissions[1]	35 % more energy efficient than the previous installed system.	90 % reduction in CO_2 emissions compared to cooling systems using synthetic coolants.
Total investment and payback		
Financing solution		
Link for more information	http://www.frigoconsulting.ch/en/news/most_southerl_co2-refrigeration_system_in_spanien.html	

Eroski Zero Emissions Supermarket in Oñati The first supermarket in Spain with BREEAM-Spain sustainable construction certification and the first in Europe to obtain energy management certification ISO 50001.		
Opening year	2016	
Location, country	Oñati, Spain	
Size [m^2]	2170	
Type	Stand-alone	

Energy efficiency measures implemented	1. Sustainable construction:
	• Use of ecological and recycled materials (e.g. mineral rockwool, recycled asphalt from used tyres, etc.). Demolition rubble from the old centre was reused as part of the filling for the new car park.
	• Roofing and closure isolation to prevent heat loss.
	• Water saving systems: double pushbuttons, tap aerators or dry urinals.
	• Roof skylights and glass front façade with prismatic lenses to capture maximum daylight and optimise its diffusion.
	• "Green" car park for bicycles and electric vehicles used for deliveries (with charge point).
	
	2. Renewable energy sources:
	20 kW solar PV installation with an annual production of 21 560 kWh.
	
	3. Energy efficiency measures
	• Refrigeration
	  ○ CO_2 refrigeration system with heat recovery for heating DHW and the ventilation air
	  ○ Fitting doors on the cold walls and covers on the frozen islands with anti-condensation resistances (both transparent);
	  ○ Highly efficient fans in the cabinets
	• Lighting: latest generation LED technology installation both inside and outside the store, and an automatic light control system,
	
	4. Other measures
	• An Energy Management System which is constantly compared with a mirror centre (conventional centre to compare the energy savings). The data obtained are published on a screen at the store entrance.
	• Waste management with "zero waste" target	

Reduction in energy demand and CO_2 emissions[1]	65 % saving in energy consumption	Zero total CO_2 emissions. Emissions derived from the consumption are compensated via green energy purchase.
Total investment and payback	Budget € 1 924 700.	
Financing solution	The proposal is supported by the European Commission and will ultimately be financed through LIFE-2012.	
Link for more information	http://www.lifezerostore.eu/onati-zero-emissions-store/ http://thecorner.eu/companies/eroski-sets-first-european-supermarket-with-energy-self-supply-technology/28935/	

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5.6 Italy

Iper Hypermarket	
Opening year	2016
Location, country	Milan, Italy
Size [m²]	10 000
Type	Italy's largest hypermarket. A part of a large (92 000 m²) shopping center.
Energy efficiency measures implemented	• CO_2 refrigeration system using 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 center 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[1]	Energy savings of up to 50 % are expected.
Total investment and payback	

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6 GOLDEN RULES AND CHECKLISTS

This chapter summarizes the most crucial energy efficiency measures discussed in the report. Figure 13 presents the energy savings in percentage of aggregate energy consumption of the refrigeration system for some of these measures.

