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RESHeat (Renewable Energy System for Residential Building Heating and Electricity Production), One System for Two Different European Climate Zone

Abstract: - At the European level, there is significant attention towards improving the energy and environmental quality of buildings, as evidenced by recent regulations such as the newly issued EPBD (Energy Performance of Buildings Directive). Specifically, building energy efficiency is responsible for almost 40% of emissions caused by energy processes.

In this context, the European project RESHeat (Renewable Energy System for Residential Building Heating and Electricity Production) was developed to create a system for heating and cooling residential buildings using renewable energy in two different climatic zones in Europe. The RESHeat system primarily consists of a heat pump, photovoltaic/thermal modules, and two thermal energy storage units, with modifications depending on the climate where it is installed. One of the innovations of the RESHeat system is the use of waste thermal energy from the photovoltaic cooling system to ensure consistent energy levels in the heat pump's cold well, thereby increasing the heat pump's energy efficiency and its COP (Coefficient of Performance). Additionally, the PV-T is integrated into the system to maximize the amount of renewable energy produced.

In Italy, the study focuses on a social housing building from the 1980s, specifically a three-storey building with 13 apartments of different sizes. A similar residential building with 9 apartments in Limanowa (Poland), was chosen.

Energy simulations were conducted using a dynamic model with TRNSYS software. The aim of this paper is to present the results obtained for the two different climatic zones, demonstrating the achievable targets and highlighting the energy and environmental savings compared to the current situation.

The results show that the average annual COP of the heat pump is very high for both Limanowa and Rome, being 4.85 and 5.4 respectively during the heating period. Additionally, another objective achieved for both buildings is to exceed 70% of the share of renewable energy for the buildings' electrical and thermal needs.

Keywords: Energy retrofit of residential buildings, Heat Pump system, Photovoltaic/thermal modules, Thermal Energy Storage.

I. INTRODUCTION

Climate change impacts the energy sector in buildings, both in the design phase and in the phase of management, due to the increase in energy consumption caused by the growing demand for cooling and the undersized or oversized capacity of heating systems for future needs [1]. However, the first step to achieving sustainable urban development concerns the generation and optimization of energy in buildings in order to implement the decarbonization process of urban areas. Indeed, as space heating and cooling in buildings is one of the most energy-intensive ends uses, energy conservation measures (ECM) are the key aspects to achieve the European Union (EU) 2050 targets on energy efficiency and greenhouse gas (GHG) emissions [2]. Several studies have focused on detailed energy modelling of buildings (BEM) [3]; optimization of internal loads; envelope insulation and heating, ventilation and air conditioning system operation (HVAC).

The building context (e.g. materials, configurations, etc.) plays a key role in the retrofit process.

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The configuration of buildings in a tight urban setting requires different strategies than isolated buildings, as shading effects and heat dissipation capacity vary significantly. In summer, buildings in a narrow canyon may benefit from shading that reduces cooling demand, but may have limited heat dissipation compared to isolated buildings [4].

Buildings located in an urban canyon, actually, are subject to complex interactions of short-wave and long-wave radiation due to multiple reflections between surrounding surfaces. This significantly affects heat fluxes and energy demand in both summer and winter. In contrast, insulated buildings receive a greater share of radiation from the sky and have greater heat loss at night. Therefore, to maximize energy efficiency, it is critical to consider the orientation and proportions of surrounding constructions.

In addition, the process of electrification, which is experiencing intensification in the recent period, implies high utilization of the power grid, which can lead to overloads. The associated electricity losses in underground power cables generate heat, which increases the temperature of the surrounding ground and urban infrastructure potentially increasing the heat island effect [5,6].

Article 4 of the EU Energy Performance of Buildings Directive (EPBD) states that each Member State should differentiate the minimum energy demand of buildings according to their year of construction and category. Moreover in many Italian municipalities, improving energy efficiency requires special actions [7].

There are multiple studies on retrofit interventions for residential buildings in Italy and Europe.

Some authors present an overview of current trends and technologies in the application of renovation measures on historical and heritage buildings, discussing the feasibility and convenience of various retrofit measures [8-13].

Such strategies can follow different approaches, focusing more on the upgrading and efficiency of the building envelope part or the energy systems part, or both, depending on what the specific objectives are. Energy retrofit of historic buildings is based on targeted strategies to improve energy efficiency without compromising architectural value. These strategies include insulating the envelope from the inside, using thermal coatings, and retrofitting windows to reduce energy losses. Other solutions include converting courtyard spaces into atriums to improve indoor environmental quality and adopting more advanced thermal comfort management technologies.

