Energy refurbishment of a public indoor swimming pool

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Abstract. The European Union's energy policy is strongly oriented towards decarbonization through the electrification of end-use energy consumption. Indoor swimming pools, as specialized buildings, are among the most energy-intensive facilities in terms of HVAC demand. This paper presents the energy renovation of a municipal swimming pool located in Florence (Italy), combining thermal insulation of the building envelope, fuel switch from gas to electricity, and installation of solar thermal and photovoltaic systems. A key design concept is an openable roof, which limits HVAC operation to the period from October to April. The indoor air system has been redesigned using micro-perforated ducts, and a relamping is also planned. The overall structural, architectural, and plant design has now been completed, and the intervention is expected to be financed through the "Sport e Periferie" call for proposals. For each intervention, this paper evaluates both the potential benefits and the implementation challenges, drawing on a comprehensive transient numerical model of the pool building and its associated HVAC. An energy–environmental assessment is presented, alongside a techno-economic analysis conducted as part of an energy audit. The final design represents the optimal compromise given operational and cost constraints, while enabling a significant reduction in CO_2 emissions and atmospheric pollutants in a densely built-up urban area.

1 Introduction

The European Union's current energy policy prioritizes reducing dependence on fossil fuel imports, with energy efficiency serving as the primary driver of the energy transition. This transition, which includes the electrification of end-use energy consumption and the increased deployment of renewable energy sources, spans all major economic sectors. In particular, the buildings sector, which accounts for the largest share of gas consumption, is targeted by measures within the Energy Performance of Buildings Directive (EPBD) and the Renewable Energy Directive (RED). Existing public buildings exhibit significant potential for energy efficiency improvements, particularly in relation to the ventilation of high-occupancy spaces [1] and the retrofit of mechanical systems [2]. Indoor swimming pool buildings are among the most energy-intensive structures in the non-residential sector, as highlighted by several studies [3, 4, 5].

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1.1 Bibliographic review

A systematic bibliographic review regarding swimming pool buildings is presented in [6]. The paper analyses literature on these facilities, focusing on heating, ventilation, and air conditioning systems. The review identifies major trends over the past few decades, with a notable emphasis on energy consumption and air quality. It points out that, with the exception of research on air quality and disinfection by-products, the body of research on these facilities remains fragmented, with no dominant contributors emerging in the various fields.

The balance between environmental quality and energy efficiency is explored in [7], who introduce an in-situ measurement method to assess air parameters and suggest scenarios for improving energy savings. Their study, conducted in a typical swimming pool building, identified seven scenarios that achieved energy savings ranging from 6% to 47% compared to initial measurements.

Benakcha et al. [8] focus on the impact of water temperature setpoints and energy strategies on indoor swimming pool performance. Their numerical analysis reveals that evaporation, which accounts for 67% of heat loss from the pool water, is the main contributor to energy demand. The study suggests that improving the building envelope and lowering the water temperature setpoint can reduce evaporation, leading to a 19% reduction in energy consumption. Two strategies are considered: using solar energy to slightly increase water temperature (saving up to 17%) and subcooling the water during unoccupied periods (saving up to 4%).

Hanafi et al. [9] examine various ventilation system configurations, including inlet and outlet placements, airflow rates, and distribution patterns. Their findings high-light the critical role of ventilation design in maintaining indoor air quality and thermal comfort in swimming pool environments. Specific configurations, such as circular inlets for spectators and rectangular inlets for the pool area, were found to improve air distribution and thermal conditions.

Sobhi et al. [10] investigate the effect of spectator occupancy on temperature, relative humidity, thermal comfort, and water evaporation rates. According to the findings, as attendance increased, the average values of temperature and Predicted Mean Vote (PMV) inside the space increased, while the average value of relative humidity decreased. The results suggest that optimal air jet placement is essential for maintaining thermal comfort, especially at higher occupancy levels.

