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Posted Date: 16 August 2023

doi: 10.20944/preprints202308.1119.v1

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Review

Rational Use of Energy in Sport Centers to Achieving Net Zero: The SAVE Project (Part B: Indoor Sport Hall)

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Abstract: Sport centers are significant energy consumers. This article outlines the engineering design for a comprehensive energy performance upgrade of the indoor sport hall in Arkalochori, Greece, and presents the projected results. The indoor sport hall constitutes a major sport facility in the mainland of Crete, hosting a broad cluster of sport municipal activities and the official basketball games of the local team in the 2nd national category. Having being constructed in the mid '90s, the facility exhibits very low thermal performance, with considerably high U-factors for all constructive elements (from 4 to 5 $W/m^2 \cdot K$), still use of diesel oil for indoor space heating and domestic heat water production and ineffective, old lamps and luminaries covering the lighting needs of the facility. The energy performance upgrade of the indoor sport hall was holistically approached, through all possibly applicable passive and active measures: insulation of opaque surfaces and replacement of openings, installation of new stone wool panels, installation of heat pumps for indoor space conditioning, elimination of diesel oil for any final energy use, installation of a solar-combi system for domestic hot water production, upgrade of all indoor and outdoor lighting equipment, installation of solar tubes on the main sport hall roof for natural lighting and installation of a photovoltaic plant on the same roof for the compensation of the remaining electricity consumption. With the proposed measures, the indoor sport hall is upgraded to zero energy facility. The payback period of the investment was calculated at 26 years, on basis of the avoided energy resources procurement cost. This work has been funded by the Horizon 2020 project with the acronym "NESOI" and was awarded with the public award of the "Islands Gamechanger" competition of the NESOI project and the Clean Energy for EU Islands initiative.

Keywords: energy performance upgrade; municipal sport facilities; indoor sport hall; solar-combi systems; energy transition; energy communities

1. Introduction

1.1. Background

Energy consumption patterns of sport centers, particularly in rural settings, remain a subject of intense scrutiny and innovation in the broader sustainability discourse. In the quest to transition these significant energy consumers to sustainable entities, the challenge is not just to harness modern energy-saving technologies but to integrate them holistically within the facility's unique operational demands. In Part A [1] of this two-series exploration, the focus was on the energy performance upgrade process for the swimming pools center within the municipal sport center in Arkalochori, Greece. It detailed an extensive approach, transforming the facility, which had not seen energy efficiency improvements since its initial construction in 2002, into a near zero-energy building. Part B focuses into the energy retrofit challenges and successes of another major municipal sport facility at the same town, the indoor sport hall.

The sports complex energy upgrade engineering design was funded by the Horizon 2020 project "New Energy Solutions Optimized for Islands" (NESOI). Its potential benefits not only underscored the significant energy savings but also emphasized the pivotal role such projects play in fostering community engagement and socio-economic benefits, as highlighted by its recognition in the "Islands Gamechanger" competition. By weaving together technical insights, local context, and broader sustainability goals, this paper aims to present a comprehensive view of the retrofit process, potentially serving as a blueprint for similar facilities in rural settings.

In the ongoing journey towards energy transition, Rational Use of Energy (RUE) stands as a foundational principle, emphasizing the importance of maximizing energy efficiency and adopting sustainable energy practices across diverse sectors, including residential, commercial, industrial, and transportation. This overarching commitment to energy conservation is entrenched in European Union (EU) policies, such as Directives 2018/844 [

2] and 2012/27/EU [3], which obligate Member States to establish definitive targets and strategies in favor of RUE. For instance, Greek legislation [4] mandates new public structures to aspire towards nearly zero-energy standards. In 2021, buildings and their construction accounted for 30% of the global annual energy consumption, and despite a slowdown since 2010, this consumption is projected to surge to 50% by 2050 [5,6]. Within the EU, the majority of household energy expenditure is on indoor heating, followed by domestic hot water and lighting. As global fuel costs rise and the push to curtail CO_2 emissions intensifies, the appeal for energy-efficient solutions grows. Although green building initiatives lead to operational cost reductions between 10-30%, their initial construction expenses remain a concern [7].

The drive towards more energy-efficient methodologies, influenced by escalating fuel costs and the urgency to curtail CO_2 and other harmful emissions, underscores the importance of adapting to our evolving ecological landscape. While buildings in general grapple with variables such as economic dynamics, available resources, and climatic conditions [6,8–11], sports centers introduce added layers of complexity. Not only are they influenced by these typical factors, but the type and intensity of their usage—which can fluctuate seasonally—further complicates their energy dynamics. It is within this intricate framework that athletic centers emerge as particularly unique subjects, navigating both the common challenges faced by most buildings and their distinctive obstacles and opportunities in the realm of energy optimization enhancements. Part B of our study builds on these considerations, focusing specifically on the sustainable retrofit of the indoor sport hall in Arkalochori.