One strategy may be to adopt targeted, minimally invasive but high-tech interventions, e.g., the insertion of a thin layer of monolithic aerogel (3 mm) in double-glazed systems. It allows to reduce thermal transmittance of more than 25%, with effects on energy waste beneficial for both historic subjected to retrofit and new buildings [14].

Agro-industrial and industrial and wastes and by-products exploitation appears promising in building materials production as well. Their use for the creation of green and low-carbon insulating materials, allows to obtain good acoustic properties and thermal insulation, enhancing the building's energy efficiency, and at the same time to reduce resources disposal, gaining environmental sustainability benefits [15].

The integration of renewable energy, such as solar and geothermal energy, is a crucial part of these interventions, although it requires care to maintain the aesthetic integrity of historic buildings [8].

With a view to energy optimization and the goals set by the EPBD, the focus must also be on the energy production and consumption part [16] and the integration with renewable sources for emission reduction and decarbonization of the building stock.

Heat pump systems are an upgrade of conventional heaters that, in addition to benefiting individual users, represent a preferable intervention for improving efficiency at the neighborhood scale in anticipation of the development of renewable energy communities [17, 18].

Hybrid (gas and electric) heat pumps facilitates fuel source switching between electricity and gas, when ambient temperatures are low or high water supply temperatures are required. Their deployment in deep building retrofits recoups about half of the heating system capital cost within 20 years [19].

Operational flexibility and demand-side management of heat pump systems can be improved by integrating them with Integrating latent heat storages [20].

The implementation of multi-energy systems, which combine renewable sources such as photovoltaic panels and electric generators with energy storage systems, emerges as an effective solution. These systems not only improve the stability of the main power grid, but also offer significant economic and environmental benefits [21].

There exists also different RES-based heating systems for buildings application. Violidakis et al. [22] analyzed the use of two heat storage systems for a residential building. One consists of a low-temperature storage system based on phase change materials (PCM) used for building heating; the second one is a high-temperature storage system used to store both thermal and electrical energy. The study indicated quite good potential for residential buildings heating of the proposed solutions with significant energy savings.

Felseghi et al. [23] studied different concepts for electricity generation in buildings using hydrogen. The work included research on integrating hydrogen technology into solar and wind power generation systems. The research showed that hydrogen energy storage is efficient but the costs of this solution are considerable. In conclusion, to implement a Renewable Energy based heating system for building a detailed heating demand analysis is needed.

To explore the influence of outdoor climate change on occupants' heating patterns is crucial for defining the optimal structure and components of an energy system, as well as for energy planning and clean-heating policy optimization [24].

Efforts in model enhancement are key aspect for the development of thermal energy systems; it is in fact essential both to accurately model the energy balances and to tend to minimal computational workload in view of models implementation in real-time control applications. For stratified water storage tanks, commonly represented by one-dimensional static-grid models but requiring a dense grid to reproduce mixing effect correctly, an adaptive-grid model is presented in [25].

The present proposal, within the RESHeat Project, aims to improve the current mechanical systems of residential buildings from an energy point of view, designing a renewable energy-based system for heating and cooling.

The proposed system uses solar energy as primary energy through the PVT modules. Using a heat pump and cold/heat buffers it is possible to deliver the heat to a building using fan coil units.

In Poland, the RESHeat project is a sun-tracked PVT-based system coupled with an underground energy storage unit. Some modelling approaches have been recently discussed for the RESHeat system [26] where the underground energy storage mathematical model is presented. The finite volume method was used for the simulation of ground and water temperature in the underground energy storage system through the entire one year period. The results show that using underground tanks only for building heating makes it possible to reduce the length of vertical boreholes and provide up to 75% of heating energy to the building through the heat pump [27].

In some cases the amount of heat extracted from the ground during the winter season can be considerably different from the amount injected in summer, causing ground thermal drift. Such energy unbalance if it can be avoided at the design stage with accurate sizing is more difficult to correct in already built systems. Coupling the external air with the ground as a heat sink for the heat pump represents a promising solution [28].

An alternative approach consists of coupling the heat pump and photovoltaic panels by means of a thermal storage thank, left unburied but sized and optimized to maintain energy levels able to guarantee the system's high [29, 30]. By replacing the underground source of the heat pump in this way, a more suitable solution is obtained for a different set of climate zones: those characterized by higher temperatures, such as those found in Italy, particularly in central-southern area [31].

Thus, current paper presents the RESHeat plant system application in a Polish and an Italian case study, demonstrating its benefits in context charachterized by different environmental conditions and heating demand.

Through dynamic analysis of the HVAC system, it was evaluated the optimal configuration of the system.