A similar focus on ventilation strategies, but for swimmers rather than spectators, is presented in [11]. The study evaluates how changes in ventilation impact evaporation rates and the reduction of trichloramine (NCl_3) concentrations in the breathing zone. Adding deck-level air extraction vents was found to reduce NCl_3 concentrations by 41% without compromising thermal comfort, while only slightly increasing water evaporation by 4%.

Finally, in [12] a case study of a public indoor swimming pool is presented, using dynamic simulations developed with TRNSYS software alongside real-world experimental data. The study investigates various energy efficiency measures, including optimizing evaporation control and increasing the share of heating from renewable sources. Both strategies resulted in a reduction in heating demand and a decrease in overall primary energy consumption.

2 Case-history

The paper presents the energy refurbishment of an indoor swimming pool for sports and recreational use, located in the San Marcellino district of Florence, Italy. The facility is owned by the Municipality of Florence and managed by the Affrico Sports Club. It is part of a larger sports complex that includes a gym and several soccer fields. The interior layout is designed to accommodate both athletes and spectators attending events. The facility exhibits a highly variable usage profile throughout the day and week, which significantly influences operational strategies and associated energy costs.

The pool building dates back to the late 1970s and was designed and constructed according to pre–oil crisis standards, with poor consideration for energy performance and indoor comfort. The building envelope is primarily composed of cast-in-place reinforced concrete, left exposed for both structural and architectural reasons. The windows are fitted with uninsulated aluminium frames and low-thickness double glazing. Originally, no air-conditioning system was installed, and during the winter season the building was heated by the heat released into the indoor environment through evaporation from the pool surface.

Fig. 1. Design render of the swimming pool building.

As the building under investigation is an existing structure, the thermal transmittance of the envelope components was estimated based on the thermal conductivity values of the individual materials, taken from UNI 10351 for homogeneous components and UNI 10355 for hollow clay–concrete (laterocement) components. A 3D survey based on a laser scanning point cloud enabled the precise determination of the thickness of all components, with particular attention to cast-in-place reinforced concrete elements. With regard to transparent components, the calculations were carried out in accordance with UNI 10077-1 for the existing windows, while for the newly installed windows the values declared in the Declaration of Performance were adopted. Heat transfer to the ground was evaluated according to the methodology provided in UNI EN ISO 13370. The internal and external surface heat transfer coefficients were defined in compliance with UNI EN ISO 6946.

The average thermal transmittance of the walls is estimated 3.0 W/(m²·K), while that of the roof, which is thinner due to its lightweight structure, is estimated 4.0 W/(m²·K). The resulting overall heat transfer coefficient is 12.1 kW/K, calculated as an average value by combining different boundary conditions, partially toward the exterior (0 °C) and partially toward the ground (8.8 °C). This corresponds to a design heating load of 245 kW for an indoor setpoint temperature of 28 °C.

Among the possible energy retrofit strategies for the building envelope, the least invasive option consists of fully insulating the roof, which represents the largest share of the heat-loss area. The most extensive intervention involves demolition and reconstruction (the “real design” option), adopting building components compliant with NZEB standards, i.e., characterized by very low thermal transmittance.

Fig. 2. Inside view of the pool room.

2.1 Current mechanical plants

The sports centre is connected to the urban energy infrastructure and is currently supplied with gas and grid electricity, with no renewable energy sources in use. The system concept is straightforward: gas serves all thermal applications, including pool water heating, domestic hot water (DHW) production, and space heating, while grid electricity powers indoor and outdoor lighting as well as auxiliary components of the technical systems, such as hydronic circulators and air handling unit (AHU) fans.

With respect to sensible loads, variable occupancy levels directly affect ventilation requirements and, consequently, internal heat gains, primarily arising from occupants and lighting. For latent loads, the main source of moisture release into the indoor environment is water evaporation from the pool, followed by showers in the dressing rooms and the presence of athletes in the pool, as well as spectators in the public seating areas.

Three distinct load profiles can be identified:

1) evaporation from the pool water, which remains approximately constant when the pool surface is uncovered and is significantly reduced when cover sheets are in use (typically between midnight and 08:00 a.m.);
2) the presence of athletes in the pool, and the use of showers in the dressing rooms, occurring regularly throughout the week during training activities;
3) the presence of spectators in the public seating areas, which is occasional and mainly concentrated on weekends during sporting events.