1.2. Literature review

Sport centers represent approximately 4% of non-residential buildings in the EU [12]. They also come with their diverse operational needs, present distinct challenges in terms of energy consumption and efficiency. Tackling these challenges through sustainable retrofits goes beyond mere technological solutions—it necessitates a deep comprehension of the various elements influencing these energy demands. This section commences by offering a categorization, shaped from the authors' viewpoint, of energy demands in sports centers. By discerning patterns and suggesting a framework influenced by previous studies, we lay the groundwork for subsequent discussions on past research. Our objective is to delve into the multifaceted nature of energy-saving retrofits in sports centers, from the role of regional climatic factors to the results observed post-implementation. In doing so, we aim to present readers with a comprehensive understanding, both broad and detailed, of the energy retrofit landscape within sport centers.

Typically, sport centers are energy-intensive, especially if they have amenities like heated pools, saunas, and extensive lighting requirements. Although several building codes and benchmark indicators exist for energy efficiency building in different part of the countries [13–15], there has not been much focus on sports centers, probably because of the specific climatic conditions and operational parameters associated with each specific installation. Additionally, this lack of information may be attributed to the fragmented definitions for even simple concepts like Zero Emission Building (ZEB), which is different in Europe, United States, Japan and Korea [16–19].

Azaza et al. [20] delved into the intricate energy consumption patterns of a large sports facilities, with a case study at Rocklunda arena in Sweden. Distinct Key Performance Indicators (KPIs) were formulated to decipher the energy consumption intricacies of sports facilities. These KPIs encompassed energy flow mapping, load factors for heat and electricity, operational hour indicators, and area indicators.

Table 1 showcases the energy requirements and their respective shares, compiled from various sources [5,21,22]. It can be seen that the over to 50% of the energy consumption is related to heating and cooling (of spaces and water). Notably, over 50% of energy consumption is attributed to heating and cooling, both for spaces and water.

Table 1. Energy needs for a sports center building and typical range of corresponding share.

Energy Need	Requirement	Share	Comments
Space heating	High	40-60%	due to large spaces, in cold climate
Space cooling	Medium.	10-25%	due to large spaces, in hot climate
Lighting	Medium	10-20%	evening activities & large indoor courts
Water heating	Medium	10-20%	showers, pools, and saunas
Ventilation & air handling	Low	1-5%	Requirement for fresh air in workout areas.
Refrigeration	Low	0-5%	For cafeterias or snack areas.
Equipment	Low	1-5%	gym equipment, scoreboards, sound systems.
Elevators & escalators	Low	0-5%	If multi-storied.
Computing & office needs	Very Low	0-1%	for administrative areas.

The energy usage of sports centers might range from under 100 to 350 kWh/m²/year (see Table 2) in the UK (CIBSE Energy Benchmark (TM46: 2008) [23] and ECON 78 (2001) [24]), depending on the facilities and location. In a similar study in Greece, Trianti-Tsourna et al. [25] reported based on audited data from 17 sports facilities, the average annual energy consumption metrics are as follows: 73.2 kW h/m² for total energy, 322.3 kW h/m² for heating, and 37.14 kW h/m² for electricity (These figures account for influences like heat pumps, ventilation, and electrical motors in operation during games). In Sweden the sports hall were reported to have an annual energy consumption between 145 and 174 kWh/m² per annum [26,27].

Table 2. Energy use in sport centers pools (CIBSE Energy Benchmark (TM46: 2008) [23] and ECON 78 (2001) [24]).

Source		CIBSE Energy Benchmark (TM46: 2008) [23]	ECON 78 (2001) [24]
Description		Sports Center	Local dry sports Center
Electricity (kWh/m²)	Good		64
	Typical	95	105
Gas (kWh/m²)	Good		158
	Typical	330	343

Also, an analysis of the Swedish GRIPEN database from 2015 [26] revealed a correlation between the construction period of sports halls and their average energy performance. Sports halls built before 1979 had an average energy consumption of 191 kWh/m². This figure decreased to 148 kWh/m² for buildings constructed between 1980 and 2009. Impressively, for buildings erected after 2010, the energy consumption further reduced to 104 kWh/m², highlighting the benefits of technological advancements over time.

Griffiths [28] in 1997 undertook a detailed analysis of the UK's Sports and Recreation sector. His study of two leisure complexes, one with double the occupancy rate of the other, revealed that, despite the disparity in user numbers, both had similar energy consumptions of approximately 10 kWh per user. Yet, their energy costs per user differed significantly, hinting at the potential for considerable energy savings and underscoring the influence of varying energy sources and pricing at the time.

Katspakakis et al. [29] focused on enhancing the energy performance of the Pancretan Stadium in Crete, Greece. Through a combination of passive and active measures, including replacing old openings, introducing a photovoltaic station, an open loop geothermal system, energy-efficient lighting, a solar-biomass combi system, and a Building Energy Management System (BEMS), the stadium achieved an impressive annual energy saving of 83%. The use of these technologies also led to the stadium's energy rank being upgraded from D to A+ as per EU directives. Specific interventions, such as the combined replacement of selected openings and the geothermal system, resulted in 48% electricity savings for indoor space conditioning. The lighting system interventions saved 52% on electricity. The study underscores the vast energy-saving potential in large sports facilities and emphasizes the need for tailored solutions based on local conditions and infrastructure.