The utilization of an innovative plant system with a heat pump with a COP of over 5.5 is therefore not decreased in consecutive years. This is thanks to solar heat storage. With a high COP, less electrical energy from the heat pump compressor. Lastly, the coupling PV-T produces an electrical energy conversion rate of up to 20% and maximizes renewable energy production.

The RESHeat systems are capable of reducing primary energy consumption and allow the employment of renewable energies within the social housing building stock.

In addition, the outcomes of the work are proposed as a guideline and prototype for efficiency actions intended for existing multifamily buildings, especially in the social housing context, taken into account the energy consumption of the occupants.

II. RESHEAT TARGETS

Development and application of a new Heating and Domestic Hot Water preparation system to cover at least 70% of the total annual energy demand of a building from a renewable energy source.

The RESHeat solution is capable of covering at least 70% of the building's energy demand, including heating, cooling, and electricity. The annual COP (Coefficient of Performance) of the heat pump, which represents a significant part of RESHeat, should be greater than 4 (for fan-coil applications) and greater than 5 for underfloor heating, thanks to advanced heat storage units with ground regeneration. The system costs should be less than €800/kW of thermal power required for a building with more than 8 apartments. The system is also almost maintenance-free (maximum €200/year for system maintenance), ensuring a return on investment within a maximum of 6 years.

III. INNOVATIONS OF THE SYSTEM ARE

1) By reusing the waste heat from the Photovoltaic System combined with underground energy storage, a high COP (Coefficient of Performance) for the heat pump is achieved, with an annual average above 5. Typical water-to-water heat pumps have a COP of 4 at most. Such a high COP allows for effective underground energy storage, resulting in 20% less electrical energy consumption by the heat pump compressor.

2) Development of a highly efficient ground regeneration technique through the transfer of heat from the underground storage unit to the ground and from boreholes to the ground, ensuring that the COP of the heat pump does not decrease over successive years. This is, in fact, the most significant innovation of the RESHeat solution, allowing for the maintenance of a constant COP over the operational years of the heat pump. No solutions currently available on the market allow for effective ground regeneration and maintenance of a constant COP for the heat pump, which otherwise would decrease in efficiency year after year.

3) Photovoltaic System with cooling and intelligent sun tracking to achieve an 18% solar/electrical energy conversion and up to 60% solar/thermal energy conversion efficiency to maximize the yield of renewable energies.

IV. DESCRIPTION OF THE BUILDINGS AND THE TWO RESHEAT SYSTEMS

The Top-Cezar V building is located in Limanowa, Poland, and is a multifamily residential building. The RESHeat system has been implemented on a single floor of the building, consisting of 9 apartments. The demonstration site is located in climate zone 3 according to the climatic zones of Poland. Currently, there is a heating system designed to consider an outside temperature of -20°C according to the PN-EN 12831: 2006 [32] standards. The floor where the RESHeat system is being constructed has a maximum heating load of 34.37 kW. The building's heating system consists of two 60 kW gas boilers used for central heating and domestic hot water preparation for the entire building. Radiators are used for central heating in the apartments, with a heating set-point temperature of 22°C. The TOP-CEZAR V building is illustrated in Figure 18.

The RESHeat system, which is in the planning and construction phase (Figure 2), will serve to heat the building and produce domestic hot water with the integration of renewable energies. The existing boiler has been replaced with a heat pump. Specifically, at this demonstration site, five tracking solar collectors will be installed to generate thermal energy. The generated thermal energy will be stored in buffer tanks to provide sufficient heat for heating and domestic hot water production. Excess heat from the solar collectors will be stored in underground storage tanks for use during the non-heating season. The tracking solar collector will be connected to the heat exchanger immersed in the domestic hot water tank and to a heat exchanger placed between the