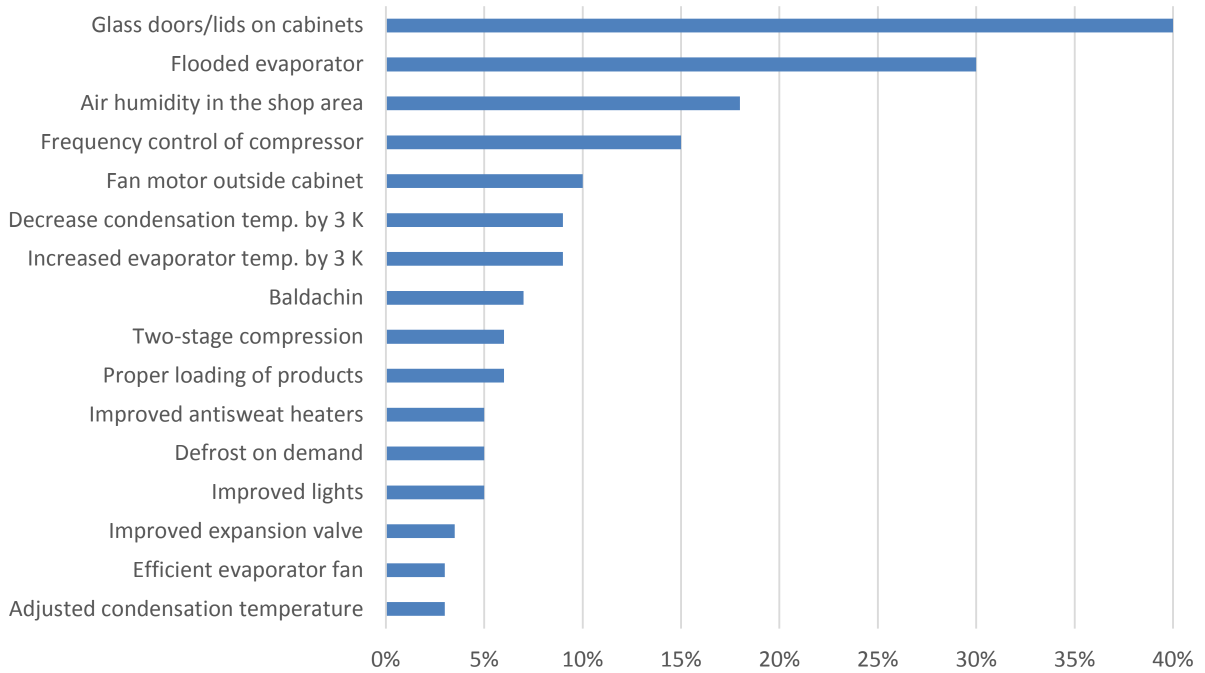

Figure 13 Energy saving in percentage of aggregated energy consumption of the refrigeration system through different measures (redrawn from (Kauffeld 2015)).

- **Refrigeration system and HVAC**
  - **Central, integrated refrigeration and HVAC system with CO_2** to cover both the refrigeration/freezing loads and the building HVAC demand (see section 3.1).
  - **Heat recovery:** See section 3.8.
  - **Energy accumulation in the form of thermal storage:** See section 3.6.
  - **Intelligent system control:** The topic is discussed in more detail in report D2.6, Eco-friendly operation and maintenance of supermarkets (Ciconkov and Ciconkov 2016).
  - **AHU unit designed for supermarkets** with room air dehumidification: see section 3.5
- **Refrigerated cabinets/rooms (see section 3.4.4)**
  - **Glass lids/doors**
  - **Improved insulation**
  - **Infra-red reflecting shades and baldachins**
  - **Improved air curtain in open refrigerated multi-decks**
  - **Improved anti-sweat heaters, edge/rim heating, dew point control**
  - **LED lighting inside the cabinets**
  - **Correct product loading of the refrigeration/freezer units**
  - **Improved fan and/or fan motor**
- **Compressor (see section 3.4.1)**
  - **Two-stage compression with intermediate cooling.** Especially favourable for LT systems. Standard in every CO_2 booster unit.
  - **Frequency control/variable speed drive compressors**
- **Expansion device**
  - **Improved expansion valves:** see section 3.4.2
  - **Ejector:** see section 3.1.3
- **Evaporator/condenser: see section 3.4.3**
  - **Improved evaporator/condenser/heat exchangers**
  - **Flooded evaporators**

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- **Defrost on demand of the evaporator**
- **Reduced condensation temperature/lower high-side pressure**
  - Floating condensing pressure (adjusted to ambient temperature). This is a standard solution for CO_2 systems, at least until technical minimum pressure is reached.
  - Evaporative condenser/gas cooler cooling
  - Serial arrangement of gas coolers: 1) heat recovery; 2) heat rejection to ambient air; 3) heat rejection towards alternative heat sinks, such as energy wells, fire water storage tanks, etc.
- **Cleaning of evaporator/condenser.**

- **Lighting**
  - **Use of LED lights**
  - **Maximizing the use of daylight in building design**
  - **Clever lighting control** with respect to traffic on corridors and amount of daylight

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7 CONCLUSIONS

New supermarkets are being built all the time. Supermarkets consume huge amounts of energy, and contribute to greenhouse gas emissions both directly through leakage from the refrigeration system, as well as indirectly due to the energy consumption. When natural refrigerants are used, all the emissions are related to energy consumption. It is hence of utmost importance that new supermarkets should be built to be energy efficient, and based on utilization of natural refrigerants. CO_2, the natural refrigerant R744, is regarded as the most energy efficient and eco-friendly refrigerant for supermarket refrigeration across Europe, including warmer climates.

In this report, three generations of central CO_2 refrigeration systems have been presented, including the 3rd generation, state of the art CO_2 system layouts using ejectors for expansion work recovery, suitable for both warm and cold climates. Ideally, most or all of the refrigeration demand should be covered by an integrated, central refrigeration system taking care of chilling and freezing the food stuff as well as AC, condenser heat being recovered for different purposes. Possible strategies for optimal heat recovery have been included in the report.