A study in 2020, focusing on Crete, Greece, and highlighted that the building stock often feature subpar insulation and poor-quality openings, which have historically led to increased energy consumption. The research offers the following promising perspective: implementation of tailored passive and active energy-saving measures, can lead to significant energy saving. Additionally, it was estimated that the Mediterranean's abundant solar and wind resources further emphasize the potential for transitioning to zero-energy buildings. Such findings suggest that regions with architectural challenges akin to the Mediterranean can harness substantial energy-saving benefits, making sustainability both an environmentally and economically viable goal.

In the realm of building design and energy conservation, passive technologies have long been recognized for their efficacy. Tracing their origins to ancient cave dwellings, these technologies have evolved over millennia and are now integral to modern energy-efficient building applications [9].

Thermal insulation stands as a cornerstone in energy-efficient building design. Over the decades, its significance has been underscored by evolving standards, with the recommended insulation thickness in northern Europe doubling between the 1970s and 2010s [30]. Proper insulation, encompassing walls, roofs, and floors, acts as a barrier, reducing heat transfer and ensuring consistent indoor temperatures. This not only conserves energy but also enhances the comfort of building occupants [31].

Optimizing the thermal mass of buildings is an often-overlooked yet pivotal passive technique. By utilizing materials that can absorb, store, and release heat over time, such as concrete or brick, buildings can naturally regulate temperature fluctuations. The innovative use of phase change materials further augments this process, offering a dynamic approach to managing thermal loads) [28,31].

Sun shading techniques, whether through external fixtures, vegetation, or architectural design, can significantly reduce the need for cooling, especially in regions with intense sunlight [31]. A study conducted on a passive sports hall in Słomniki emphasized the role of sun shading, which reduced sunlight access by up to 30% [32].

The quality and design of building openings, or fenestration, play a crucial role in energy conservation [31]. Advancements in materials, such as aerogel and vacuum glazing, offer superior insulation properties [28,31]. Additionally, the strategic placement and design of windows can maximize natural light while minimizing heat gain or loss.

Roofing techniques can drastically reduce a building's energy consumption, because roofs are directly exposed to sunlight, which present unique challenges and opportunities. Green roofs offer insulation and absorb sunlight, photovoltaic installations harness solar energy, and radiant-transmittive barriers reflect excessive heat [28,31].

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Designing spaces to promote the natural flow of air can significantly reduce the reliance on mechanical ventilation. By allowing fresh air to circulate, natural ventilation not only conserves energy but also enhances indoor air quality, promoting a healthier living environment.

Finally the optimized Building Orientation Strategically can capitalize on seasonal sun positions and can lead to substantial energy savings by effectively reduce heat absorption, further diminishing the need for artificial cooling in summer, and allowing more sun irradiance heat to enter the home, thus reducing heating requirements. The important parameter of the climate can be modelled by computational tools and methods [33].

Active measures in building design and energy conservation encompass a range of technologies and systems aimed at optimizing energy use, often harnessing renewable sources or maximizing the efficiency of existing resources [9]. These measures, backed by extensive research, offer promising avenues for sustainable energy management in various settings.

Heating, Ventilation, and Air Conditioning (HVAC) systems play a pivotal role in the energy efficiency of buildings. Among these, Radiant Heating and Cooling (RHC) systems are emerging as a preferred choice. Their growing popularity is attributed to their ability to provide consistent thermal comfort levels while consuming less energy. This is achieved through their design, which allows for high-temperature cooling and low-temperature heating [9]. Nevertheless, RHC systems are not standalone; they often integrate with auxiliary systems such as heat pumps and boilers [34]. These auxiliary components, particularly heat pumps and boilers, have been in development for over a century. Their enduring relevance in modern HVAC systems is a testament to their efficiency and the continual advancements made over the years [35].

Heat Pumps, both as auxiliary components and primary systems, offer a versatile solution for heating and cooling needs. For instance, a study that compared a Water Solar Assisted Heat Pump (W-SAHP) with conventional gas-boiler plants in Italy found that W-SAHPs could achieve energy savings ranging from 35 to 50% [36].However, it's worth noting that the efficiency of these systems tends to decrease with the site's Degree Days. Further research by Chow et al. into solar-assisted heat pump systems for indoor swimming pool water heating revealed that such systems could achieve a Coefficient of Performance (COP) of 4.5. Impressively, this translates to an energy-saving fraction of 79% when compared to traditional energy systems [37].

Another innovative approach to heating and cooling is the use of Variable Refrigerant Volume (VRV) heat pumps [30,32]. VRV systems are designed to modulate the amount of refrigerant sent to individual evaporators, allowing for precise temperature control in different zones or rooms. This adaptability ensures that each area receives the exact amount of cooling or heating required, optimizing energy consumption. The inherent flexibility of VRV systems makes them especially suitable for buildings with varying occupancy patterns or diverse thermal demands. By adjusting the refrigerant volume based on real-time requirements, VRV systems can achieve significant energy savings, reduce wear and tear on components, and enhance overall system longevity. Their modular design also allows for scalability, making them a viable choice for both small and large installations.