Fig. 1. The TOP-CEZAR V demo site

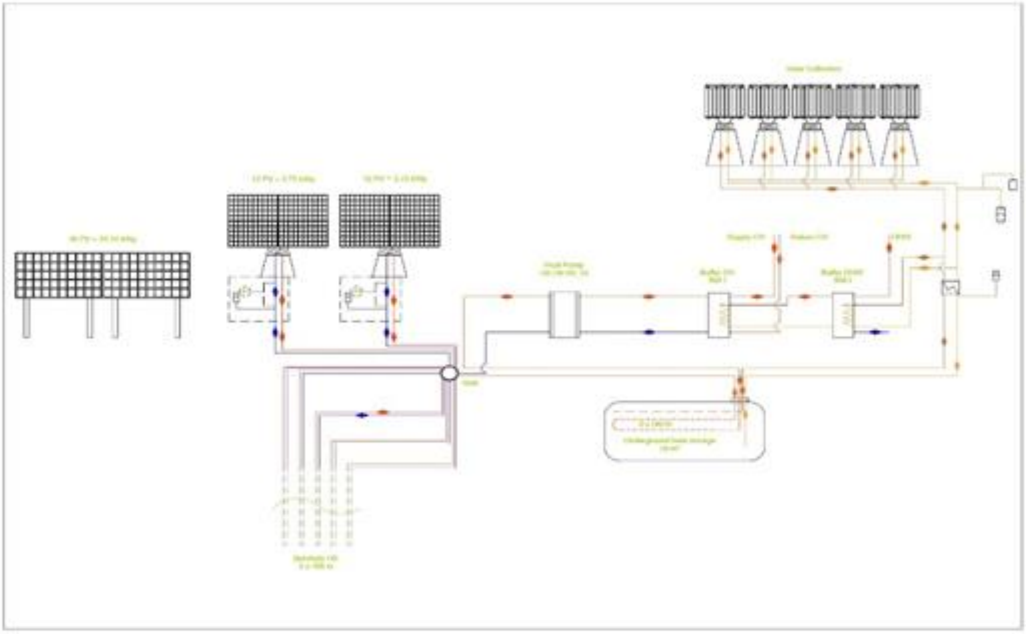


Fig. 2. The RESHeat concept for the Top-Cezar V demo site in Limanowa, Poland

underground heat storage accumulators. A temperature sensor at the bottom of the domestic hot water tank sets the temperature for the operation of the tracking solar collectors. The temperature is set to 45°C. Therefore, the tracking solar collectors supply the domestic hot water tank based on the set temperature. When the ambient temperature and solar irradiation levels are low, the set temperature, the underground heat storage temperature, and the solar collector temperature are compared. The RESHeat system then decides to turn on the pump and supply the domestic hot water tank or the underground heat storage accumulator when there is enough heat if the pump is not off.

Forty-six fixed photovoltaic panels will be installed to generate electricity to cover the power consumption of the HP, the control system, and the overall RESHeat system. Two solar tracking PV/T systems will be installed to support electricity generation, and the low-temperature thermal energy generated will be stored in the heat exchanger of the well. The RESHeat control system will constantly monitor the temperature of the PV/T modules and ground heat exchangers to decide whether to turn on the pump to collect waste heat from the PV/T modules. When the temperature of the PV/T modules is higher than that of the wells, the pumps turn on to collect waste heat from the PV/T modules. The low-temperature thermal energy will be used during the winter to maintain the HP's COP as high as possible. A water-to-water heat pump with a heating capacity of 42 kW is already installed at the demonstration site and will be used during the demonstration. The RESHeat system components and their respective capacities installed at the Limanowa demonstration site are as follows:

- 5x sun tracking solar collectors – 19.0 kWt (peak) capacity,
- 46x stationary PV modules – 20.24 kWe (peak) capacity,
- 2x sun-tracking PV/T system each with consisting of 12 PV/T modules – 7.44 kWe (peak), 5.60 kWt (peak) capacity,
- A heat pump with maximum heating capacity of 42 kW,
- 5x each 100 m deep ground heat exchangers (boreholes),
- 2x buffer tanks each with immersed heat exchanger and each with 500 L capacity,
- A 50 m3 non-insulated underground heat storage unit.

MATH TOP-CEZAR V demo site simulation results

Table I. Summary of the energy analysis

Generation and Demand	MWh/y
Central heating demand	37.96
Domestic hot water demand	10.62
PV/T thermal energy generation	14.19
Solar collector thermal energy generation	22.65

Generation and Demand	MWh/y
Heat pump thermal energy generation	42.19
System losses (Controls, pumps, hydraulics)	4.22
PV electricity generation	17.89
PV/T electricity generation	11.74
Heat pump electricity consumption	9.02