Furthermore, owing to the excellent transport properties of CO_2, direct system solution can be recommended also for larger supermarkets. Direct systems offer better energy efficiency and more stable temperature levels in the refrigerated cabinets, and are additionally less complex to operate than indirect systems.

A prerequisite for energy efficient refrigeration are good components, including compressors, evaporators, condensers, and expansion devices, as well as a good cabinet design. Flooded direct expansion evaporators, enabled through the use of ejectors, are highly recommended. These evaporators allow increased evaporation temperatures due to the improved heat transfer, and consequently also reduced demand for defrosting cycles, leading to a significantly higher overall system COP. Regarding cabinet design, having glass doors and lids is a crucial first step, allowing energy savings of 40 % or more. A detailed list of the design aspects leading to optimal cabinet energy efficiency is provided in the report.

Thermal energy storage is an important part of an energy efficient supermarket refrigeration system, allowing reduction in the peak heating and cooling demands and thereby lower installed refrigeration capacity. Thermal storage options suitable for supermarkets, including energy wells, hot water storage tanks and PCM, are widely discussed in the report. Energy wells are a seasonal storage, providing a heat sink independent of the ambient temperature, as well as a heat source in climates with high heating demand. PCMs are suitable as short-term storage, and could be integrated directly in the refrigerated cabinets. Such a solution would allow shifting parts of the cooling load to the night when electricity prices (and temperatures) are lower, and provide extra operational security, maintaining a stable temperature in the cabinet upon defrosting or if a system failure should occur.

For lighting in supermarkets, LED lights both in- and outside the store, as well as inside the cabinets, should be used owing to the low electricity demand and low heat production. LEDs have the additional advantage that they consume less energy the cooler they are kept, opposite to fluorescent tubes. LED lights together with adapted utilization of daylight and intelligent control with respect to traffic and amount of daylight available can thus enable significant energy savings.

Apart from the technical aspects, the report discusses the non-technical barriers for the uptake of new eco-friendly supermarkets, as well as possible solutions to overcome these barriers. Increased investment costs are often regarded as the biggest non-technical barrier, and financing opportunities to overcome this barrier are therefore included for different European countries as an appendix.

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A Appendix A Financing

A.1 EU and partner countries

NAME OF THE GRANT OR THE PROGRAM	BENEFICIARIES	WHAT IS FINANCED?	CALL DATES	COMPETENT BODY
LIFE	EU member states and some partner countries	"*The general objective of LIFE is to contribute to the implementation, updating and development of EU environmental and climate policy and legislation by co-financing projects with European added value" (European Commission 2016).* From 1992 till 2013, 3954 projects were funded, with together approximately €3.1 billion, or about €0.8 million per project on average. The programme is called the LIFE Multiannual work programme. The European Commission contains two sub-programmes, **Environment** and **Climate action**	Running for four-year-periods, The relevant programme is the 2014-2017-programme.	Executive Agency for Small and Medium-sized Enterprises (EASME). (Delegated by The European Commission - The Directorate General for the Environment and DG Climate Action)
LIFE – Environment (European Commission 2016b)		Projects focuses on management of the nature and resources in a good way, that is; utilizing the resources efficiently, reduce wasting of resources and pollution, especially CO_2, only use a sustainable part a the nature's resources, and ensuring safe operation and no health risks neither from operation/processes nor their environmental impact.	Continuously	
LIFE - Climate action (European Commission 2016a)		The programme has different priority areas, but the most recent are those of biodiversity and preservation of natural habitats, monitoring of resource use, possible technologies and their potential, network establishment, action plans/completing list for red listed species and birds listed in Annex I and II of the Birds Directive[2] on the one hand, and exchange of researchers, students and knowledge, increase awareness and recruitment to the field of LIFE and its work and results (European Commission 2014).	Continuously	

[2] Directive 2009/147/EC of the European Parliament and of the Council of 30 November 2009 on the conservation of wild birds. http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32009L0147.

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The European Commission funds "projects and initiatives that promote its policy priorities throughout the European Union and further afield." (European Commission 2015) There are opportunities for both implementing environmentally friendly technology and for innovation within the same field.

