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ORIGINAL PAPER

Economic and environmental improvements using high energy efficiency HVAC in supermarkets

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Abstract

The commercial sector in Europe consumes a lot of energy and has one of the highest rates of energy consumption in supermarkets. Thus, supermarkets are an important part for the purposes of meeting the targets for reducing greenhouse gases which Europe has set as 10% by 2020. This article discusses the potential of economic and energy consumption savings in addition to the reduction in greenhouse gases that a high energy efficiency air conditioning installation can have in supermarkets. An analysis of the air conditioning installation is carried out in a commercial infrastructure considered as a model. Exploring the way energy is used at different times of the year and comparing the results obtained from a traditional duct installation and a high energy efficiency installation. High energy efficiency installation uses inverter technology and energetically takes advantage of the residual heat from industrial cooling processes. When high energy efficiency system is used for supermarket air conditioning, the savings in electricity consumption vary between 56 and 62%, reducing CO_2 emissions to less than half with a payback period in high energy efficiency installation of three-to-four years and this reduces the ecological footprint of the products sold in supermarkets.

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* Definition adapted from ASHRAE Terminology of Heating, Ventilation Air Conditioning & Refrigeration Second Edition 1991.

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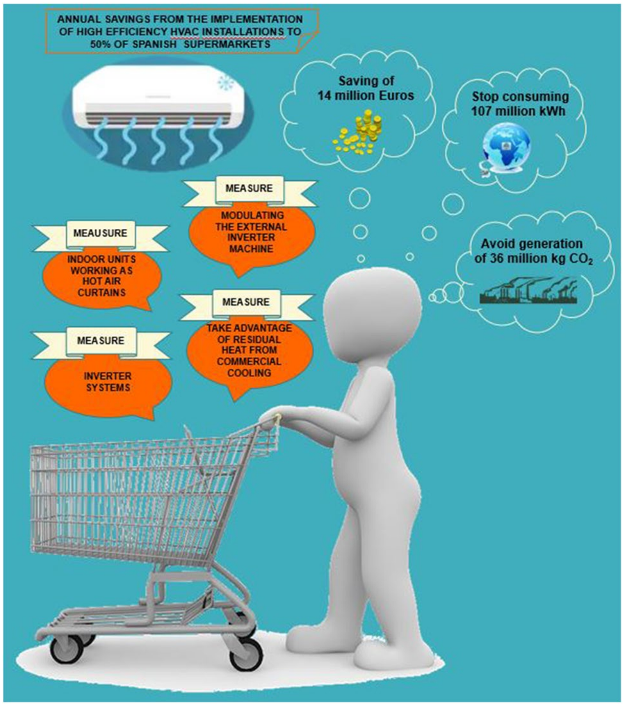
Graphic abstract



Keywords Air conditioning · Efficient facilities in supermarkets · Sustainable development · Inverter technology · Greenhouse gas emissions reduction · Residual heat · Retail building · Environmental economics

Abbreviations

COP	Coefficient of performance
CO_2	Carbon dioxide
DB	Dry bulb temperature
EER	Energy efficiency ratio
EU	European union
GHG	Greenhouse gas
HEES	High energy efficiency HVAC system
HVAC	Heating, ventilation and air conditioning
kW	Kilowatt
m^2	Square meter
$MtCO_2$	Million tonnes of CO_2
PI	Performance improvement using high energy efficiency system (%)
PI*	Performance improvement using high energy efficiency system and taking advantage of the residual heat from the industrial cooling system (%)
R	Supermarket food refrigeration
Rh	Relative humidity
RHC	Residual heat from condensers of supermarket industrial cooling system
t	Ton
TS	Traditional HVAC system
Zoning*	1. division of a building or group of buildings into separately controlled spaces (zones), where different environmental conditions can be maintained simultaneously, 2. practice of dividing a building into smaller sections for control of heating and cooling (each section is selected so that a thermostat can be used to determine its requirements)
€	Euro
WB	Wet bulb temperature
ºC	Degree centigrade

Introduction

The building sector has a huge impact on the environment, this consumes 30–40% of global natural resources and 40% of energy (Hossaini et al. 2015). Hence, sustainability of buildings is a necessary condition to safeguard the environment and insure the wellbeing of the global population (Milutienė 2012). Depending on the building type, different specifications should be assured such as thermal comfort (Yang et al. 2014) and indoor air quality (Steinemann 2017). Since in developed countries inhabitants spend almost 90%

of their time indoors, including commercial establishments such as supermarkets, it is necessary to achieve optimum air conditioning conditions in these areas. (Lotfabadi and Hancer 2019).