The building's central heating is currently provided by a single plant comprising two gas fired boilers, one in operation and the other serving as a backup unit. The boilers are connected to a high-temperature primary distribution loop, which supplies several secondary circuits in parallel:

1) two storage tanks for domestic hot water storage;
2) two heating coils serving the air handling units;
3) one heat exchanger for pool water heating.

However, temperature measurements indicate that only the DHW secondary circuit requires high-temperature operation, with the setpoint of the two DHW storage tanks at 60 °C. The heating coils of the AHUs could be supplied with medium-temperature water, with flow and return temperatures of 50 °C and 40 °C, respectively, while the heat exchanger serving the pool could operate at low temperature.

Reducing the operating temperature levels is advantageous for integrating direct renewable energy sources, such as solar thermal systems, and indirect sources, such as heat pumps, which can potentially be powered by solar photovoltaic systems.

2.2 Calculation of the pool water evaporation

In the absence of a codified national regulatory reference, the methodology defined in the German standard VDI 2089 Blatt 1:2023-09 was adopted. The pool has a surface area of 25 × 16 m, corresponding to 400 m^2, and an average depth of 2 m, resulting in a total water volume of 800 m^3. The pool water is maintained at a temperature of 28 °C to minimize surface evaporation, as the surrounding indoor environment is also controlled at 28 °C. Approximately 2,000 litres of water evaporate each day and must therefore be replenished, taking into account that the pool is covered for 8 hours per day (typically between midnight and 08:00 a.m.).

3 Energy refurbishment

The architectural and structural design involves the demolition and reconstruction of the pool building roof, while retaining the perimeter walls and existing windows. The mechanical plant design incorporates a partial fuel switch from gas to electricity for the heating system, as well as the installation of solar thermal and photovoltaic systems. Complete electrification of end-use energy remains a desirable objective from an NZEB perspective; however, it would require a substantial investment exceeding the available resources. Therefore, the design strategies focus on optimizing the use of available resources in terms of both efficiency and simplicity of implementation.

Looking ahead, the operation of the swimming pool will be highly seasonal: during winter, the new mobile cover is closed and the internal thermohygrometric conditions are actively controlled; conversely, in summer, the cover is open and indoor conditions are subject to natural variation. The mobile cover consists of 20 cm-thick mineral wool insulated sheet metal panels, with a thermal transmittance of 0.20 W/(m^2·K) and a periodic thermal transmittance of 0.18 W/(m^2·K), in compliance with regulatory requirements for the energy upgrading of individual building envelope components.

With the addition of an insulated opaque movable wall along the east side, the building's overall heat transfer coefficient is reduced from 12.1 kW/K to 8.7 kW/K (average value calculated by combining different boundary conditions). The corresponding thermal load is approximately 150 kW, representing a 35% reduction compared to the current state. Heat losses through ventilation remain unchanged but are mitigated by the presence of a heat recovery unit in the AHU, which operates in cross-flow mode with a nominal efficiency of 80% and a seasonal average of 64%, calculated using the transient simulation model.

3.1 Mechanical plants design concept

The mechanical plant design is based on temperature criteria and retains gas as the primary energy source for pool water heating. For AHU heating and DHW production, gas is used only as a backup. The main power supply for the AHU is an air-to-water aerothermal electric heat pump with inverter technology, connected to a photovoltaic solar system. DHW production is primarily supplied by a solar thermal system with flat-plate glazed collectors. The high-temperature primary distribution loop remains unchanged, while the new devices are integrated at the secondary circuit level.

The mechanical ventilation system constitutes the technological core for managing sports facilities, particularly indoor swimming pools, and buildings subject to cyclic high occupancy. Its design must ensure both adequate air renewal, to maintain Indoor Air Quality (IAQ), and control of relative humidity within the acceptable range of 50–60% by removing excess moisture through dilution.