A.2 Germany

A.2.1 Call for project grants and financial support

NAME OF THE GRANT OR THE PROGRAM	BENEFICIARIES	WHAT IS FINANCED?	CALL DATES	COMPETENT BODY
Maßnahmen zur Nutzung erneuerbarer Energien im Wärmemarkt (Marktanreizprogramm) Heating with renewable energies	All sizes of companies and also individuals, freelancers, municipalities, local authorities and municipal syndicates and other legal persons of private law, in particular non-profit organizations or cooperatives.	Heat pump systems having up to 100 kW nominal power, but not air/air or direct to air heat pumps (BAFA 2016b). Additional funding is given to heat pumps: capable of load management ("Smart Grid Ready"); combination with a heat network or simultaneously established eligible solar collector or biomass plant; energy optimization of the heating system and hot water production in existing buildings in connection with the establishment of an eligible heat pump or optimizing a supported heat pump. Optimization of heating equipment can give additional funding in the following cases -building of a new, support worthy heat pump -Optimization of an earlier granted investment in a heating system or heat pump. If the installation of the energy system was more than 3 years ago, but less than 7 years, but the system has to be in the catalogue of the funding program. Cost below 100 are not funded. An analysis might have to be carried out (DIN EN 15378). -Optimization of a heat pump one year of operation, measurements after at least one year should be compared to calculated results and eventual improvements may be funded-	Continuously	BAFA[3] on behalf of the Federal Ministry for Economic Affairs and Energy (Bundeswirtschafts ministerium)

[3] BAFA: Bundesamt für Wirtschaft und Ausfuhrkontrolle (Federal Office for Economic Affairs and Export Control)

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Richtlinie zur Förderung von Maßnahmen an Kälte- und Klimaanlagen (Kälte-Richtlinie) Stationary refrigeration and air conditioning systems	Businesses of any size, non-profit organizations, municipalities, municipal Authorities, syndicates and municipal enterprises, schools, hospitals and religious institutions	Air-conditioning and refrigeration systems; Consulting measures; Renovation of existing systems; Installation of new systems; Installation of air handling units and absorption units; heat- and cooling integrated systems; Measures for using heat recovery from production processes and cooling units or refrigeration plants. The solution should use environmentally friendly refrigerants and be so efficient that environmental impacts are significantly reduced (Bundesministerium and für Umwelt 2015, BAFA 2016).	Continuously	BAFA on behalf of the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (Bundesumweltministerium)
Kraft-Wärme-Kopplung Power-heat-coupling	Storage system owners	Storages that have at least 50% of heat/cold for heating storage and cooling storage from CHP, is to be installed before 31.12.2020 and is a completely new, unused installation or an upgrade of an existing storage unit. €250 per m^3 water equivalent can be funded, but maximum of 30% of the total investment costs or 5 million € per project (BAFA 2016c).	Continuously	BAFA

Project funding from BAFA is normally equity financing, that is, non-repayable grants. Application needs to be sent to BAFA and paying the grant is done after proof of the use of evidence. This should be an electronic application containing application documents, proof of installation of highly-efficient technologies, commercial registration and energy savings concept. Examples of funded projects include engines, pumps, ventilation, heat recovery systems, lighting. There is no funding for used machinery, measures that have to be done by law, cooling units, components and systems of the refrigerant circuit (not sure what way that means supermarkets).

A.2.2 Soft loans

BENEFICIARIES	WHAT IS FINANCED?	CALL DATES	COMPETENT BODY
Companies, that are mainly private owned, in **both Germany and other countries,** as well as in some cases, other institutions or	Three main areas are funded: -Renewable energy: storage, solar, wells deeper than 400 m, fluid at least 20 °C, -Energy efficiency: heat recovery/utilization, efficient buildings, renovation of non-residential buildings (including heat/cold equipment, lighting, monitoring and controlling systems, ventilation...), -Environment and innovation: protection of resources and environment, water treatment, reduced waste, energy efficiency.	Continuously	KfW

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individuals/ freelancers	Generally, planning and equipment can be financed. Spreading effects are important (KfW 2016).		
No requirements given	Initiatives sparing the environment, like the building of renewable energy plants and passive houses: They consider the entire life cycle: building, operation and demolition. Priorities are solutions for organic development, clean nature and protecting the environment. No projects violating human rights or legislations are accepted. A set of positive criteria and excluding criteria are given on their webpage (UmweltBank 2016).	Continuously	Umweltbank

Positive criteria (as listed on their webpage, both translated and in their own words in German):

