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Comparative analysis on the energy use of different refrigeration systems for supermarket application

Analiză comparativă a utilizării energiei diferitelor sisteme frigorifice pentru aplicații în supermarketuri

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Rezumat. *Această lucrare investighează oportunitatea utilizării căldurii recuperarte de la sistemele frigorifice, din supermarket-urile de capacitate medie, pentru climatizare. Consumul de energie electrică pentru sistemul de aer condiționat și frigul tehnologic din supermarket-uri reprezintă o pondere importantă din consumul total de energie electrică din acestea. Eficiența energetică a supermarket-urilor poate fi îmbunătățită prin optimizarea proiectării componentelor, recuperarea caldurii din sistemele frigorifice, adoptarea de soluții tehnologice inovatoare, integrarea sistemului HVAC de temperatură medie și joasă cu instalațiile frigorifice. Acest studiu are ca scop evaluarea consumului de energie a unui sistem frigorific pentru frig tehnologic si climatizare care utilizează agentul frigorific R410A. Sunt analizate 2 sisteme frigorifice:*

- *Solutie clasică: instalație pentru frig tehnologic ZEAS+ instalație de climatizare cu VRV;*
- *Soluția propusă: instalatie pentru frig tehnologic cu recuperare de căldură pentru instalația de climatizare CONVENIPACK*

Soluțiile investigate permit o economie anuală de energie mai mare de 17% față de soluția de bază pentru climatele avute în vedere.

Cuvinte cheie: eficienta energetica, recuperare caldura, sistem frigorific comercial

Abstract. *This paper investigates the opportunity of utilizing the heat recovery from refrigeration systems in supermarkets with medium requirement capacity for air conditioning. The electricity consumption for air conditioning and refrigerated cases in medium supermarkets represents an important share of the total electricity consumption. The energy efficiency of supermarkets can be improved by optimizing components design, recovering energy, adopting innovative technology solutions, integrating the HVAC system with medium temperature and low-temperature refrigeration plants. This study is aimed at investigating the energy consumption of a refrigeration system for commercial refrigeration and air conditioning that uses the refrigerant R410A. Two refrigeration systems are analyzed:*

- traditional solution: system for commercial refrigeration using equipment type ZEAS + air conditioning equipment type VRV IV;

- new proposed solution: system for commercial refrigeration with heat recovery using equipment type Conveni-Pack for air conditioning.
The results obtain shape the potential for improving energy efficiency and environmental impact over traditional system in climates from Romania. The investigated solutions allow an annual energy saving higher than 17% to the baseline solution for the considered climates.

Key words: *energy efficiency, heat recovery, commercial refrigeration system*

1. Introduction

The European Green Deal sets in stone our green transition ambitions, including our climate targets towards net-zero by 2050 [1, 2, 3].
Conventional supermarket refrigeration systems are responsible for considerable CO_2 emissions due to the direct effect of refrigerant leakage and the indirect effect of high energy consumption [4].

Conventional supermarket refrigeration systems are also responsible for considerable CO_2 emissions due to the direct effect of refrigerant leakage and the indirect effect of high energy consumption. The new systems not only operate at higher efficiency, but also reduce refrigerant charge and refrigerant leakage. The IEA [4] reports that 3-5% of total electricity consumption in industrialized countries stems from supermarkets. Conventional supermarket refrigeration systems are also responsible for considerable greenhouse gases emissions. These emissions are due to the direct effect of refrigerant leakage and indirect CO_2 emissions related to the energy consumed [5, 6, 7]**.**

The EU's Eco-design Directive 2009/125/EC is designed to encourage the market to use more efficient products. It also helps manufacturers to agree a better definition of efficiency for remote condensing units. Since 01/07/2016 refrigeration units also need to comply to this system of minimum efficiency requirements. In this catalogue the seasonal data is marked with the seasonal flower [8]. The new F-gas regulation comes into effect on January 1st 2015 and requires a phased reduction of HFCs from 2015 to 2030 based on a quota system, and with bans on high GWP refrigerants in certain sectors.

In the past refrigeration and deep freeze systems have traditionally been separated from air conditioning and heating systems. Changing the initial project from store with a new solution combines them into an all-in-one-system which covers all your refrigeration and climate control needs.