The pool building is equipped with a mechanical ventilation system. The energy efficiency measures focus on the ventilation system of the pool room and the public seating areas, which will undergo a complete renovation of the distribution network using micro-perforated ducts, along with modifications to the power supply and control of the AHU, transitioning from on/off operation to a 0–10 V control mode.

The Italian National Olympic Committee (CONI) has published standards for sports facilities covering thermal, lighting, and acoustic design aspects, including indoor air renewal rates. For the mechanical ventilation system design, values from UNI 10339 were compared with CONI standards, and the most restrictive criteria, i.e., those requiring higher airflow rates, were adopted in the calculation model.

The solar thermal system comprises a puffer, dimensioned at 50 litres per square meter of collector surface, which serves two heat exchangers immersed in two storage tanks dedicated to DHW storage. Under favourable weather conditions, the system is capable of maintaining storage tank temperatures; however, during adverse weather conditions or periods of high user demand, the gas fired boiler assumes operation, as currently implemented. Considering the installation of twelve panels on the building's roof with an optimal south-facing orientation and a 1,200-litre puffer, the solar thermal system is estimated to satisfy approximately 70% of the annual DHW thermal demand on average.

The solar photovoltaic system supplies all electrical loads of the sports center, including the heat pump responsible for AHU heating. A puffer, sized at 10 litres per kW of thermal output, is interposed between the heat pump and the AHU to provide thermal inertia to the hydronic system and decouple the activation profiles of the two devices. Furthermore, it functions as a thermal flywheel during the heat pump's defrost cycles.

3.2 Transient building energy model

A swimming pool building constitutes a complex energy system, in which, in addition to outdoor climatic conditions and indoor user activities, the building performance is strongly influenced by the presence of the pool water. The HVAC system must maintain adequate thermohygrometric setpoints while ensuring a ventilation rate sufficient to effectively dilute and remove moisture, carbon dioxide, and chloramines.

The operation and usage patterns of the swimming pool vary over time according to daily and weekly schedules. Pool water evaporation is influenced by the nightly use of a tarpaulin cover. Overall, the energy system exhibits continuously evolving dynamics; therefore, it was necessary to develop a complete transient model of the building and HVAC system to accurately characterize its behaviour under non-steady-state conditions.

The HVAC system was modelled using TRNSYS v.17 software within the Simulation Studio environment, and the building was modelled using the TRNBuild v.17 plugin. Given the complex geometry of the building, which was architecturally designed on curvilinear matrices, three-dimensional input via the TRNSYS 3D plugin was not employed; instead, individual building components were manually inserted. The simulation was carried out over an entire year, using a calculation step of 15 minutes, which was considered an adequate compromise between convergence accuracy and computational efficiency. The main system components were characterized using TESS libraries.

All existing and newly designed building components were modelled by creating a customized library of thermophysical parameters in TRNBuild, derived from the combined use of UNI 10351, UNI 10355, and the technical data sheets of the materials. This approach ensured consistency of the underlying assumptions and reproducibility of the thermal transmittance results within the framework of the Italian Law 10/91 and the Energy Performance Certificate (EPC). A similar library was developed for the assessment of thermal bridges using the finite element software Berkeley Lab THERM, in order to achieve full alignment among the different calculation tools employed.

3.3 Validation of the transient building energy model

In The Affrico Sports Club, which manages the S. Marcellino sports centre, provided gas and electricity bills only for the period September 2023–August 2024 for the purposes of the Energy Audit, conducted under the Italian Law D.Lgs. 115/2008 regulatory framework. Nevertheless, the calculation model was validated using actual climate data for the period, available in open-data format from the Agrometeorological Service of the Regione Toscana. The reference parameter was cumulative Heating Degree Days (HDD), calculated with a base of 28 °C instead of the standard 20 °C, reflecting the heating setpoint of the pool room. The winter of 2023/2024 was generally milder than the climatic average for the location.