Water heating is a significant energy consumer in buildings, often accounting for a substantial portion of a building's total energy use. Efficient water heating not only reduces energy consumption but also contributes to a building's overall sustainability and reduces operational costs.

Solar thermal technology has emerged as a frontrunner in sustainable water heating solutions. Unlike photovoltaic systems that generate electricity, solar thermal systems harness the sun's radiation directly to produce hot water [38]. Its growing significance is evident from the 2019 data, which showed that the global market for Solar Heating and Cooling reached a remarkable 479 GWh [39]. Among the various solar thermal technologies, evacuated solar thermal collectors stand out, offering superior payback periods and efficiency [40].

Geothermal systems offer another innovative approach to water heating. Research into the integration of geothermal systems for water heating at low temperatures has shown promising results. Passive solar systems integrated with geothermal components can achieve reductions in heating loads by over 90% when compared to traditional methods [30,32]. Furthermore, Geothermal

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Heat Exchangers (GHE) and Geothermal Heat Pumps (GHP) have been recognized as potent supplementary systems for water heating, providing consistent and efficient thermal energy [30,41].

Another noteworthy development in the realm of water heating is the advent of solar combi systems. These systems, essentially hybrid thermal power plants, combine solar collectors, biomass heaters, and thermal storage tanks. They are particularly adept at meeting thermal energy needs for hot water production at low temperatures, ensuring optimal energy utilization and reduced reliance on non-renewable energy sources [42].

In the modern era of building design and management, the integration of intelligent systems is paramount. Smart thermostats and BEMS stand at the forefront of this technological evolution. These systems not only streamline energy consumption but also potentially optimize it based on real-time data and predictive analytics. Their ability to adapt to changing environmental conditions and occupant preferences ensures both comfort and energy efficiency. Studies have consistently shown that the implementation of these systems can lead to significant energy savings, making them both technically and economically viable solutions [30,32].

Lighting, often a major energy consumer in buildings, has seen transformative advancements with the introduction of LED technology. LED lights, known for their longevity and efficiency, can drastically reduce energy consumption compared to traditional lighting solutions. Their ability to provide consistent and high-quality illumination while consuming a fraction of the power makes them an essential component in modern energy-efficient buildings [30,43,44].

Furthermore, the global shift towards sustainable energy solutions has elevated the importance of renewable energy sources, particularly solar and wind turbines. These technologies harness natural resources to generate electricity, reducing dependency on fossil fuels and decreasing carbon footprints. Integrating these renewable sources into a building's energy system not only diversifies its energy portfolio but also enhances overall energy efficiency. The potential of solar and wind energy, both in terms of capacity and cost-effectiveness, has been well-documented, emphasizing their crucial role in the future of building energy management [45,46].

A pivotal element of this research underscores the prevalence of energy measures being integrated as part of extensive retrofitting projects rather than new installations. The significance of retrofitting, has been meticulously explored by authors [47–51] and several methodologies have been proposed for assessing the economic effect of retrofits [52,53]. When considering expansive retrofit projects Swan et al. have proposed methods for the modelling of end use energy consumption [54]. Also, Pittarello et al. have proposed an artificial neural network (ANN) methodology to optimize zero energy building projects from early design stages [55].

1.3. Research aim

This article constitutes the second part of the overall work implemented within the frame of the project "Sustainable Actions for Viable Energy" (SAVE), funded by the European Commission's Horizon 2020 project "New Energy Solutions Optimized for Islands" (NESOI) [56]. In the first part, the work accomplished and the calculated results for the energy performance upgrade of the municipal sport centre in the small town of Arkalochori, Crete, Greece were presented. In this second and final part, similarly the implemented work and the anticipated results from the energy performance upgrade of the indoor sport hall at the same town are analysed. As with the first part of this work, also in the under study indoor sport hall, the target set is its upgrade to a zero energy facility. All the most technically feasible and economically competitive passive and active measures were examined and proposed for the specific facility, following a detail computation simulation, siting and sizing. The article aims to constitute an essential holistic reference (methodology, mathematical background, data and assumptions, application details and results) for the study and the design of similar energy performance upgrade projects for indoor sport halls.

The whole SAVE project was implemented by the Minoan Energy Community [57]. Apart from the energy performance upgrade of the municipal sport facilities, the SAVE project was integrated with the design on application level of the first smart grid in Crete, including decentralized production and storage and certain Demand Side Management strategies. The SAVE project was awarded with the public award of the Islands Gamechanger competition [58], organized by the European Commission's Secretariat of the "Clean Energy for EU Islands" initiative and the NESOI Consortium.

2. The sport facility

As stated previously, the under consideration indoor sport hall is located in Arkalochori, Crete. Arkalochori is a small town with 5,000 population, located at the very centre of the mainland of the Heraklion Prefecture, roughly 25 km from both the northern and the southern coastline of the island, with an absolute altitude from 350 m to 400 m.