Heat rejected from the refrigeration system can be recovered and used for supermarket heating. Using the equipment with 100% recovery of heat from the refrigeration showcases and evaporators inside store generated the energy efficiency and cost is saving. The total heat is used by the indoor air conditioning units to heat the retail space and delivery comfort thermal without additional cost.
Space cooling and refrigeration equipment are responsible for numerous environmental impacts, particularly with respect to overall contribution to GHG

emissions (Greenhouse Gas) [9]. Overall GHG emission for the commercial refrigeration systems have a highest value for the refrigerant leakage rate 35,8% and for energy consumption is 64.2%. [10, 11, 12].

2. The ambient conditions

A supermarket operating in Iasi was considered for this analysis. The refrigeration system simulated in this study is a classical R410A vapor compression refrigeration system type ZEAS without heat recovery. Average temperature variation Considering the latest year under observation (2022) in Iasi (Figure 1) implies that the refrigeration systems perform well in January/February and the load is extreme during July/August.

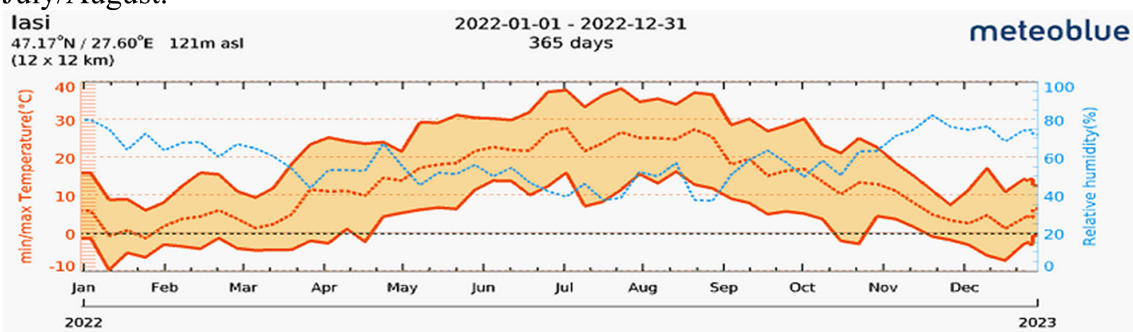

Fig. 1. Outside temperature for one year (2022) in Iasi [13].

The use of indicators or indexes such as heating degree days (HDD) and cooling degree days (CDD) can contribute to the correct interpretation of energy consumption for cooling and heating buildings [14]. Considered the annual report from EUROSTAT in the five years ago for Iasi the highest HDD values was in 2021 (3078.36) and the highest CDD values was in 2022 (128.26), table 1. This means that in 2022 was more days for cooling than in the past and this depends on ambient temperature during the cold and warm season. The evolution on the CDD has an upward trend with an increase of approx. 22.9% compared to the year 2021.

Tabel 1

Cooling and heating degree days – annual data.

TIME	2018	2019	2020	2021	2022
CDD					
Romania	84.67	123.62	96.36	137.94	145.61
Iasi	58.71	114.20	100.98	104.40	128.26
HDD					
Romania	2,748.49	2,568.23	2,665.91	2,993.60	2,751.22
Iasi	2,951.93	2,622.68	2,566.66	3,078.36	2,762.26

Weather-related energy consumption for heating and cooling in supermarket indicators such as HDD and CDD can contribute to monitoring energy demand for cooling and heating under climate change. Considering the data provided table 1 the decrease in energy consumption will be observed in this paper, where the authors propose a new technical solution.

2.1. The traditional solution

The system is assumed to be located in Iasi, therefore, weather data for this location has been used and the store opened during 24h. There are two levels of temperature for display cabinets and cold storage rooms: medium and low temperatures (MT and LT) for chilled and frozen food. The initial description of the supermarket is presented in table 2, the data are based on an audit energetically. In the summer-time, the air – conditioning set point is 26°C, while in the winter time the set point for ambient heating is 20°C, the relative humidity is set to 50%.

Table 2

Initial description of the store (commercial refrigeration)

Supermarket area	400 m^2
Power for display cabinet (MT)	12.9 kW
Power for display cabinet (LT)	2.14 kW
Power for cold room (MT)	3 kW
Power for freezer room (LT)	3 kW

The cooling load of the refrigerated display fixtures depends on space air temperature and relative humidity. Space heating is required in the sales area, offices and back rooms for customer and personnel thermal comfort with distribution system, delivery temperature 30-50°C, using eco-friendly options.