Gas consumption was calculated on an aggregate basis, referring to the single Punto di Riconsegna (PDR) supplying the boiler currently in operation (the other boiler serves solely as a backup). No heat meters are installed on the mechanical plant sections; therefore, gas consumption for space heating, DHW production, and pool water heating is considered in aggregate. To estimate the quota attributable to space heating, it was observed that gas consumption during the months from November to March is significantly higher than the nearly constant baseline for the spring–autumn period.

On a monthly basis, a correlation was established between the extrapolated gas consumption for heating and the actual HDD recorded during the same month, resulting in a normalized average gas consumption of 10 m^3/HDD. The transient model representing the current configuration was calibrated to reproduce this consumption, based on the ratio between the actual HDD for the winter of 2023/2024 and the standard HDD for the city of Florence, defined as 1,821 HDD at a 20 °C base according to the Italian Law D.P.R. 412/93, corresponding to 3,118 HDD at a 28 °C base. The model representing the design configuration was parameterized using these data.

4 Energy audit

The techno-economic analysis aims to inform the design decision-making process by quantifying the implementation costs associated with each alternative (initial capital expenditure) and the costs related to periodic component replacement (subsequent capital investments). These costs are then compared with operating expenses, including energy consumption and maintenance. All design alternatives share the common goal of ensuring a safe and comfortable environment for users of the sports centre across all swimming activities, both during training sessions and competitive events, while simultaneously addressing comfort and safety requirements for spectators.

Cost-effectiveness is evaluated through a comprehensive assessment of both fixed costs (capital expenditures) and variable costs (operating expenditures). A discount rate of 2% per annum is applied, which is considered all-inclusive, except for energy price escalation, which is treated separately. The reference unit costs used in the analysis are € 0.26/kWh for electricity and € 0.84/m³ for natural gas, as derived from archived periodic utility bills of the Affrico Sports Club.

4.1 HVAC system

The actual ventilation flow rate and the heat recovery efficiency were modulated using a transient calculation model. The two AHUs currently in operation allow for inverter-controlled fan speed; however, the installed control system is limited to on/off logic. A key aspect of the planned energy and system upgrade involves modulating the airflow by adjusting the fan speed of the AHUs, with control based on hygrostat sensors placed inside the pool room. The model accounts for the external air flow rate required to maintain internal humidity at a target design value of 50% relative humidity. Additionally, it incorporates a daily/weekly schedule that distinguishes between periods when only athletes are present (training sessions) and when both athletes and the public are present simultaneously (sporting events). During training sessions, the fans typically operate at partial capacity, while they run at full capacity during sporting events.

The AHUs are equipped with a heat recovery unit of cross-flow type with a by-pass, which is not necessary in this case since the pool is uncovered during the summer months, and the ventilation system is off. The seasonal average heat recovery efficiency, compared to the nominal 80%, was calculated at 64%, considering the temperatures of both the fresh and extracted air, the ventilation flow rate, and its modulation.

The energy audit assesses four distinct HVAC system refurbishment scenarios. The integration of solar photovoltaics is understood to facilitate the transition from fossil fuels to renewable energy sources, while promoting the electrification of end-use energy applications. This principle is broadly applicable, including to DHW production. However, to streamline the energy audit, the analysis adopts a basic approach: combining solar thermal with DHW production and solar photovoltaics with AHUs heating, without exploring additional combinations of cross-solarisation. This approach also minimizes the invasiveness of the necessary modifications to the existing mechanical plants.

The four scenarios considered are as follows:

1) AHU supply with gas fired boiler (current system)
2) AHU supply with air-source electric HP (design solution)
3) AHU supply with ground-source electric HP
4) AHU supply with hybrid system

5) **Table 1.** Performance comparison of the HVAC scenarios.

	gas [Nm³/Y]	**electricity [kWh/Y]**	**CO_2 emissions [kg/Y]**
gas fired boiler (current plant)	54,092	0	101,759
air-source HP (design plant)	0	137,204	63,114
ground-source HP	0	104,216	47,939
hybrid system	8,390	112,031	67,318