On the one hand, within the commercial sector the entire supermarket-type establishments have one of the highest rates of energy consumption per square meter in all commercial and industrial sectors (Ríos and Roqueni 2018), consuming 3% of the total electric energy in developed countries (Tassou et al. 2011). These establishments consume energy for long periods of time in many ways. Heating, ventilation and air-conditioning (HVAC) systems contribute to a considerable amount of this total energy use of supermarkets (Ríos 2019a). In this way, HVAC systems constitute 8–9% of total electricity consumption in a supermarket (Ríos and Roqueni 2018). On average air conditioners are responsible for approximately 5% of global electricity consumption with a variable percentage for each country, e.g. 14% in US and 40% in India (Arteconi and Polonara 2017). Furthermore, the retail trade in EU-27 shows a significant turnover with almost constant growth (European Commission 2008), supermarkets being the first sales channel and a consolidated model in continuous growth. Currently, there are over one million supermarkets in Europe just a low percentage reduction in energy use can result in substantial savings (Mylona et al. 2018).

As well as, the global warming related to CO_2 (carbon dioxide) emissions, coupled with steeply rising energy prices and the recent global financial institutional melt-down are causing massive societal concerns giving rise to increasing demand for ways to improve societal and individual energy efficiency and also for ways to shift increasingly to alternative, low or non-carbon-based energy systems (Dovì et al. 2009). As a result, the growing environmental sensitivity of consumers brings on the adoption of energy saving and efficiency measures could be an important competitive advantage for supermarkets that adopt these improvements (Ríos 2015). Moreover, the increase in the cost of energy that penalizes the benefits obtained and the growing competition in the commercial sector that motivates the adoption of improvements in the design of the establishments encourages the adoption of measures aimed at achieving savings in energy consumption (Ríos 2019b).

In addition, supermarkets generate a large amount of greenhouse gas (GHG) emissions associated with energy consumption (Ríos 2019a). For instance, in the UK emissions from retail food outlets amounted to 4 $MtCO_2$, which represented 1% of total GHG emissions to the atmosphere (Tassou et al. 2011), these emissions have a negative impact on climate but contribute to global warming. Apart from the inherent problems of climate change caused by GHG have led to a change in the sensitivity of energy issues and a growing global concern, which has resulted in international and regulatory agreements aimed at avoiding the generation of GHG. Sustainable development calls for the use of sustainable energy systems (European Commission 2017). Consequently, the indirect impact on the environment related to high electrical energy consumption makes shopping malls non-sustainable buildings (Polzot 2017).

All in all, modernizing the supermarket sector with more efficient HVAC equipment increases environmental commitment of companies, meaning a competitive advantage and difference of the same with an opportunity to increase the economic benefit due to the savings in energy consumption (Ríos 2015).

A current literature that analyses different procedures for reducing energy consumption in the air conditioning of supermarkets exists. In this way, Mylona et al. (2018) presented a control strategy optimization for night ventilative cooling, Frate et al. (2018) analysed the electric energy consumption of seven supermarkets to assess the effectiveness of an automatic energy management system which controls the lighting and the HVAC systems. Even though most of the studies analysed the energy consumption savings achieved by linking the supermarket food refrigeration (R) system with the HVAC system. In this manner, Cecchinato et al. (2010) developed a mathematical model that provided an estimate of the energy consumption integrating refrigeration units and the HVAC system of a supermarket, Gimeno-Frontera et al. (2018) analysed measures of energy efficiency in the combination of HVAC & R, Haida et al. (2018) performed a mapping of the refrigerant ejectors for refrigeration and air conditioning supermarket application finding the best performance conditions. Moreover, D’Agaro et al. (2019) validated a model in TRNSYS to evaluate the feasibility and effectiveness of the integration of HVAC and refrigeration systems.

The majority of the previous publications focus on analysing in a general way the consumption of the refrigeration and air conditioning installations of supermarkets. Thus, under ASHRAE Research Project RP-1467 it was shown that refrigeration factors dominate supermarket energy issues and changes to the HVAC design have less overall influence (Cole 2017). As well as electric power consumption of a combined air conditioner and refrigerator system was reduced by 32% with respect to isolated systems (Ha and Jeong 2015). Other researches published the consumption and emissions savings from air conditioning systems by using alternative refrigerants. Beshr et al. (2017) asserted that shifting to lower GWP refrigerants in the refrigeration and air conditioning systems helps to reduce the total emissions and negative environmental impacts of these systems.

To sum up, prior studies in HVAC efficiency do not compare the real results in terms of energy consumption, polluting emissions, costs, possible savings and design modifications obtained with the replacement of a traditional

HVAC system (TS) by a high energy efficiency HVAC system (HEE). The contributions of this study lie on different optimization problems in energy consumption, associated pollutant emissions and the strategies used to solve different problems related to the air conditioning of a supermarket by replacing a TS for a HEES combined with the use of residual heat from the food refrigeration system. This action reduces the carbon footprint of the supermarket and benefit society.