The space heating demand was calculated using the SR EN 12831-1:2017 Q_{SH} = 15kW and the cooling demand is Q_{SC} = 9kW using the national regulation I5:2022. Refrigeration solution for medium and low temperature applications with variable load conditions and high energy efficiency requirements uses the equipment type ZEAS condensing units. The scheme of refrigerant circuit is presented in figure 2. With the booster it is possible to have medium and low temperature cooling in a single system, reducing the piping requirements from 4 to 2 pipes compared with conventional system. In tables 3 and 4 is presented the report with list of equipment, piping diagram (figure 3) design using Xpress software refrigeration professionals for ZEAS condensing units and VRV IV.

Table 3

List of equipment

Model	Quantity	Description
LREQ12BY1	1	MT condensing unit
LCBKQ3AV19	2	Booster unit
Evaporator	1	Freezing room
Evaporator	1	Cooling room
Freezer display cabinet	1	Freezing
Refrigerated display cabinet	6	Cooling

Tabel 2

The cooling load for equipment

	Model	$t_{evaporation}$ [°C]	Q_{load} [kW]	$Q_{evaporator}$ [kW]
Sistem_1	LREQ12BY1 MT condensing unit		25.10	24.80
POS IV.1	Freezer display cabinet	-34	2.14	3.40
Freezing room	Evaporator	-28	3.00	4.53
POS III.5	Refrigerated display cabinet	-7	2.15	2.15
POS III.3		-7	2.15	2.15
POS III.4		-7	2.15	2.15
POS III.2		-7	2.15	2.15
POS III.1		-7	2.15	2.15
POS II.1		-7	2.15	2.15
Cooling room	Evaporator	-6	3.00	3.00

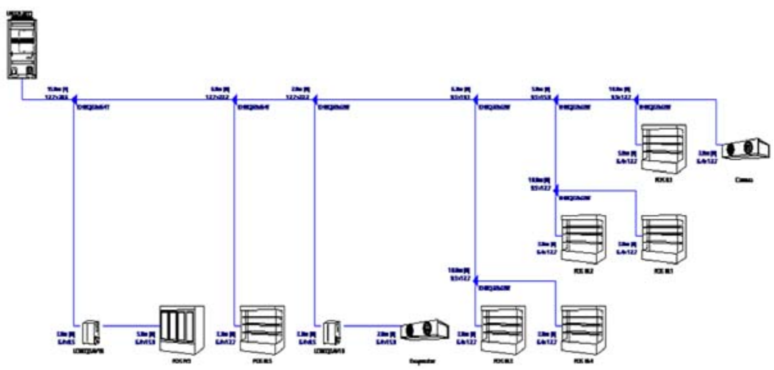

Fig. 2. Scheme of technological cooling refrigerant for traditional system (ZEAS).

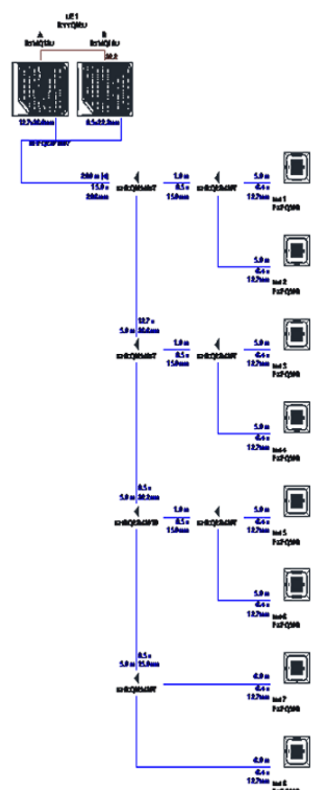

Fig. 3. The piping diagrams for air conditioning system (traditional system).

For air conditioning system (AC) it's using the VRV IV technologies system type RYYQ-U in combination with internal round flow cassette type FXFQB with technical specification in table 5. This AC system is reversible this means can have the possibility to heating and cooling on during the year.