• Energy saving measures • Renewable energy • (Wind energy, photovoltaic, solar thermal, biomass and biogas, hydropower) • Decentralized energy production/ energy recovery, CHP plant • Environmentally friendly buildings • (Low energy building techniques, passive houses, use of organic building materials, landscape protection/ reduction of area use, reuse of rainwater) • Organic agriculture and organic forestry • Cycling/circular processes/recycling (Reduction of waste, saving raw materials, and protecting resources, environmentally justifiable depositing, nature cleaning plant) • Reduction and Removal of emissions (Environmentally friendly transport, soil protection and restoration, noise reduction, prevention of air pollution) • Sustainable economic operation (Development, production and distribution of long-lasting, resource preserving, regional and thereby environmentally friendly products)	• Energiesparmaßnahmen • Regenerative Energie • (Windenergie, Photovoltaik, Solarthermie, Biomasse und Biogas, Wasserkraft) • Dezentrale Energiegewinnung/ Energierückgewinnung, Blockheizkraft/Kraft-Wärme-Kopplung • Umweltschonende Gebäude • (Niedrigenergiebauweise, Passivhäuser, Verwendung organischer Baustoffe, Landschaftsschutz / Reduktion von Flächenverbrauch, Regenwasserrückgewinnung) • Organische Landwirtschaft und Organische Forstwirtschaft • Kreislaufwirtschaft/Recycling (Abfallvermeidung, Rohstoffeinsparung und Ressourcenschonung, umweltverträgliche Entsorgung, Naturkläranlagen) • Schadstoffverringerung und -beseitigung (Umweltschonende Verkehrsmittel, Bodenschutz/ Sanierung, Lärmverminderung, Luftreinhaltung) • Nachhaltige Wirtschaftsweise (Entwicklung, Herstellung und Vertrieb von langlebigen, ressourcenschonenden, regionalen und damit umweltfreundlichen Produkten)

Excluding criteria (as listed on their webpage, both translated and in their own words in German):

• Large power plants (brown/stone coal, nuclear power) • Weapon or military goods (production/trade)	• Großkraftwerke (Braun- / Steinkohle, Atomenergie) • Waffen oder Militärgüter (Produktion/Handel)

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• Products or technologies harmful for the environment. (production/trade) • Violation of environmental specifications • Socially incompatible projects, e.g. child exploitation for production • Genetic engineering in agriculture • unfair trade practices, e.g. corruption, violation of human rights	• Umweltschädliche Produkte oder Technologien (Produktion / Handel) • Nichteinhaltung von Umweltauflagen • Sozial unverträgliche Projekte, z.B. auf Ausbeutung von Kindern basierende Produktion • Gentechnik in der Landwirtschaft • unfaire Geschäftspraktiken, z. B. Korruption, Menschenrechts-verletzungen

A.3 Norway

A.3.1 Call for project grants and financial support

NAME OF THE GRANT OR THE PROGRAM	BENEFICIARIES	WHAT IS FINANCED?	CALL DATES	COMPETENT BODY
Støtte til konsept-utredning for innovative energiløsninger i bygg og områder (Enova 2016c)	Firms planning innovative energy solutions in one/more buildings, starting within three years	New energy solutions for building projects, which will start within three years; both new and established technologies; clusters/integrated systems, storage and peak shaving, heating, cooling, use of waste heat and free cooling (use of outdoor cold to cover cooling demands, completely or partially) and local energy production, insulation and solar panels, ventilation and other indoor equipment. The higher the degree of innovation, and the larger the further spreading effects the project has, the higher the chance for funding.	Continuously	Enova
Støtte til eksisterende bygg (Enova 2016a)	Owner(-s) and renter (-s) of existing residential and non-residential buildings	Implementation of measures for reduced energy demand and increased use of renewable sources in existing buildings and for upgrading to passive house or low energy standard (built after criteria in "NS 3701 - Kriterier for passivhus og lavenergybygninger, Yrkesbygg") which start within three years, giving at least 10 % energy reduction and having a follow-up system (Energioppfølgingssystem - EOS).	Continuously	Enova
Støtte til energieffektive nybygg	Those economically responsible for a building project after higher standards than required, reducing energy demand significantly	Projects leading to significant energy reductions, including innovative elements and fulfilling a set of minimum requirements (Enova 2016b). Applicant(s) must be economical responsible for the investments, and the application must include dynamic energy simulations, resulting energy demand and profitability, which other support the project receives, and description and documentation of new/rarely used technology to be included.	Continuously	Enova

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Miljø-teknologi: tilskudd til fremtidens løsninger	Firms in all sectors in Norway can apply. However, SMEs and ventures in the districts are generally given priority.	Solutions that have lower impacts on the environment than those presently used, the applications with highest potential/spreading effects are prioritized. Additional costs compared to conventional solutions for new technology for the environment (with repeatable results and identified spreading measures) and **test plants are funded.** The solutions must enhance value creation in Norway	Continuously	Innovasjon Norge
Generell bedrifts- og prosjektfinansiering	Firms in all sectors in Norway can apply. However, SMEs and ventures in the districts are generally given priority.	Pre-projects/analyses resulting in a clear plan for implementation of energy efficient measures (a market growth potential should be documented); Use of consultant services; Buildings and equipment; "... profitable projects that include building expansions, modernizing, transition/adaptation to new external conditions, development or new establishments." (Enova 2016a)	Continuously	Innovasjon Norge