The hybrid system consists of a gas-fired boiler and an air-source electric heat pump, which operate alternately, with a bivalent temperature set at 5 °C, based on the characteristic

temperature/relative humidity pairs for the location (hourly climate data for Florence). The gas-fired boiler directly supplies the hot coils of the AHUs. A puffer, sized at 10 litres per kW of thermal capacity, is installed between the heat pump and the AHUs to provide inertia to the hydronic system and decouple the activation profiles of the two devices. Additionally, the puffer serves as a thermal flywheel during the heat pump's defrost cycles. The hybrid system allows for a smaller heat pump capacity, resulting in savings on both initial investment and periodic replacement costs.
The results of the calculations for the four scenarios are presented in Table I, differentiated by energy carrier and CO_2 emissions. The table focuses exclusively on thermal generation, omitting auxiliary equipment such as electric circulators, electronic control units, and other non-essential components for clarity.

4.2 DHW production systems

The energy audit assesses four different scenarios for DHW production. In each scenario, the solar thermal system serves an integration role. This is necessary because, if designed to meet the entire user demand, the system would be significantly oversized. This consideration is particularly important, given that the utilization of the sports centre varies seasonally and is minimal during July and August, when solar energy production reaches its peak. The solar thermal system comprises flat-plate glazed panels with selective absorbers, installed on the building's roof. It also includes a forced circulation circuit and a puffer, sized at 50 litres per square meter of collector surface area.
The four scenarios considered are as follows:

1) gas-fired boiler (current system)
2) gas-fired boiler with solar thermal system (design solution)
3) air-source electric HP
4) air-source electric HP with solar thermal system

Table 2. Performance comparison of the DHW production scenarios

	gas [Nm^3/Y]	**electricity [kWh/Y]**	**CO_2 emissions [kg/Y]**
gas fired boiler (current plant)	4,215	0	7,930
gas fired boiler + solar thermal (design plant)	1,265	0	2,379
air-source HP	0	11,328	5,211
air-source HP + solar thermal	0	3,398	1,563

In all four scenarios, the two existing DHW storage tanks are retained. These are vertical cylindrical stratified boilers, each equipped with immersed coil heat exchangers. In the two solar integration scenarios, an additional heat exchanger, connected to the solar circuit puffer, is installed in each boiler. The puffer serves to increase the overall thermal storage capacity of the system, as well as to stabilize the temperature regime, preventing overheating of the water supplied to users.
The control strategy is designed so that when the setpoint of 60 °C is reached in the DHW storage tanks, the solar heat exchanger is disconnected. Furthermore, when the temperature

in the solar puffer reaches 80 °C, any excess thermal energy is redirected to the pool water via an auxiliary external heat exchanger. The volume of pool water is adequate to store the excess solar thermal energy.

The solar thermal system contributes, on an annual basis, an average of 70% of the DHW production, assuming the sports facility operates year-round. This percentage decreases if the facility is partially or fully unused during July and August.

The results of the calculations for the four scenarios are presented in Table II, differentiated by energy carrier and CO_2 emissions. The table focuses exclusively on thermal generation, omitting auxiliary equipment such as electric circulators, electronic control units, and other non-essential components for clarity.

4.3 Life Cycle Cost (LCC) analysis

Delegated Regulation EU 244/2012 establishes a 30-year time horizon for calculating the Life Cycle Cost (LCC) of public buildings and buildings for public use. The energy audit follows the methodology outlined in UNI EN 15459-1:2018. The expected useful life of the primary mechanical system components is estimated at 15 years. Therefore, in addition to installation, annual maintenance, and operational costs, periodic replacement costs must also be considered.

The energy audit applies the LCC criterion "from gate to grave," a framework specific to the building sector, which complements the "from cradle to gate" approach typically employed for industrial products. In this context, the term "grave" refers to the residual value at the end of the calculation period for a mechanical component. The cost to the installer for a device includes all production costs, including the procurement of raw materials. This methodology has been integrated into the calculation of periodic replacement costs for components with an expected useful life of less than 30 years, which applies to most components within the designed system.