This article analyses two cases of HVAC systems use in a "type" European supermarket: a TS and a HEES. Pretending to serve as a reference to the implementation of high energy efficiency technologies in supermarkets where these technologies do not have much implementation (European Commission 2013).

Firstly, an analysis of the energy consumption of the two HVAC systems in different outdoor environmental conditions was presented as well as the heating and cooling efficiencies. Furthermore, a synergy between commercial refrigeration and HVAC system by taking advantage of residual heats was proposed. As a result, performance improvement is acquired.

Secondly, annual electric consumption and CO_2 production using each system were obtained. This allowed to obtain the amortization period, the energy and pollutant emission savings by using high energy efficiency system and by taking advantage of the residual heat from the industrial cooling system (RHC). Hence, the standardized use of HEES in supermarkets had a triple interest: economic, social and environmental.

Material and methods

The article compares from the economic and environmental point of view, a TS with a HEES. Sustainable development calls for the use of sustainable energy systems (Shortall et al. 2015). Designing a facility which supplies energy services for a building (i.e. ventilation, cooling, heating and/or domestic hot water) requires a preliminary assessment of energy loads (Picallo-Perez et al. 2019). An analysis of the air conditioning installation is carried out in a commercial infrastructure considered as a model. Exploring the way energy is used at different times of the year and comparing the results obtained from a traditional duct installation and a high energy efficiency installation. To this end, a typical supermarket has been analysed in Spain, with a sales area of 950 m^2 and two entry doors to the store. The following demands for heating and cooling have been obtained by the supermarket. The study contemplated the type of commercial establishment more widespread in Spanish level, surpassing 40% of the market share (The Nielsen Company 2013). Currently, the number of supermarkets of this type in Spain exceeds 8000 establishments with a tendency to grow in the coming years. Table 1 shows the temperature and relative humidity inside and outside the supermarket in different environmental conditions of summer and winter and the thermal loads are reflected in Table 2 and have been obtained using a computer program based on the calculation of Carrier thermal loads.

The average relative humidity in Spain varies in winter in the northern areas with a relative humidity of 80–85%, centre areas of the peninsula with 70–80% or eastern areas with 65–80%. In summer, the humidity decreases due to the reduction in rainfall with variation between the interior and coastal areas. An extreme measure due to the low relative humidity corresponding to the summer seasons which can serve as a national average reference was 25%. Likewise, the other outside conditions-extreme environmental values of relative humidity in winter and temperature in summer and winter are uncommon average values which were possible to achieve. These values should be considered (IDAE 2010).

Table 2 Cooling and heating loads in a supermarket for usual and extreme thermal conditions

	Cooling loads (kW/h)			Heating loads (kW/h)
	Total	Sensible	Latent	
For usual thermal conditions	76	67	9	71
For extreme thermal conditions	84	75	9	79

Table 1 Temperature and relative humidity inside and outside of the supermarket in different environmental conditions of summer and winter

	Inside conditions		Outside conditions extreme environmental		Outside conditions usual environmental	
	Temperature (ºC)	Relative humidity. Rh (%)	Temperature (ºC)	Relative humidity. Rh (%)	Temperature (ºC)	Relative humidity. Rh (%)
Summer	25	40	35	25	30	30
Winter	20	45	– 5	90	0	80

In commercial HVAC facilities, it is advisable to place more than one machine distributing the required thermal power between two or more units. In this way, the supermarket can be thermally zoned, reducing the length of the air distribution ducts, avoiding complete shutdown of the installation in the case of a breakdown. Furthermore, facilitate air intakes and outlets by distributing the necessary evacuation sections into various locations of the supermarket.

To combat thermal demand, a comparison between a TS and a new one with high energy efficiency has been carried out. The traditional HVAC system (Fig. 1) is composed of two constant compressor air conditioning machines, with indoor units for connection to a network of ducts with electric resistance support. An electric air curtain is also installed on each of the two entrance doors to the supermarket.

The HEES (Fig. 2) is composed of an air conditioning unit with inverter compressors, six indoor cassette units and two indoor units of conducts to perform in the two entrances as the air sweeping functions of the replaced air curtains. In such a way, during summer all indoor cassette units are working and the two indoor units work as door air curtains although only in ventilation mode without hot air. Whereas, in winter the thermal demand is distributed by the facades of the supermarket. Thus, the central cassette units are stopped, and the indoor units work as hot air curtains. On the other hand, the HEES allows to take advantage of the hot air from the units of industrial cooling, increasing the performance of the HVAC system and thus reducing both the energy consumption and the production of CO_2.