The Indoor Sport Hall (Figure 1a) was constructed in the mid-nineties. It belongs to the local Municipality and hosts several sport activities either of the local sport club and the municipal sport department, as well as the official basketball games of the local team. It consists of two discrete parts (Figure 1b), the main sports hall, with an area of 1,196 m^2 and 7 m height, and the auxiliary building, which hosts the changing rooms, a canteen, offices, a gym room, medical service, etc, with a covered area of 269 m^2 and 3.2 m height. More details on the building's constructive elements and geometry are given in Section 5.2.1.

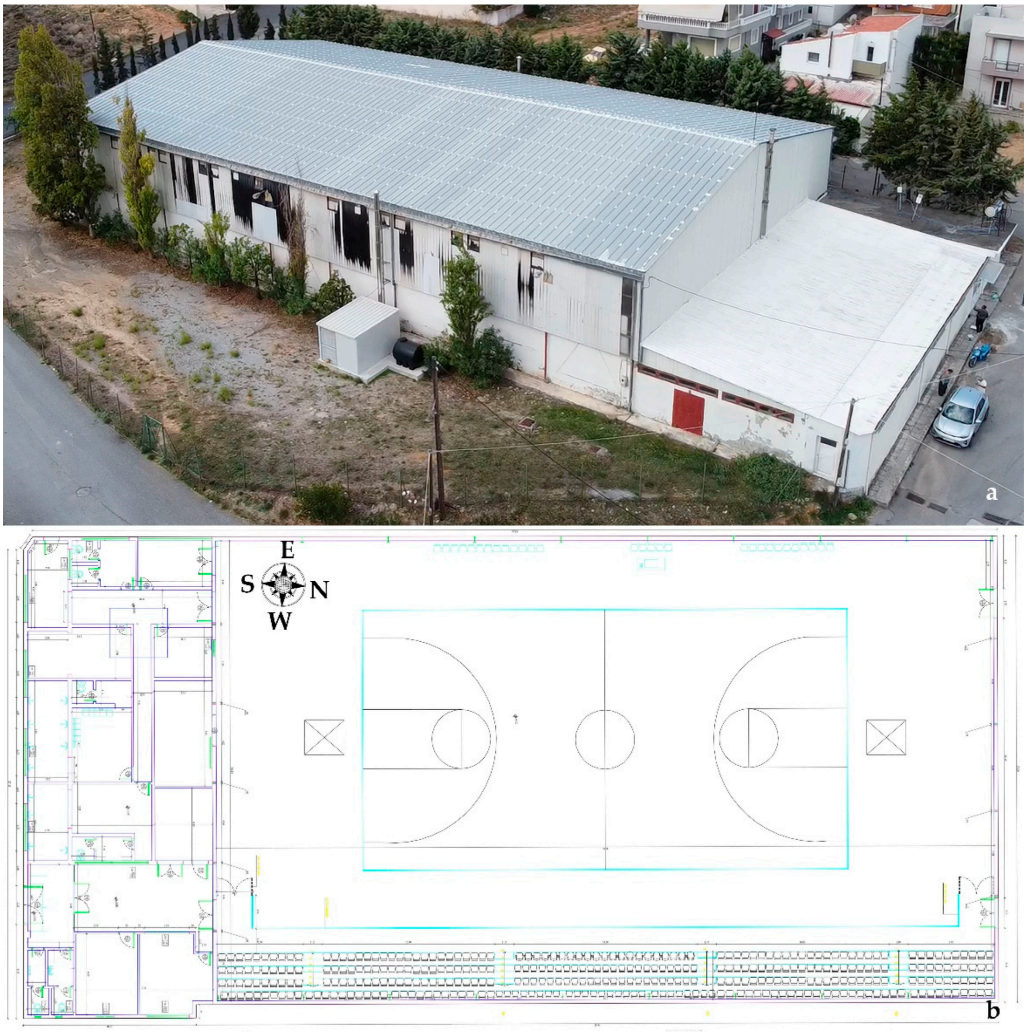

Figure 1. General aerial view (a) and top view drawing (b) of the indoor sport hall in Arkalochori.

3. Methodology

The methodology applied in this work can be analysed in the following discrete steps:

- invitation for collaboration with the Municipality and establishment of an open communication line with the staff in charge for the operation and the maintenance of the facility;

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- an initial visit in the sport facility and on-site investigation and collection of all required data regarding the existing architectural elements, the operation schedule and the energy demand;
- first computational simulation of the sport facility's operation in the existing condition and calculation of the indoor space heating and cooling load for full annual operation;
- calculation of the current primary energy consumption for full coverage of all final energy needs, with the existing active systems for indoor space conditioning, domestic hot water production and lighting;
- selection, siting and sizing of the most technically feasible and cost-effective passive measures, aiming at the minimisation of the indoor space heating and cooling load;
- second computational simulation of the sport facility's operation with the introduction of the proposed passive measures and calculation of the indoor space heating and cooling load for full annual operation;
- selection and sizing of the most technically feasible and cost-effective active measures for indoor space conditioning, domestic hot water production and lighting;
- calculation of the primary energy consumption for full coverage of all final energy needs with the proposed active systems;
- sizing and siting of a photovoltaic park, for the annual compensation of the remaining electricity consumption;
- calculation of the achieved annual energy saving, the project's total budget and other typical Key Performance Indicators (KPIs).