Regarding the HVAC system, calculations performed using the UNI EN 15459-1 methodology provide the following global costs over a 30-year period, expressed as the Net Present Value (NPV) relative to the starting year. The costs associated with the ventilation and heating of the pool room, using a full-air ventilation system with air distribution via micro-perforated ducts, are also considered:

1) gas boiler (current system)
   Cg = €8,187,137
2) air-source electric HP (design solution)
   Cg = €4,590,873
3) ground-source electric HP
   Cg = €5,064,327
4) hybrid system
   Cg = €5,044,520

The results indicate that the design solution offers superior economic performance compared to the current system, as well as compared to alternative options such as geo-thermal systems or intermediate configurations, such as the hybrid system. Furthermore, any contribution from photovoltaic energy significantly benefits the heat pump scenarios over the gas-based system, and to a lesser extent, the hybrid system.

Regarding the DHW production system, calculations based on the UNI EN 15459-1 methodology yield the following global costs over a 30-year period, expressed as the NPV relative to the starting year:

1) gas-fired boiler (current system)
   Cg = €591,305
2) gas-fired boiler and solar thermal system (design solution)

Cg = €300,171

3) air-source electric HP
   Cg = €313,337
4) air-source electric HP and solar thermal system
   Cg = €304,456

The results indicate that, except for the outdated gas-only configuration, all other options considered are competitive with one another. This further strengthens the argument in favour of investing in renewable energy systems. The contribution of solar thermal energy is significant throughout the year in meeting the demand for DHW, allowing the combination of the gas-fired boiler and solar thermal system to remain competitive when compared to the heat pump and solar thermal system.

5 Conclusions

Renewable energy sources play a crucial role in the ongoing transition from fossil fuels to alternative energy resources, both at the national level and locally, through the deployment of solar thermal and photovoltaic systems. In compliance with European energy policy, the electrification of end-use energy consumption offers a high degree of flexibility in matching demand profiles with on-site energy generation, while simultaneously reducing reliance on external grid infrastructure.

Complete electrification of end-use energy consumption remains a desirable goal from the perspective of nearly zero-energy buildings (NZEB). However, in the case-history, achieving this would require substantial investment, exceeding available financial resources. As a result, the design choices made focus on optimizing the use of available resources, with a strong emphasis on both energy efficiency and the simplicity of the proposed interventions.

Looking ahead, the operation of the swimming pool will be highly seasonal. During the winter months, the new movable cover will remain closed, and indoor thermo-hygrometric conditions will be actively controlled. In contrast, during the summer, the cover will be open, and indoor conditions will be subject to natural variation.

The mechanical system design is based on temperature criteria, with gas retained as the primary energy source for pool water heating. Gas is used as a backup for AHU heating and DHW production. The main power supply for the AHU is an air-to-water aerothermal electric heat pump with inverter technology, integrated with a photovoltaic solar system. DHW production is primarily provided by a solar thermal system with flat-plate glazed collectors. The high-temperature primary distribution loop remains unchanged, while the new devices are integrated at the secondary circuit level.

The energy audit confirms that the design choices are the most suitable from both a technical and economic point of view, considering design constraints, user needs, and available financial resources. In compliance with the core principles of European energy policy, as outlined in the EPBD and RES Directives, the refurbishment of the sports centre, particularly the swimming pool building, aims to reduce primary energy consumption and, consequently, the emission of atmospheric pollutants. Furthermore, it introduces alternative energy sources, specifically solar thermal and photovoltaic systems, which were previously.

The authors would like to thank the Municipality of Florence, in particular the Technical Services Office, represented by the executive director and project manager Alessandro Dreoni, for granting permission to publish the paper. They would also like to thank the engineering firm "Studio Tecnico Andrea Ugolini" for providing the structural design, which was preparatory to the HVAC design. Finally, they would like to thank the Thermo Group of the Department of Industrial Engineering of the University of Florence, in particular Prof. Eng. A. Rocchetti and Eng. L. Socci, for their technical and scientific support in the development of the paper.

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