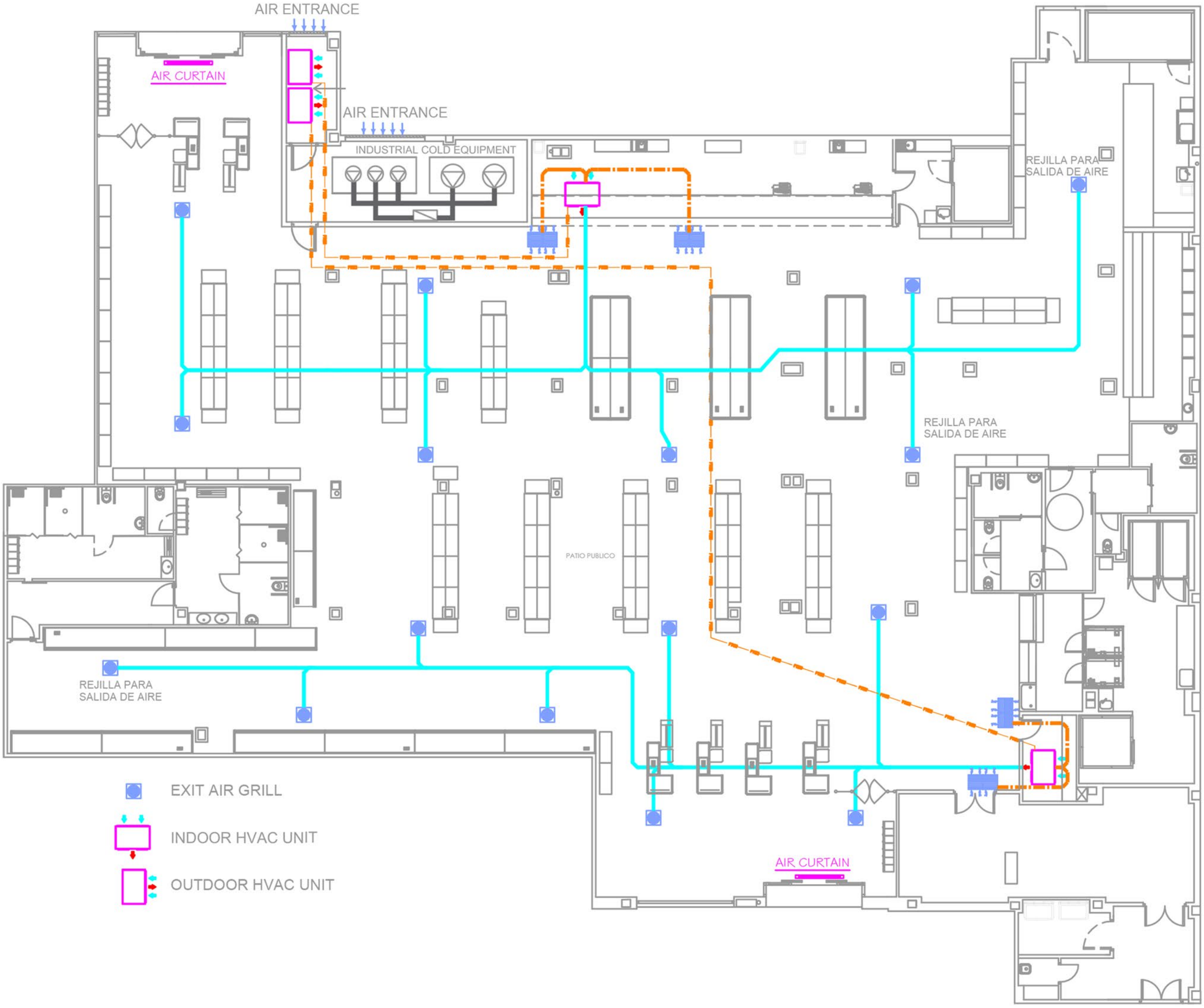


Fig. 1 Traditional HVAC system design for a supermarket

Fig. 2 High energy efficiency HVAC system design for a supermarket

Analysis of a traditional HVAC system of a supermarket with duct machines

The nominal capacity for the TS is 41.5 kW for cooling and 36.3 kW for heating. The unit is supplied with refrigerant R-410A and the start-up current is 157.5 A. Moreover, the compressor type is a hermetically sealed scroll and the fan type is a propeller fan.

Operating limits for the cooling cycle operation of the TS are as follows:

- Indoor temperature: maximum temperatures of 32 °C DB/23 °C WH and minimum temperatures of 21 °C DB/15 °C WH. DB: dry bulb temperature; WB: wet bulb temperature.
- Outdoor temperature: maximum temperatures of 47 °C and minimum temperatures of 15 °C.

Operating limits for the heating cycle operation of the TS are as follows:

- Indoor temperature: maximum temperatures of 27 °C DB and minimum temperatures of 15 °C DB.
- Outdoor temperature: maximum temperatures of 27 °C (with 20 °C outdoor temperature) and minimum temperatures of – 12 °C (with 20 °C indoor temperature).

Beginning with the powers supplied by the machines and their performances in the different service, the results were obtained by using the following thermodynamics parameters and equations.