Tabel 5

Air conditioning system components

Model	Quantity
RYMQ12U (VRV IV Continuous Heating)	1
RYMQ10U (VRV IV Continuous Heating)	1
FXFQ50B - Round Flow Round flow cassette (IU)	8

2.2. The new propose solution

Supermarkets present a unique space conditioning challenge because of the interaction between the Heating, Ventilation and Air Conditioning (HVAC) system and the refrigerated display cases. The display cases provide significant sensible cooling and increase the latent load fraction on the HVAC system. The energy consumption of the HVAC systems in retail food stores can be between 15% and 25% of the total energy consumption depending on the system design, geographic location and controls.

The heat recovered from the refrigerated and freezer display cabinets can be used to provide heating for the supermarket. In spring or autumn, heat recovered from freezer display cabinets can be used to heat the store and the excess is discharged to the environmental. In winter, heat is extracted from the outside air and combined with the heat recovered from the freezer cabinets and used to heat the internal air for achieve thermal comfort. Heat recovery from the refrigeration system is one of the most efficient ways to increase the total efficiency of the refrigeration system and to decrease the heating purchase demand. This solution AC system introduced in this paper is based to integration of AC into refrigeration system, a recent technology, solution more efficiency than the old system. In tables 6 and 7 is presented the report with list of equipment, piping diagram (figure 4 and 5) design using Xpress software refrigeration professionals for Conveni-Pack with heat recovery [15, 16].

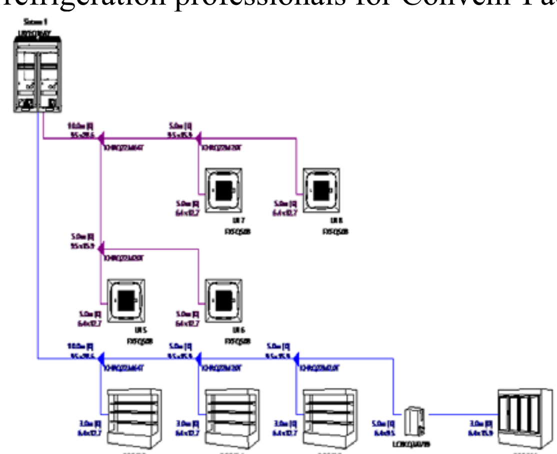

Fig. 4. The piping solution for new system-part 1.

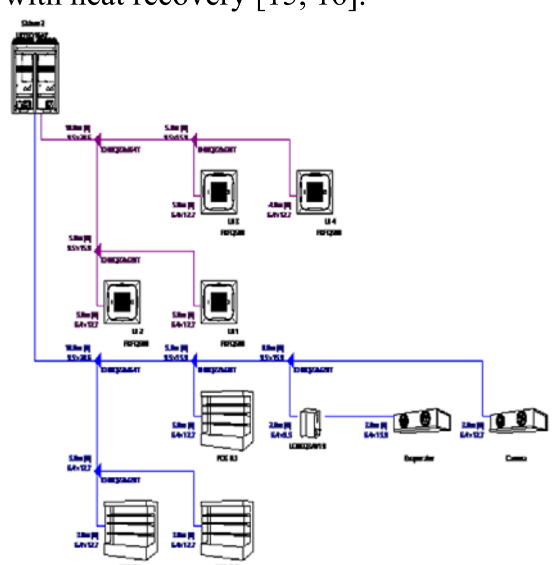

Fig. 5. The piping solution for new system–part 2.

Tabel 6

List of equipment

Model equipment	Quantity	Description
LRYEQ16AY	2	Heat pump condensing unit
FXFQ50B	8	FXFQ-B - Round Flow - Round flow cassette (IU)
LCBKQ3AV19	2	Booster unit
Evaporator	1	Freezing room
Evaporator	1	Cooling room
Freezer display cabinet	1	Freezing
Refrigerated display cabinet	6	Cooling

For new system part 1 the following values results: the heating capacity delivered to the shop is 25.2 kW and the cooling capacity actually delivered to the shop is 13.52 kW after equipment selection. The maximum available heat recovery capacity is 19 kW, enough to cover the heat requirement.