A.3.2 Tax incentives

NAME OF THE GRANT OR THE PROGRAM	BENEFICIARIES	WHAT IS FINANCED? CALL DATES	COMPETENT BODY
Skattefunn	Enterprises	Skattefunn reduces the tax of businesses working with R&D that will benefit their operation, provided the money are all spent on R&D. There is a maximum border for tax refunding (≤2 million NOK per year, depending on conditions). SMEs can have 20 % covered, larger enterprises 18 % (Forskningsrådet 2016).	Innovasjon Norge

Enova funds investments in equipment and technology for lowering energy demand and reduced CO_2 emissions. The application must be written in advance of building start, and the expenses, also in terms of analysis and planning, project realization and results must be documented to receive financing. All buildings and sizes can receive funding, but high ambitions compared to requirements and high further impact is mandatory to achieve this. Enova funds additional costs, but not more than the extra costs for making the building more energy efficient than the legal requirements, and gives priority to higher savings for less money and sooner starts.

Similarly to Enova, Innovasjon Norge requires that an application is submitted to them before the project has started. They also offer loans and guaranties, in addition to funding. Innovasjon Norge will discuss with applicants to find the most suitable support for each case. The difference compared to Enova is that Innovasjon Norge is more focused on innovation projects and new development, whereas Enova is primarily focused on bringing the new technologies to the market, thus the research should (normally) already have been done. Yet, the programme *"Støtte til konseptutredning for innovative energiløsninger i bygg og områder"* also includes innovation, thus, there is some overlap in focus areas.

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A.4 Spain

A.4.1 Call for project grants and financial support

NAME OF THE GRANT OR THE PROGRAM	BENEFICIARIES	WHAT IS FINANCED?	CALL DATES	COMPETENT BODY
AYUDAS EEA-GRANTS (CDTI 2016)	Empresas establecidas en España. En el caso de proyectos en colaboración entre empresas españolas, Agrupación de Interés Económico (AIE) o consorcio regido por un acuerdo privado **Companies established in Spain. In the case of collaborative projects among Spanish companies, Economic Interest Group (EIG) or consortium must be governed by a private agreement**	Se financiarán proyectos empresariales de carácter aplicado para la creación y mejora significativa de un proceso productivo, producto o servicio, en el ámbito de las energías renovables, la eficiencia energética, el cambio climático y las tecnologías medioambientales. Pueden comprender tanto actividades de investigación industrial como de desarrollo experimental **Business projects for the creation and significant improvement of a production process, product or service in the field of renewable energy, energy efficiency, climate change and environmental technologies will be financed. They may include both industrial research and experimental development**	Última convocatoria: **10/02/2014 a 10/04/2014** **Last call: 10/02/2014 to 10/04/2014**	Centro para el Desarrollo Tecnológico Industrial (CDTI) **Centre for the Development of Industrial Technology**
Programa Estatal de I+D+i Orientada a los Retos de la Sociedad (Ministerio de Economía y Competitividad 2014)	Empresas, y asociaciones empresariales sectoriales, además de otros organismos tanto públicos como privados **Companies, and trade associations, and other organizations, both public and private**	Proyectos en cooperación entre empresas y organismos de investigación, con el fin de promover el desarrollo de nuevas tecnologías, la aplicación empresarial de nuevas ideas y técnicas, y contribuir a la creación de nuevos productos y servicios **Cooperation projects between companies and research organizations in order to promote the development of new technologies, business application of new ideas and techniques and the creation of new products and services**	Última Convocatoria: 23/12/2013 a 28/01/2014 **Last call: 23/12/2013 to 28/01/2014**	Dirección General de Innovación y Competitividad. Ministerio de Economía y competitividad **Directorate General for Innovation and Competitive-ness, Economy and Competitive-ness Ministry**