Thermodynamics parameters and equations:

COP is the ratio of useful heating or cooling provided to work as required and EER is the energy efficiency ratio of the cooling energy production process are obtained as follows:

$$\text{COP} = \text{Total heating energy generated}/\text{Total electric energy consumption for heating} \tag{1}$$

$$\text{EER} = \text{Total cooling energy generated}/\text{Total electric energy consumption for cooling} \tag{2}$$

Both ratios are determined by the amount of heating and cooling generated by the air conditioning compared with the 1 kW of electricity it consumes.

Heating power is obtained by adding all machine heating powers including curtain heating power. Whereas, output cooling energy is obtained by adding all machine cooling power, curtain power is not included since curtains do not carry out cooling effects. Colling effects are obtained as follows:

$$\begin{aligned}\text{Heating power} = \sum &(\text{Machines heating power} + \text{Curtain heating power})\\ 1 &= \text{Total heating energy generated}\end{aligned} \tag{3}$$

$$\begin{aligned}&\text{Total electric energy consumption for heating}\\ &\quad = \sum (\text{Machines absorbed power} + \text{Curtain absorbed power})\end{aligned} \tag{4}$$

$$\text{Total cooling energy generated} = \sum (\text{Machines cooling power}) \tag{5}$$

$$\text{Total electric energy consumption for cooling} = \sum (\text{Machines absorbed power}) \tag{6}$$

Thermal demand in winter obtained with extreme conditions was 78.82 kW. To achieve this power, the HVAC system was supported with the air curtains located above the entrance doors to the establishment. Each curtain had an electrical resistance with a consumption of 15 kW. Operating the two machines and the two air curtains the performance went down to:

$$\text{Total heating energy generated} = 64.38\text{ kW} + 2 \times 15\text{ kW} = 94.38\text{ kW} \tag{7}$$

$$\text{Total electric energy consumption for heating} = 20.02\text{ kW} + 2 \times 15\text{ kW} = 50.02\text{ kW} \tag{8}$$

$$\text{COP} = 94.38\text{ kW}/50.02\text{ kW} = 1.89 \tag{9}$$

Therefore, the coefficient of performance has dropped by 41%.

Taking into account the consumption of the two air curtains of the entrance doors to the supermarket, the following results were obtained with usual conditions:

$$\begin{aligned}\text{Total heating energy generated} &= 72.64\text{ kW} + 2 \times 15\text{ kW}\\ &= 102.64\text{ kW}\end{aligned} \tag{10}$$

$$\begin{aligned}&\text{Total electric energy consumption for heating}\\ &\quad = 21.52\text{ kW} + 2 \times 15\text{ kW} = 51.52\text{ kW}\end{aligned} \tag{11}$$

$$\text{COP} = 102.64\text{ kW}/51.52\text{ kW} = 1.99 \tag{12}$$

Analysis of a HVAC system of a supermarket using machines of high energy efficiency with Inverter system

The HEES was supplied with refrigerant R-410A and the electrical power supply was 3 Ø/380 V ~ 415 V/50 Hz. Moreover, the compressor type was a hermetically sealed scroll (2 Inverter units) and the fan type was a propeller fan. The facility carried out the following specifications:

- Nominal capacity: cooling 78.4 kW; heating 89.7 kW.
- Operation range: cooling from − 10 to 43 ℃ DB; heating from − 25 to 18 ℃ WB.

HEES consists of eight air conditioning units located inside the supermarket and one outdoor unit placed in the engine room. In summer, the cassettes would work and in winter two indoor units working as hot air curtains and the cassettes closest to the facades and doors would work. Thus,

Table 3 Cooling and heating result of a traditional HVAC system of a supermarket, with duct machines in usual and extreme conditions

	Extreme conditions outdoors				Usual conditions outdoors			
	Cooling at 35 °C		Heating at − 5 °C		Cooling at 30 °C		Heating at 0 °C	
	Working one machine	Working two machines	Working one machine	Working two machines	Working one machine	Working two machines	Working one machine	Working two machines
Cooling or heating energy generated (kW)	41.90	–	32.19	–	43.80	–	36.32	–
Electric energy consumption by compressors (kW)	12.40	–	8.73	–	11.30	–	9.48	–
Electric energy consumption by external fans (kW)	1.28	–	1.28	–	1.28	–	1.28	–
Electric energy consumption for cooling or heating (kW)	13.68	–	10.01	–	12.58	–	10.76	–
Total cooling or heating energy generated (kW)	–	83.80	–	64.38	–	87.60	–	72.64
Total electric energy consumption for cooling or heating (kW)	–	27.36	–	20.02	–	25.16	–	21.52
COP				3.22				3.38
EER		3.06				3.48		

the calculations were made for a maximum of six machines running at the same time. Analysing the technical data of the equipment were obtained:

$$\text{Nominal cooling capacity of the external machine} = 78.40\ \text{kW} \tag{13}$$

$$\text{Nominal cooling power of the internal machines} = 6 \times 14.10\ \text{kW} = 84.60\ \text{kW} \tag{14}$$