All the aforementioned calculations both for passive and active systems were executed computationally, on the basis of annual time series with hourly average values. The process and the corresponding mathematical background is given in section 5. The above described methodology is given graphically in Figure 2.

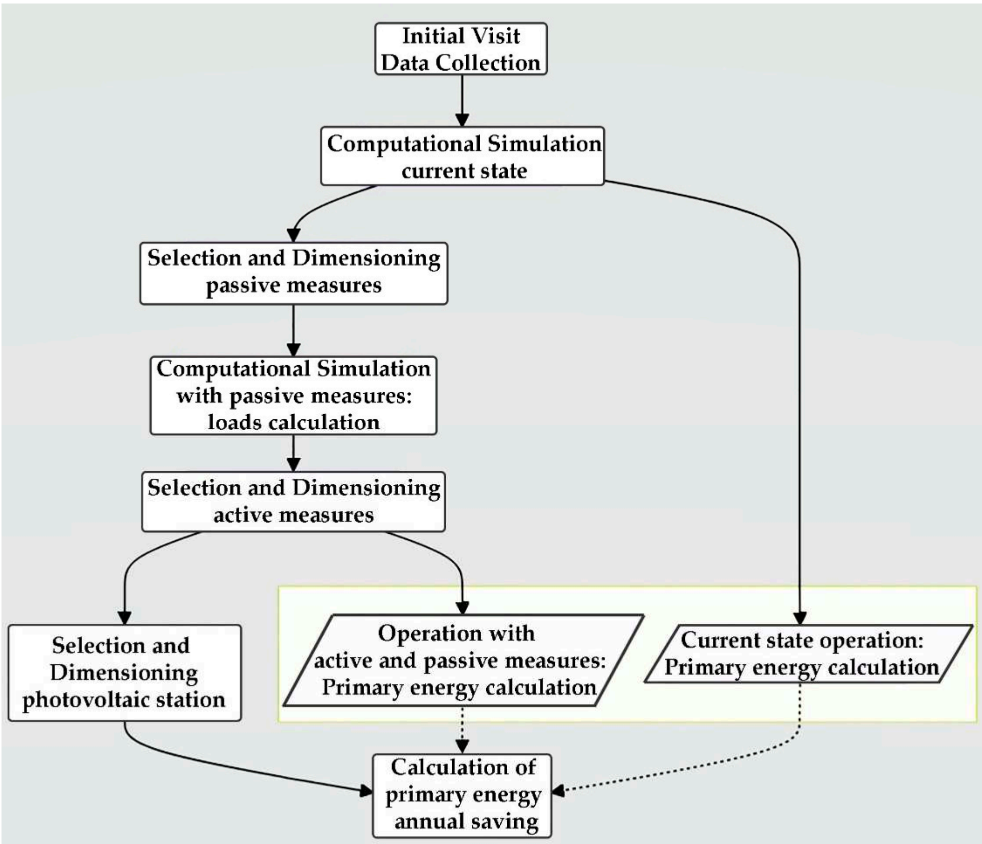

Figure 2. The methodology logical flow chart.

Finally, regarding the data involved in this study:

- the meteorological data were retrieved from the European Centre for Medium-Range Weather Forecasts (see Section 4)

- the data regarding the new proposed equipment and the materials were retrieved from the manufacturers' datasheets
- the data regarding the existing constructive elements in the facility were calculated or taken from the literature.

4. Climate conditions – meteorological data

The local climate in the town of Arkalochori is characterized by rather mild winter, with ambient temperature usually between 5 °C and 15 °C, and cool summer, with ambient temperature rarely higher than 30 °C. For the purposes of this work, meteorological data were retrieved by the available climate data in the European Centre for Medium-Range Weather Forecasts (ECMWF) and for the period 2010 – 2020 [59] for a geographical point only 13.5 km to the north of the town. All meteorological data were downloaded in the form of annual time series with hourly average values. Indicatively, in Figures 3–5 the fluctuation of the ambient temperature, the ambient relative humidity and the wind velocity at 2 m height above ground are presented for the two consecutive years 2019 and 2020. The annual periodicity for all three magnitudes is observed in these Figures. The annual average ambient temperature for 2019 and 2020 was 18.0 °C and 18.1 °C respectively. The annual average wind velocity for 2019 and 2020 was 4.9 m/s and 5.1 m/s respectively.