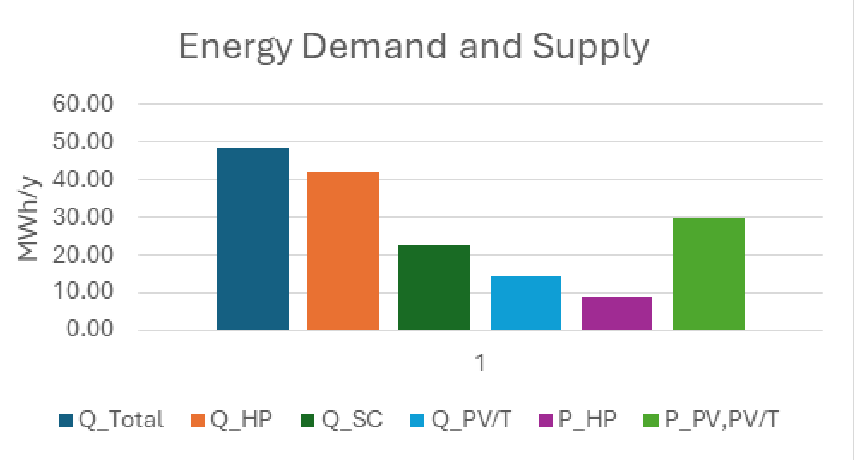


Fig. 3. Energy demand and supply

This section presents the simulation results of the system installed in the Top-Cezar V building. In particular, the main results obtained from the energy analysis are summarized in the table (Table I).

The energy demand and generation, both thermal and electrical, are shown in Figure 3

Where Qtotal is the total energy demand of the floor, while Q_HP, Q_SC, and Q_PV/T are the thermal energy generation of the heat pump, the solar collectors, and the PV/T system, respectively. P_HP is the electricity consumption of the heat pump. P_PV and PV/T indicate the total electricity production of the PV and PV/T systems.

The simulation results show that the heat pump consumes 9.02 MWh/a of electricity during the annual working period, while the electricity consumption of the control system, pumps, and system losses is around 4.22 MWh/a. The total electricity consumption of the RESHeat system is 13.24 MWh/a for this demonstration site. The annual electricity production of the PV and PV/T systems is 17.89 MWh/a and 11.74 MWh/a, respectively. The monthly electricity generation and consumption are illustrated in Figure 4.

The monthly average COP trend of the heat pump is illustrated in Figure 5. The simulations show that the yearly

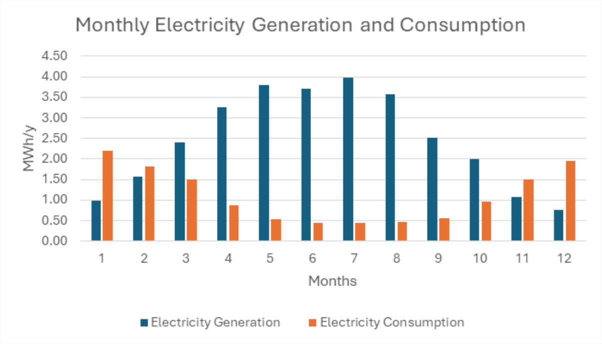


Fig. 4. Monthly electricity generation and consumption

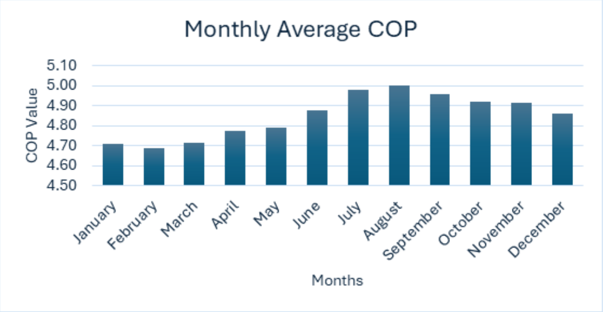


Fig. 5. The average monthly COP

average COP of the heat pump is 4.85. As can be seen, the preliminary phase target has been achieved in accordance with the European project. The other target of producing 70% of electricity from renewable sources has also been attained. The figure also illustrates the monthly variation of the COP (Coefficient of Performance).

V. ATER PROVINCIA DI ROMA- DEMO SITE SIMULATION RESULTS

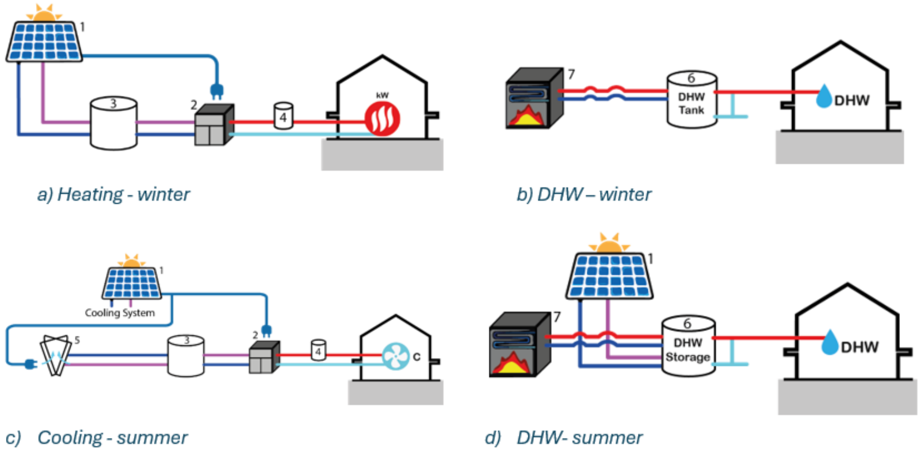
Regarding the building selected for the Italian climatic zone, it is an ATER building located in Palombara Sabina (RM). It is a three-story reinforced concrete building with a total of 13 apartments. It has a heated area and a volume of 943 m^2 and 2484 m^3 respectively. The building features a roof with two pitched slopes at 25°, oriented one at 25° northeast and the other at 25° southwest. Figure 6 shows the main facade of the ATER building.