The Capacity Index is the percentage of power demanded by the indoor units compared to the nominal power of the outdoor unit:

$$\text{Capacity Index}:\ (84.60\ \text{kW}/78.40\ \text{kW}) \times 100 = 108\% \cong 110\% \tag{15}$$

Total refrigerating power supplied, total absorbed power and energy efficiency ratio in extreme and usual conditions are reflected in Table 4. The demand of the internal machines with respect to the power supplied by the outdoor unit is 110%, but the thermal need of the supermarket is 78.82 kW, which is achieved by modulating the external inverter machine to 90% of its nominal value, resulting:

Table 4 Cooling and heating results of a HVAC system of a supermarket using machines of high energy efficiency with inverter system in usual and extreme conditions

	Extreme conditions outdoors			Usual conditions outdoors		
Working six machines	Cooling at 35 °C	Heating at − 5 °C	Heating at 5 °C (advantage of RHC)	Cooling at 30 °C	Heating at 0 °C	Heating at 10 °C (advantage of RHC)
Total cooling or heating energy generated (kW)	83.10	94.00	80.70	85.70	72.20	72.20
Total electric energy consumption for cooling or heating (kW)	17.37	26.55	18.33	15.89	17.76	13.89
COP	–	3.54	4.40	–	4.07	5.20
EER	4.78	–	–	5.39	–	–

$$\text{Heating energy generated } 90\% = 80.70 \text{ kW} \tag{16}$$

$$\text{Electric energy consumption} = 23.01 \text{ kW} \tag{17}$$

$$\text{COP} = 80.70 \text{ kW}/23.01 \text{ kW} = 3.51 \tag{18}$$

Cassette HVAC units were distributed dispensing the air conditioning in a balanced way among the different areas of the supermarket. Zoning of the establishment considering the sales area of the supermarket, the interior zones and the areas close to the air currents of the entrances such as the two till zones has been carried out. Number of cassette HVAC units depended on the unit capacity, the thermal demand and the zoning.

The generation of industrial cooling produced residual hot air which, instead of being completely discharged outside the supermarket, was partly recovered to improve the performance of the HVAC system which reduces energy consumption. To achieve this, motorized gates were placed in the air discharge ducts of the condensing units of the industrial cooling system. Thus, when the temperature of the engine room dropped below 10 °C hot air was discharged into the room where HVAC units were located. Therefore, this did not penalize the condensation from the industrial cooling and the air intake conditions by HVAC equipment were improved. In this way, increases in the air intake temperature of 10°, consequently, consumption of the HVAC system was increased, and the electrical consumption of the heat pumps was decreased. In winter, when the temperature at which the HVAC system takes the outside air was rather low, this system was especially recommended.

Results

Energy consumption, powers supplied by the traditional HVAC system and their performances in the different service are described in Table 3, including energy efficiency ratio (EER) and coefficient of performance (COP). In extreme conditions, the energy consumption of compressors was increased by 10% for cooling and decreased by 8% for heating. According to the technical characteristics of the machines, this was due to technical characteristics (type of compressor, fixed speed units, refrigeration fluid) and decrease in technical capacity of the equipment on account of the extreme conditions of the inlet air temperature to the outdoor unit. In other matters, electric energy consumption by external fans (air curtains) did not vary due to outdoor conditions. Therefore, coefficients of efficiency EER and performance COP are 12% and 5%, respectively, lower with extreme conditions than with usual conditions.

By using machines of high energy efficiency with inverter technology in extreme conditions, the electric energy consumption for cooling was increased by 9%. Electric energy consumption for heating varies in these machines as they allow modulations according to thermal needs and work with percentages of cooling or heating energy generated. In this way, to reach the thermal requirements for heating to 0 ºC, the external machines with inverters were modulated at 80% of their power. Technical capacity of these inverter systems did not decrease because of the extreme conditions. Therefore, electric energy consumption for heating was higher in extreme conditions. But once the system in extreme conditions took advantage of RHC, the air temperature increased by 10ºC and electric energy consumption decreases. Additionally, a substantial improvement in COP was obtained, with an increase by 24%. Moreover, when in usual conditions the HVAC system takes advantage of RHC, increasing the temperature at which the air conditioning equipment takes the outside air by 10ºC, an increase of 28% in COP was achieved. Likewise, EER was 12% lower in extreme conditions. Results are shown in Table 4.

The HEES design by zones or "zoning" increasing the number of machines with respect to TS allowed the different HVAC units to operate independently and make it possible to choose different temperatures for each area of the supermarket depending on the need for cold or heat. In this way, the different temperature needs depending on the areas were satisfied with more energy efficient. Additionally, it was possible to select the most efficient and comfortable mode of operation of the HVAC system and a simple adaption to the flow of the equipment to the needs of the installation during commissioning.