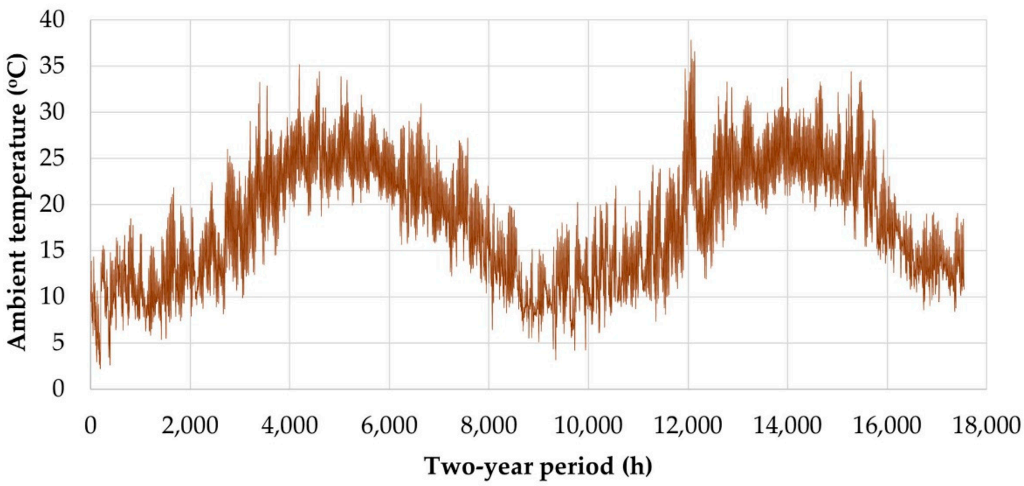

Figure 3. Ambient temperature fluctuation for 2019 and 2020 in Arkalochori.

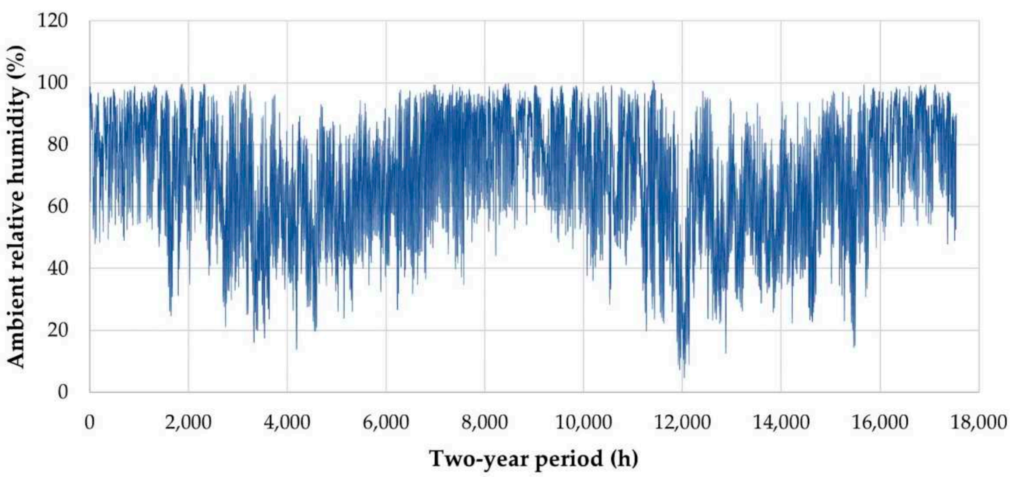

Figure 4. Ambient relative humidity fluctuation for 2019 and 2020 in Arkalochori.

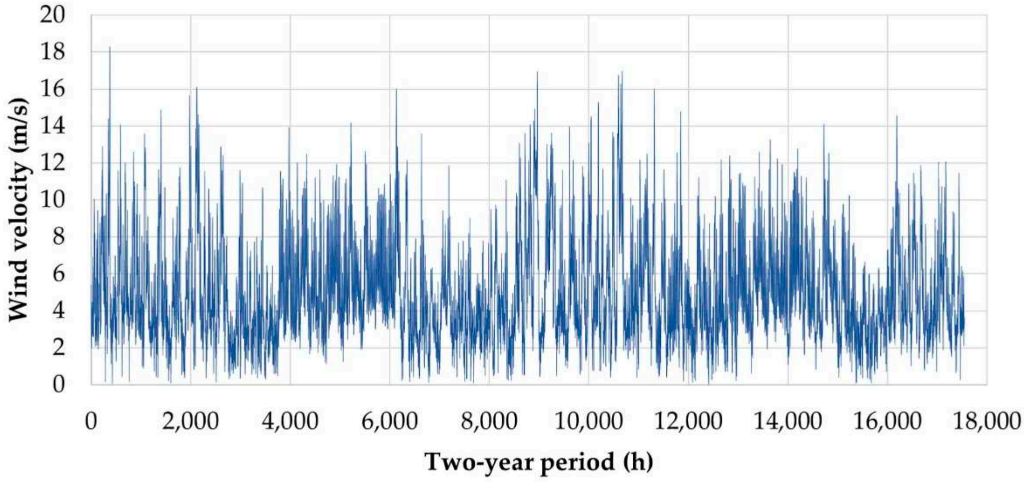

Figure 5. Wind velocity fluctuation for 2019 and 2020 at 2 m height above ground in Arkalochori.

In Figure 6 the annual wind velocity rose graph for 2020 is presented, showing a predominant northwestern wind direction. This pattern is influenced by the consistent local northwest summer winds, known as “meltemia”, which contribute to a cooler summer climate.