The building is constructed with external walls consisting of two layers of hollow bricks separated by air and a thin layer of insulating material. The horizontal structure is made of reinforced concrete and bricks without thermal insulation, except for the floor adjacent to the attic. Transparent elements include single-pane windows with metal frames without thermal breaks.

The demonstration site is located in climate zone D according to Italy's climatic zones (DPR 412/93). Based on the climatic zone and standards UNI EN 12831:2006 [32] and UNI 5364:1976 [33], the comfort indoor temperature setpoint is 20 ± 2°C, and the design outdoor temperature is 0°C. In summer, the design outdoor temperature for cooling is 32°C with 60% relative humidity, and the comfort temperature is set at 26°C.

The centralized heating system is served by a natural gas boiler with a maximum power of 69 kW.

Fig. 6. ATER building north-west view



a) Heating - winter

b) DHW – winter

c) Cooling - summer

d) DHW- summer

Fig. 7. RESHeat system

The RESHeat system designed and currently being installed is intended for integrated production of heat, cooling, and electricity. Figure 7 schematically and conceptually illustrates the layout of the system.

Key components include a water-to-water heat pump (2), a hybrid photovoltaic system (1), and two distinct thermal energy storage tanks (on the source side (3) and on the load side (4) of the heat pump). The system utilizes a water-to-water heat pump for thermal energy generation capable of meeting both winter heating and summer cooling demands. This system is integrated with a photovoltaic array consisting of 75 panels, which are cooled by a 3 m3 buffer tank (3) on the heat pump source side. Additionally, this tank is connected to a dry cooler (DC) necessary for heat removal during summer. On the load side of the heat pump, connections are made to fan-coil units for heating and cooling indoor spaces. The RESHeat system's control mechanism is strategically designed to optimize the use of renewable energies.

The operational principles governing the RESHeat control system are as follows: the circulation pump activates when the temperature under the photovoltaic panels' heat exchanger (1) exceeds 20°C ± 2°C. During winter, the heat pump activates when the temperature inside the inertial accumulator (4) drops below 45°C ± 5°C. The heat pump operates between 5 AM and 11 AM and between 4 PM and 10 PM according to Italian norms. In summer, the heat pump activates when the temperature of the inertial accumulator (4) exceeds 15°C ± 5°C. During summer, the dry cooler (5) is activated to facilitate the heat pump's operation, especially when the heat storage tank (3) temperature exceeds 20°C.

During the winter season, heat generated by the heat pump, and in summer months, cold produced to meet increased cooling demand, is stored in a buffer tank (3). Enhancing the heat pump's efficiency is crucial through synergistic use of photovoltaic panels. In winter, the photovoltaic system's cooling circuit feeds the 3 m3 buffer storage (3), producing thermal energy used to maintain the tank's average temperature around 15.45°C, thereby increasing the heat pump's efficiency. Simultaneously, the liquid temperature inside tank (3) is lowered by the heat pump's evaporator side power, ensuring adequate cooling for the panels. During the summer season, heat produced by the photovoltaic panels is used for domestic hot water, while excess heat in the TES (3) connected to the heat pump condenser side is dissipated by a dry cooler.

Table II. Summary of annual energy analysis

$\boldsymbol{E_{th,PVT,st}}$	31	MWh/y
$\boldsymbol{E_{th,HP,e}}$	16	MWh/y
$\boldsymbol{E_{th,DHW}}$	25	MWh/y
$\boldsymbol{E_{el,PVT}}$	30	MWh/y
$\boldsymbol{E_{el,demand}}$	28	MWh/y
PE_{nREN}	56	MWh/y
PES	36	MWh/y
f_{sol}	98%	%
f_{sc}	15%	%

sCOP	6	-

To understand the integration of the RESHeat system into the studied building in Italy, a monthly and annual analysis was conducted, considering thermal energy consumed and generated, as well as electricity required and produced. Furthermore, system efficiency is considered, particularly the seasonal and monthly average COP of the heat pump. Additionally, to express renewable energy penetration, solar fractions achieved are presented. Table II provides the annual summary of the main energy aspects considered.