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A.4.2 Soft loans

NAME OF THE GRANT OR THE PROGRAM	BENEFICIARIES	WHAT IS FINANCED?	CALL DATES	COMPETENT BODY
Financiación por terceros (F.P.T.) (IDAE 2016a)	Empresas industriales **Industrial enterprises**	Solución integrada técnica y financiera para inversiones en proyectos energéticos. IDAE realiza directamente la inversión y la amortiza con los ahorros energéticos generados **Technical and financial comprehensive solutions for investment in energy projects; IDAE makes directly investment and amortizes energy savings generated**	Continua **Continuosly**	Instituto para la Diversificación y Ahorro de la Energía (IDAE) **Institute for Diversification and Saving of Energy**
Fondo de Inversión para financiar proyectos de eficiencia energética y energías renovables. (IDAE 2016b)	-ESEs. -Otras empresas privadas. -Entidades público-privadas. -Entidades Públicas. **-ESCOs** **-Other private companies.** **-Public-private entities.** **-Public entities.**	Este fondo financiará todas las inversiones relacionadas con el aumento de la eficiencia energética y la utilización de energías renovables en entornos urbanos. Comunidades Autónomas: Andalucía, Islas Canarias, Castilla y León, Castilla-La Mancha, Ceuta, Comunidad Valenciana, Extremadura, Galicia, Melilla y Región de Murcia. **This fund will finance all investments related to increasing energy efficiency and renewable energy use in urban environments. Autonomous Communities: Andalusia, Canary Islands, Castile and Leon, Castile-La Mancha, Ceuta, Valencia, Extremadura, Galicia, Melilla and Region of Murcia.**	Vigencia: hasta el 30 de abril de 2015 **Validity: until April 30, 2015**	Instituto para la Diversificación y Ahorro de la Energía (IDAE) **Institute for Diversification and Saving of Energy**
Financiación de Proyecto y Arrendamiento de Servicios (IDAE 2016c)	Empresas **Enterprises**	Este tipo de financiación es aplicable a proyectos de inversión en materia de ahorro, eficiencia energética y energías renovables, que dispongan de un análisis previo de viabilidad técnico-económica. **This type of funding applies to investment projects in savings, energy efficiency and renewable energy, which have a preliminary analysis of technical and economic feasibility.**	Continua **Continuously**	Instituto para la Diversificación y Ahorro de la Energía (IDAE) **Institute for Diversification and Saving of Energy**

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A.4.3 Tax incentives

NAME OF THE GRANT OR THE PROGRAM	BENEFICIARIES	WHAT IS FINANCED? CALL DATES	COMPETENT BODY
REAL DECRETO LEGISLATIVO 4/2004, de 5 de marzo, por el que se aprueba el texto refundido de la Ley del Impuesto sobre Sociedades. Artículo 39. Deducciones por inversiones medioambientales. (Ministerio de Hacienda y Administraciones Públicas 2004)	Empresas **Enterprises**	1. Las inversiones realizadas en bienes del activo material destinadas a la protección del medio ambiente consistentes en instalaciones que eviten la contaminación atmosférica procedente de instalaciones industriales, contra la contaminación de aguas superficiales, subterráneas y marinas para la reducción, recuperación o tratamiento de residuos industriales para la mejora de la normativa vigente (deducción en la cuota íntegra del 10 por ciento de las inversiones) 2. Adquisición de nuevos vehículos industriales o comerciales de transporte por carretera, sólo para aquella parte de la inversión que reglamentariamente se determine que contribuye de manera efectiva a la reducción de la contaminación atmosférica. 3. Aprovechamiento de fuentes de energías renovables consistentes en instalaciones y equipos con cualquiera de las finalidades que se citan a continuación: a) Aprovechamiento de la energía proveniente del sol para su transformación en calor o electricidad. b) Aprovechamiento, como combustible, de residuos sólidos urbanos o de biomasa procedente de residuos de industrias agrícolas y forestales, de residuos agrícolas y forestales y de cultivos energéticos para su transformación en calor o electricidad. c) Tratamiento de residuos biodegradables procedentes de explotaciones ganaderas, de estaciones depuradoras de aguas residuales, de efluentes industriales o de residuos sólidos urbanos para su transformaciónen biogás. d) Tratamiento de productos agrícolas, forestales o aceites usados para su transformación en biocarburantes (bioetanol o biodiésel). **1. Investments in active material for the protection of the environment consisting of installations to avoid air pollution from industrial plants, pollution of surface, ground and sea water; reduction, recovery and treatment of industrial waste to improve existing legislation (the total tax deduction of 10 % of investments)** **2. Acquisition of new industrial or commercial road transport vehicles, but only for that part of the investment determined by regulation that effectively contributes to reducing air pollution.** **3. Use of renewable energy sources in facilities and equipment consistent with any of the purposes cited below:** **a) Use of energy from the sun for conversion into heat or electricity.** **b) Use of municipal solid waste or waste biomass from agricultural and forestry industries,**	Ministerio de Hacienda y Administraciones Públicas **Ministry of Finance and Public Administration**