The HVAC system fitted its refrigeration production and air flow to the circumstances of each moment. Thus, in winter the demand for the equipment located at the entrance doors to the supermarket and next to the tills was greater than the equipment located inside the establishment. On the other hand, in summer the equipment located inside the supermarket presented higher demand percentages than those located near the entrances.

Table 5 contains the performance improvement using machines of traditional and high energy efficiency with inverter system in usual and extreme conditions for cooling and heating and taking advantage of the residual heat of the industrial cooling system for heating.

Firstly, with the same outdoor conditions TS has lower COP and EER than those achieved with HEES. Performance improvement using high energy efficiency system (PI) was 55–105%. This was due to the fact that the zoning of two limited areas presented an increased energy consumption with the use of air curtains at the entrance doors to the supermarket. In addition, on account of the low efficiency technology and the machine setup with the wards of HVAC and

Table 5 HVAC performance improvement using traditional and high energy efficiency HVAC with inverter system in usual and extreme conditions for cooling and heating and taking advantage of the residual heat of the industrial cooling system for heating

	Extreme condition outdoors					Usual condition outdoors				
	Cooling at 35 ºC		Heating at − 5 ºC			Cooling at 30 ºC		Heating at 0 ºC		
	TS	HEES	TS	HEES	HEES + RHC	TS	HEES	TS	HEES	HEES + RHC
COP	–	–	1.89	3.54	4.40	–	–	1.99	4.07	5.20
EER	3.06	4.78	–	–	–	3.48	5.39	–	–	–
PI (%)	56		87			55		105		
PI* (%)	–		133			–		161		

Table 6 HVAC performance improvement using traditional and high energy efficiency HVAC with inverter system in usual and extreme conditions for cooling and heating and taking advantage of the residual heat of the industrial cooling system for heating

	Extreme condition outdoors					Usual condition outdoors				
	Cooling at 35 ºC		Heating at − 5 ºC			Cooling at 30 ºC		Heating at 0 ºC		
	TS	HEES	TS	HEES	HEES + RHC	TS	HEES	TS	HEES	HEES + RHC
Consumption (MWh/year)	1.10	0.70	0.75	0.35	0.27	12.10	7.63	29.37	10.12	7.92

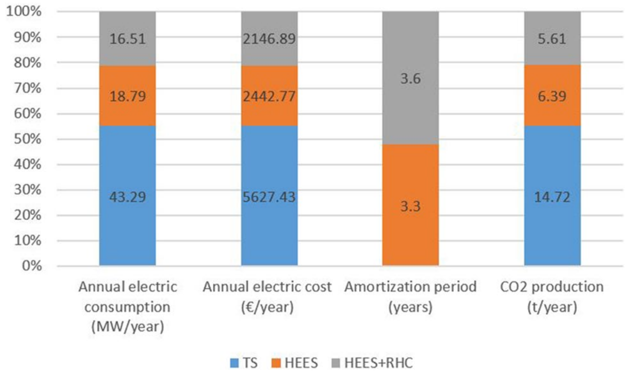


Fig. 3 Annual electricity consumption and cost, amortization period and CO_2 production of a traditional installation of HVAC in a supermarket, with duct machines, using machines of high energy efficiency with inverter system or taking advantage of the residual heat of the condensers of the industrial cooling system

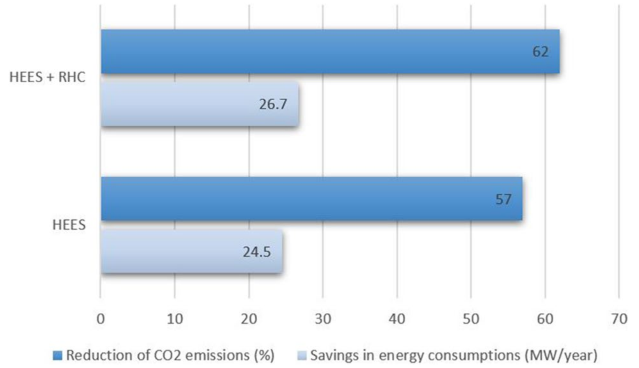


Fig. 4 Savings in energy consumptions and reduction of CO_2 emissions obtained with the high energy efficiency HVAC system or taking advantage of the residual heat of the condensers of the industrial cooling system

non-communicated cooling, it was not possible to increase the performance of TS by taking advantage of RHC. Secondly, performance improvement in HEES with RHC (PI*) was significant, with COP increases of 133–161% compared with TS.

Table 6 analyses the electricity consumption values in the different environmental conditions of TS and a HEES using machines of high energy efficiency with inverter and taking advantage of the residual heat of the industrial cooling system for heating.