An essential aspect of the system is its ability to maintain a high level of efficiency, with the heat pump COP consistently above 5. The combined operation of the heat pump and photovoltaic panels is crucial for optimizing system performance. During winter, the panel cooling circuit, powered by the heat pump's cold source, exchanges heat with the thermal storage, maintaining an average temperature inside above 8°C. According to simulations, the heat pump achieves an annual average COP of 6. Specifically, the seasonal heating performance factor (sCOPh) is 5.4, and the seasonal cooling performance factor (EER/sCOPc) is 6.9 (Figure 8).

In summer, based on the heat pump's characteristics, increasing the DC set point temperature increases the heat pump's COPc. When the set point temperature is 25°C, the average inlet temperature of the heat pump is maintained at 26.37°C, and its seasonal average COPc is 6.99.

Another crucial aspect of the proposed system is the integration of the photovoltaic array. Specifically, during the winter months, the low-temperature heat produced by the panels is utilized to supply the heat pump's cold side, ensuring the high efficiency levels discussed earlier. Conversely, during non-winter months when the panels can provide heat at higher temperatures, they are coupled into the system for heating domestic hot water. The thermal generation through the panel operation is thus analyzed in relation to these two distinct needs.

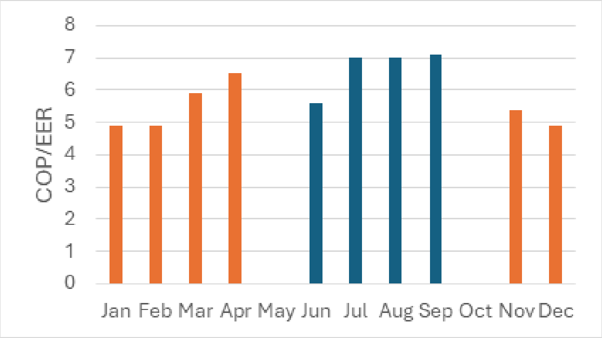


Fig. 8. Monthly performance: a) heating COP (orange); b) cooling EER (blue)

In Figure 9a, the thermal energy generated by the collectors and stored in the accumulator (E_(th,PVT,st)) is depicted, subsequently utilized by the heat pump, with E_(th,HP,e) indicating the thermal energy required by the heat pump's cold side. Additionally, the solar factor (fsol,th) is provided for each month. During the winter period, the useful heat production from the panels amounts to 7.64 MWh, while the thermal demand from the heat pump's evaporator is 15.9 MWh. In this specific case, considering only the winter season, the solar thermal fraction (fsol,th,H) is 0.54.

During months outside the heating season, the heat produced by the photovoltaic panels is directed towards the production of domestic hot water (Figure 9b). From April to October, the demand for domestic hot water (E_(th,DHW)) amounts to 25.18 MWh. The total theoretical production of thermal energy by the photovoltaic panels could reach 32.6 MWh, but the actual thermal energy available depends on the capacity of the domestic hot water storage tank (number 6 in Figure 7). According to UNI TS 9182 [34] and the previously indicated domestic hot water demand, a volume of 1500 liters is considered. Since the heat source is variable in nature, the actual storage tank capacity must be verified through dynamic simulation.

If the volume is 1500 liters, the thermal energy provided by the PVT and retained in the buffer tank amounts to 23.65 MWh, with renewable energy covering 94% of the thermal energy demand.

Directing the heat derived from the cooling of the panels, which would otherwise be dissipated by a dry cooler, to meet the summer load of domestic hot water, is an effective strategy to avoid heat wastage and the electrical load of the potentially connected dry cooler. This simultaneously increases the renewable energy coverage of the building, thereby reducing current consumption from fossil sources.