Tabel 7

The cooling load for equipment – new system part 1+2

Model equipment	$t_{evaporation}$ [°C] Set point		Q_{load} [kW]		$Q_{evaporator}$ [kW]	
	Part 1	Part 2	Part 1	Part 2	Part 1	Part 2
LRYEQ16AY Heat pump condensing unit	-	-	13.99	11.10	19.58	19.58
FXFQ50B	-	-	-	-	6.30	6.30
FXFQ50B	-	-	-	-	6.30	6.30
FXFQ50B	-	-	-	-	6.30	6.30
FXFQ50B	-	-	-	-	6.30	6.30
Freezer display cabinet	-	-34	-	3.00	-	3.44
Refrigerated display cabinet	-	-7	-	2.15	-	2.15
Refrigerated display cabinet	-	-7	-	2.15	-	2.15
Refrigerated display cabinet	-	-7	-	2.15	-	2.15
Evaporator	-28.0	-	3.00	-	4.51	-
Refrigerated display cabinet	-7	-	2.15	-	2.15	-
Refrigerated display cabinet	-7	-	2.15	-	2.15	-
Refrigerated display cabinet	-7	-	2.15	-	2.15	-
Evaporator	-6	-	3.00	-	3.00	-

For new system part 2 the following values results: the heating capacity delivered by the indoor units is 25.2 kW and the cooling capacity actually delivered by the indoor units is 22.95 kW after equipment selection. The maximum available heat recovery capacity is 14.57 kW, enough to cover the heat requirement.

3. Methodology

The comparison between the two commercial refrigeration systems refers to the energy efficiency. Each systems was selected from DAIKIN's products. The efficiencies of each system were mapped and simultaneously compared to one another, showing how each system performs in varying climatic conditions throughout the year taking into account the input data. This level of modeling using software Pack Calculation Pro allowed for the simulation of monthly consume of electricity in each system but and power usage throughout the year to ensure cooling capacity demand. The total monthly consumes electricity for systems include compressors, fans from evaporators and condensers. For the systems analyzed, their parameters are input into Pack Calculation Pro. This included type of refrigerant system, refrigerant, type of compressor, location, schedule for supermarket, type condenser and the cooling capacities.

A complete comparison of the energy usage and energy efficiency of the two systems was collected. The baseline environment weather data there is in library of software, information allow for an accurate analysis of system performance over the course of a year. When run during a year, the peak loads for each solution were calculated and exported in graph. The program allowed to simulate when cooling systems would run based on outdoor conditions, but with the constant maintenance of the evaporation temperature. If a parameter needed to be changed, it could update all systems at once.

4. Result for energy efficiency

Improving the energy efficiency of space cooling and refrigeration systems can mitigate energy related emissions, which is particularly important given the high proportion of total emissions associated with electricity consumption of cooling services. The electricity consumed for the compressors was calculated using CoolPack, Excel spreadsheet and Pack Calculation Pro programs [17, 18].

The monthly electrical energy consumption results are present here are for 300square meter store. Figures 6 and 7 show the annual energy consumption for the initial and the proposed solution analyzed in this paper. One can see that the trend of the energy consumption is the same for one year. In figure 8 is presented a comparison between both solutions analyzed here. The high energy consumption in the initial solution with 17.8% then new solution results from experimental data.

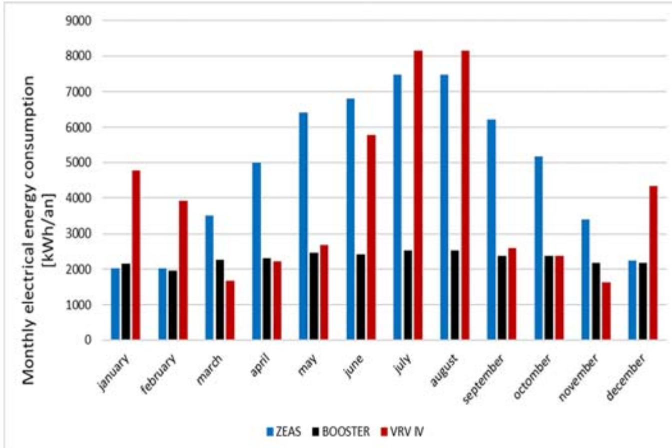

Fig. 6. The monthly electrical energy comsumption for traditional system.