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		agriculture residues and forestry and energy crops as fuel for transformation into heat or electricity. **c) Treatment of biodegradable waste from farms, from sewage treatment plants, industrial effluents or solid waste for biogas transformation stations.** **d) Treatment of agricultural, forestry or oil products used for processing into biofuels (bioethanol and biodiesel).**	

A.4.4 Financing by means of energy service companies

La **Directiva 2006/32/CE** del Parlamento Europeo y del Consejo define la Empresa de Servicios Energéticos (ESE) "como una persona física o jurídica que proporciona servicios energéticos o de mejora de la eficiencia energética en las instalaciones o locales de un usuario y afronta cierto grado de riesgo económico al hacerlo. El pago de los servicios prestados se basará (en parte o totalmente) en la obtención de mejoras de la eficiencia energética y en el cumplimiento de los demás requisitos de rendimiento convenidos".

En este sentido, las ESEs tienen el objetivo final de ahorrar energía, lo que deriva en un ahorro tanto económico como de emisiones de CO_2. Su actividad se centra en el desarrollo de proyectos que garanticen una gestión eficiente de la energía, comprometiéndose económicamente con los resultados. El pago de los servicios prestados se basará (en parte o totalmente) en la obtención de mejoras de la eficiencia energética y en el cumplimiento de los demás requisitos de rendimiento convenidos.

El cliente tiene la posibilidad de conseguir un beneficio económico de la optimización de su consumo energético a la vez que reduce el riesgo ante variaciones de los precios de la energía, todo ello sin tener que realizar ninguna inversión.

En España existen varias asociaciones a las que recurrir para encontrar una ESE. Concretamente, y con el fin de facilitar el conocimiento de las empresas de servicios energéticos, el IDAE ha elaborado una base de datos que contiene información de contacto, servicios comercializados y su ámbito geográfico de actividad (IDAE 2016d).

Directive 2006/32/EC[4] defines the Energy Service Company (ESCO) "as a natural or legal person that delivers energy or improving energy efficiency in facilities or premises of a user services and facing some degree of financial risk in doing so. Payment for services rendered will be based (partially or entirely) in obtaining improvements in energy efficiency and the fulfillment of the other agreed performance criteria. "

In this sense, ESCOs have the ultimate goal of saving energy, resulting in both economic savings and CO_2 emissions. Its activity focuses on developing projects to ensure efficient management of energy, economically promising results. Payment for services rendered will be based (partly or fully) in obtaining improvements in energy efficiency and the fulfillment of the other agreed performance criteria.

[4] Directive 2006/32/EC of the European Parliament and of the Council of 5 April 2006 on energy end-use efficiency and energy services and repealing Council Directive 93/76/EEC. http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32006L0032.

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The customer has the possibility to get an economic benefit from optimizing their energy while reducing the risk to changes in consumer energy prices, all without having to make any investment.

In Spain there are several associations that go to find an ESCO. Specifically, and in order to facilitate the understanding of energy service companies, the IDAE has developed a database containing contact information, services sold and its geographical area of activity (IDAE 2016d).

A.5 Macedonia

A.5.1 Call for project grants and financial support

NAME OF THE GRANT OR THE PROGRAM	BENEFICIARIES	WHAT IS FINANCED?	CALL DATES	COMPETENT BODY
Western Balkans Sustainable Energy Financing Facility II Macedonia Serbia BiH Croatia	-Private businesses -Public Private bodies -Public bodies	- Modern technologies that cut energy consumption or CO_2 emissions by at least 20% - Retrofitting of buildings, provided the investment will make them at least 30% more energy efficient - Stand-alone renewable energy projects Businesses will receive investment incentives of 5% - 10% of the loan amount upon successful completion and verification of eligible projects.	Permanent till funds available	EU/EBRD European bank for research and development (EBRD 2016)

A.5.2 Soft loans

NAME OF THE GRANT OR THE PROGRAM	BENEFICIARIES	WHAT IS FINANCED?	CALL DATES	COMPETENT BODY
Western Balkans Sustainable Energy Financing Facility II Macedonia Serbia BiH Croatia	-Private businesses -Public Private bodies -Public bodies	- Modern technologies that cut energy consumption or CO_2 emissions by at least 20% - Retrofitting of buildings, provided the investment will make them at least 30% more energy efficient - Stand-alone renewable energy projects Businesses will receive investment incentives of 5% - 10% of the loan amount upon successful completion and verification of eligible projects.	Permanent till funds available	EU/EBRD European bank for research and development (EBRD 2016)

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