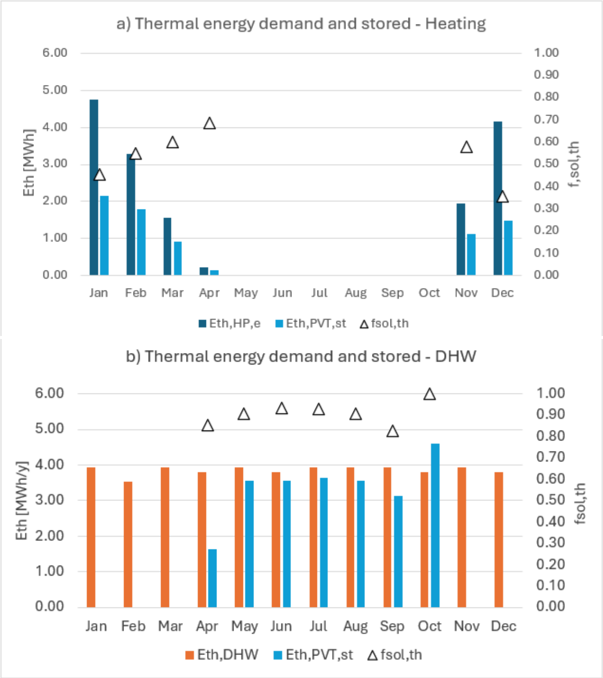


Fig. 9. Thermal energy produced and stored by PVTs(Eth,PVT,st) and thermal solar fraction (fsol,th) related to thermal energy consumed by different services: a) HP; b) DHW

The Photovoltaic System annually generates 30 MWh/a. From the simulation, the electrical energy consumed by the heat pump during its annual operational period amounts to 9.28 MWh/a (Figure 10). The estimated electricity consumption post-intervention is calculated based on simulations (MWh) and increased by 10% to account for auxiliary electrical and electronic device consumption. Additionally, the current electricity consumption related to non-heating condominium usage is increased by 15% to consider future additional condominium expenses. This results in an electricity consumption of 23 MWh/a, indicating that annual production ensures a positive balance between consumption and production.

The net annual solar electricity fraction is 1.27 (Figure 11). In all months except for the winter months (December, January, February), electricity production exceeds demand with a net solar fraction (fsol,el,net) greater than 1. Specifically, there is a minimum fsol,el,net of 0.22 recorded in December. Conversely, as indicated in the previous section (4.2 Thermal Energy), the annual thermal solar factor is 0.67, with a minimum in January (0.25) and a peak exceeding 0.95 in June and July. Given the thermal and electrical solar factors, the global solar fraction (fsol,gl) resulting in an annual value of 0.98. During months of high thermal and electrical demand but low production, solar sources require auxiliary support to meet these demands, reaching a minimum of 0.29 in January and December. In contrast, during months with higher production and lower electrical and thermal demand, fsol,gl exceeds 1, with the maximum occurring in April, the month with the lowest electrical and thermal consumption, at 2.

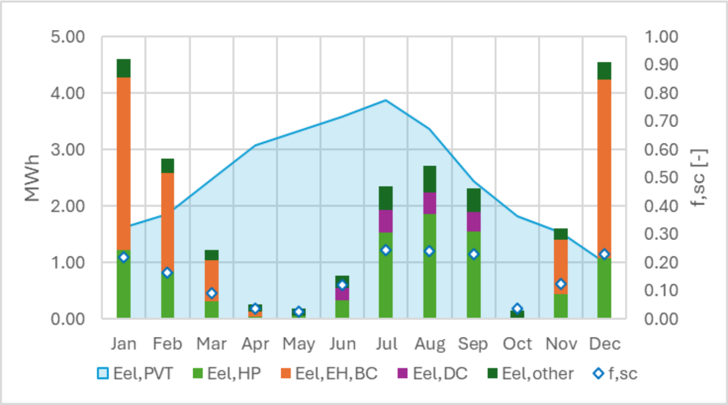


Fig. 10. Electrical production and consumption

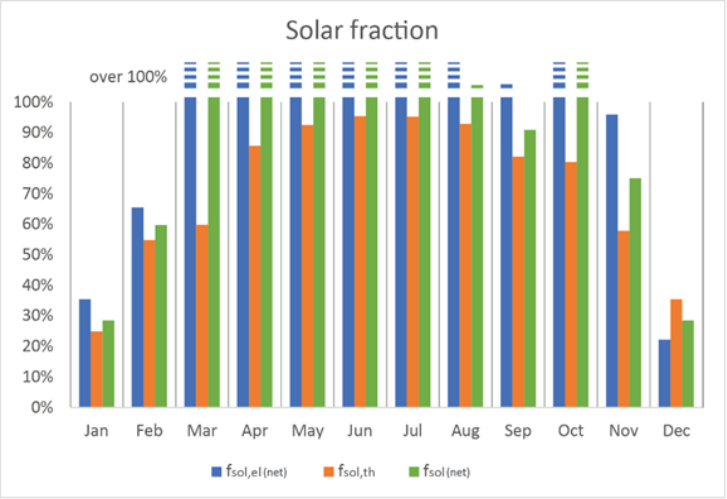


Fig. 11. Electrical, thermal and global solar fraction; (net) indicates that the considered electricity is the whole produced, including the self-consumed and the share fed into the grid

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