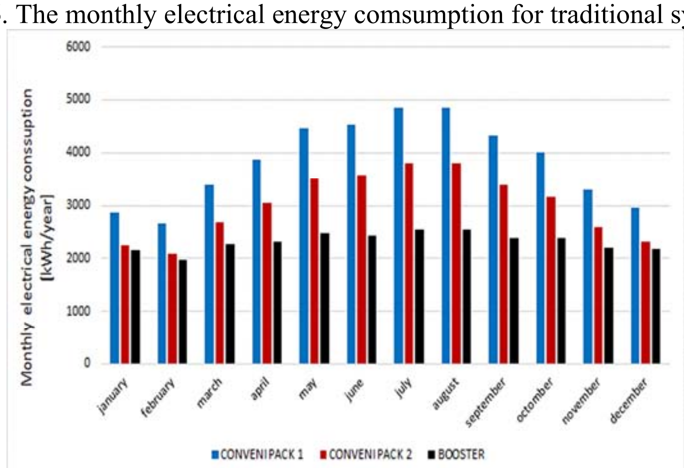

Fig. 7. The monthly electrical energy comsumption for new system.

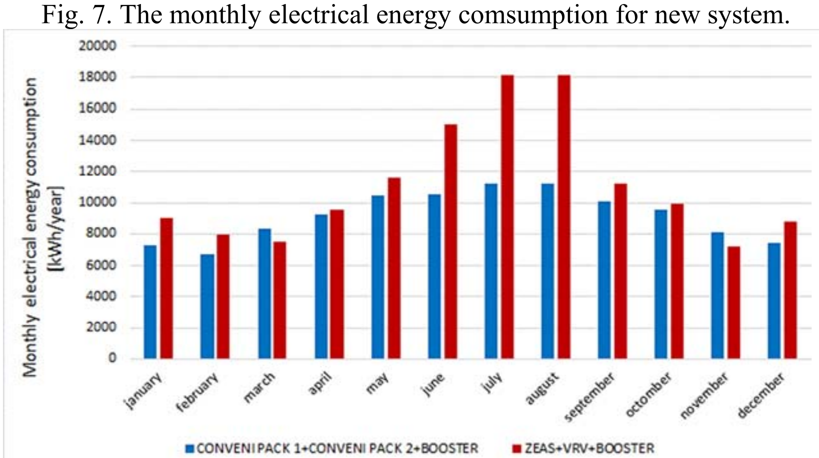

Fig. 8. The monthly electrical energy comsumption traditional system vs. new solution.

5. Discussion

Overall, there is a reduction in the total energy use for refrigeration system and air conditioning. In the last decades, an important demand of electric energy is observed worldwide to respond to the industry's development. Large food stores as supermarkets are energy-intensive buildings. The energy saving of the proposed solutions is 17.8% in the case of initial solution. During the wintertime and summertime, the integration between the refrigeration units and the air conditioning system, resulting from recovery heat of the condensation heat, leads a very low energy consumption for Conveni-Pack. The refrigerant charge is lower with 44% for new solution, dropping from 40.79 kg to 22.8 kg. Cold production is responsible for 17% of the world energy consumption. Refrigeration is necessary to maintain cold temperature in display cabinets or cold storage rooms to preserve food. This study aims to assess energy performances of two refrigeration system architectures in a supermarket: without and with heat recovery for air conditioning system.

6. Conclusions

In this paper, a comparative study for two different commercial refrigeration system configurations is performed for medium-size supermarket, with refrigerant system for commercial refrigeration and air conditioning/heating system. The evaluation was carried out for Iasi weather file, where maximal monthly temperature is equal 36°C and CDD increasing with 22.9% for 2022 then 2021. The baseline model that was used is a real case study supermarket which has as a reference refrigeration system. The model is validated against real monitoring data for both energy and environmental conditions. From the alternative refrigeration systems configurations considered, the Conveni Pack system with heat recovery was found to be the more energy efficient system not only in terms of energy performance but in terms of refrigerant charge. This system concluded to a 17.8 % reduction in the total annual energy use of the case study store. Calculations show that the proposed solution offer a benefit in term of energy efficiency over the reference traditional solution. The new systems can limit the refrigerant charge, drop with 44% and annual leak rate decrease in close connection and can also save energy and provide better operational control. The low charge of the new system it has an impact on the footprint environmental.

As a final remark, the new solution should be proposed also for different climatic zone from Romania with consideration of their significant energy consumption. The future step is to continue this study for other towns with different outdoor conditions and also to calculate the total emissions CO_{2eq} over the lifetime of the system.

The technological advancements described above can produce important benefits as regards energy costs and the environment.

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