The annual energy consumption values and CO_2 production of the two HVAC systems analysed are listed in Fig. 3. The amortization period of efficient facilities, which are more expensive compared to TS, is also reflected in the figure.

Discussion

Savings in energy consumptions (MWh/year) obtained with HEES are represented in Fig. 4. These energy savings translate into significant savings of indirect CO_2 emissions (t/year) due to electricity consumption which are greater if combined with taking advantage of the residual heat of the condensers of the industrial cooling system. The GHG emission factor used was the energy mix of 2018, according to official values issued by the National Energy Commission of Spain, which was 0.38 kgCO_2/kWh for the main electricity trading company in Spain (Ministerio para la Transición Ecológica 2019) and the price of electricity at the time of this analysis of 0.13 €/kWh. Additionally, savings of indirect CO_2 emissions using HEES and HEES with RHC are represented in Fig. 4 as percentage in respect to the annual electric consumption of TS.

HEES require significant initial economic investment, even more in the case of taking advantage of the residual heat of the condensers of the industrial cold system and their maintenance costs are also slightly higher than TS. The return times of the investment are sort, being between 3 and 4 years. The probable increase in the price of electric power and the consolidation of the inverter technology in the HVAC installations in supermarkets may cause the cost to decrease as its implementation increases. The EU Member States established in 2013 their national indicative targets for energy efficiency by 2020 and in 2014, the final energy consumption of seventeen States members was already below its indicative target of final energy for 2020. The rest of the Member States are far from their national indicative targets expressed in final or primary energy consumption by 2020 (Ríos 2019a, b). The European Commission considers that the EU should make sure that energy efficiency is taken into account throughout the energy system, i.e. actively managing demand so as to optimize energy consumption, reduce costs for consumers and import dependency, while treating investment in energy efficiency infrastructure as a cost-effective pathway towards a low carbon and circular economy. This will enable retiring generation over-capacity from the market, especially fossil fuel generation (European Commission 2016). The legal binding and enforcement played an important role in pushing all member states to strengthen their building regulations and introduce energy performance certification of buildings (Ming and Qiu 2019). Economic growth leads to environmental degradation (Kahuthu 2006) and there is a limit on exploiting natural resources, it is a finite resource and time bounded (Hossaini 2018); therefore, the need to reduce energy consumption is essential. In the present scenario, where legal constraints force the reduction in GHG emissions, it certainly improves the prospect meaning the high energy efficiency installation is advisable. Additionally, domestic environmental issues and weather events draw the government's attention to energy conservation and emission mitigation (Xie et al. 2016); therefore, in order to broadly implement HEES it would be recommendable to create a financial aid or grants to offset the increased cost compared to TS.

By applying the proposed measure of energy reduction for the HVAC systems, reaching 50% of the Spanish supermarkets, it would allow savings compared to the traditional systems of 14 M€/year, a decrease, in energy consumption of 106,800 MWh/year and would avoid the generation of 36 $ktCO_2$/year.

Conclusions

The effectiveness of reducing energy consumption and the level of associated emissions as well as the economic profitability of replacing traditional supermarket HVAC system with others of high efficiency such as residual heat from industrial cooling has been investigated in this study. The following conclusions were drawn:

The greater zoning allows to increase both the comfort of the installation and the operating range of the equipment in operation. This allows increasing energy efficiency. In all climatological situations analysed, the performance improvement was evident and far more accentuated when the more extreme the external conditions are. Thus, COP improves 25–28% by taking advantage of the residual heat. Furthermore, savings in energy consumptions obtained were 43.5% increasing 5% using residual heat. Likewise, this use reduces the generation of greenhouse gases resulting from non-industrial energy combustion with a decrease in CO_2 emissions from the "type" supermarket of 8.3 t/year increasing 0.8 t/year by using residual heat. This implementation was interesting in order to achieve the environmental commitments of q GHG emissions that States are obliged to comply with. This satisfies the normative requirements set in the norms for building new constructions in the increase in energy efficiency.

The payback period in high energy efficiency HVAC systems vary between three and four years. This period can be significantly reduced in the case of public subsidies for the use of high energy efficiency systems, for the expected increase in the price of energy and the reduction in the cost of inverter technology by increasing its implementation. Such a short period makes the widespread adoption of this technology recommendable in all supermarkets.

Adopting the HEES, supermarkets would reduce the ecological footprint of the products sold since the resources necessary for the conservation, storage, distribution, retail sale of food and other products of the supermarket would be reduced. Moreover, this would provide a significant achievement in the search for a more sustainable consumption system.

The results obtained in the case of the supermarket could be supported in other commercial establishments and also in sectors such as Additionally, in future research it would be interesting to know the results based on the size of commercial establishments and the viability of administrations through granting economic aid for the implementation of high energy efficiency air HVAC in order to reduce energy consumption.

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