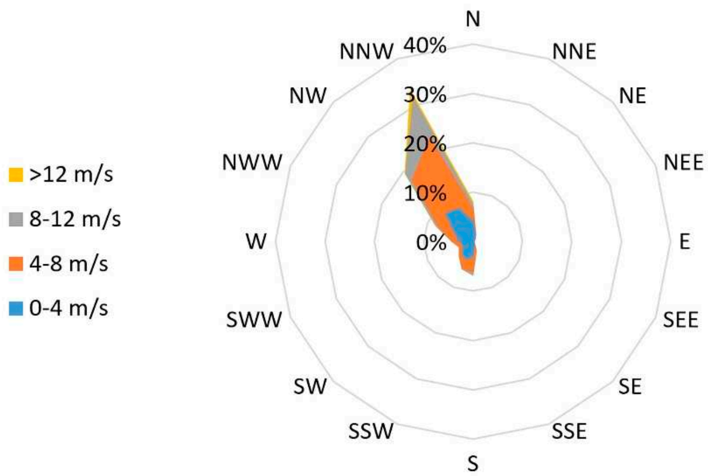

Figure 6. Annual wind velocity rose graph at 2 m height above ground in Arkalochori for 2020.

Finally, in Figure 7 the annual fluctuation for the year 2020 is presented of the hourly average incident solar irradiance and the daily cumulative solar radiation on the horizontal plane. The yearly cumulative incident solar radiation on the horizontal plane is calculated at 1675 kWh/m^2, indicating the availability of considerable solar potential in the area.

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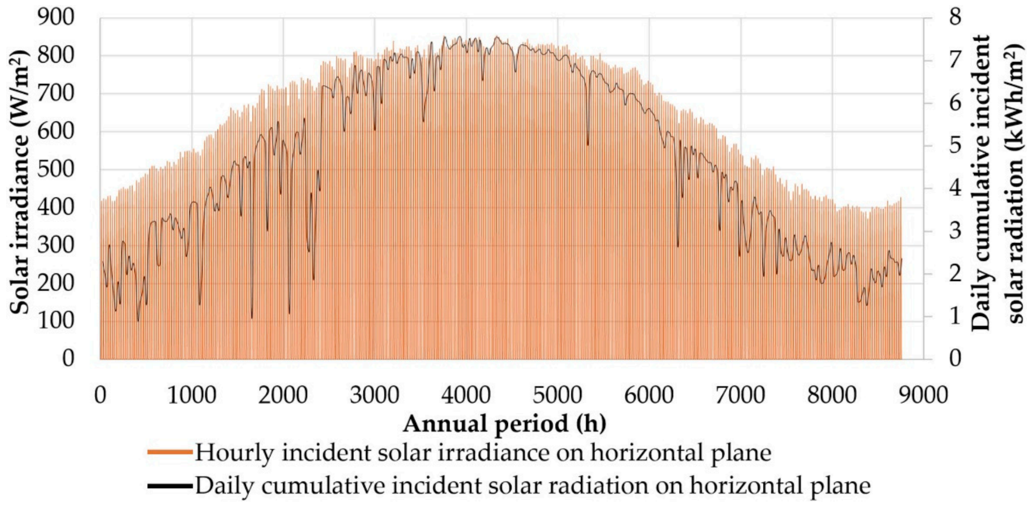

Figure 7. Annual fluctuation for 2020 of the hourly average incident solar irradiance and the daily cumulative solar radiation on the horizontal plane.

The above presented annual time series of the meteorological magnitudes will be used in this study for the calculation of the indoor space conditioning load, the electricity production from photovoltaic panels and the heat production from solar thermal collectors.

5. The energy performance upgrade of the indoor sport hall

5.1. Current state

Currently in the main sport hall there is no indoor space cooling active system. There are two central oil burners of 291 kW nominal thermal capacity each, combined with a hydraulic network and 22 hydronic terminal units for the main sport hall's heating. This system was installed in 2021, to serve the heating needs of the main sports hall because it was used to host some hundreds of homeless residents of the town, due to the strong, 6.1 Richter earthquake that struck the area in September 2021. The existing central heating system, with an oil boiler, a hydraulic network and radiators, covers only the auxiliary building, however it is not used due to the expensive diesel oil. An electrical boiler is used for the production of hot water for the changing rooms. One autonomous heat pump (split unit) is installed in the facility's main administrative office. The indoor and outdoor space lighting equipment consists of old, ineffective luminaires, with fluorescent lamps and halogen floodlights.

The only source of energy currently consumed in the indoor sport hall is electricity, for hot water production, indoor space lighting and the one and only heat pump. Diesel oil was consumed only in the 2021-22 winter, during the accommodation of the homeless citizens in the main sports hall. The actual annual electricity consumption in the facility in 2019 was 19,804 kWh, according to the provided electricity procurement bills by the local Municipality. However, the expecting energy consumption on the assumption that the facility will operate normally through the whole year, with full coverage of the indoor space conditioning load, given the existing infrastructure (normal operation of the existing central heating systems with diesel oil), should be expected strongly higher, as analysed in the next section.

5.2. Energy consumption in the current state

The energy consumption of the indoor sport hall in the current state is calculated separately for the discrete final energy uses presented below:

- indoor space conditioning;
- domestic hot water production;
- indoor and outdoor space lighting.

For the these final energy uses, the annual electricity and diesel oil consumption in the municipal indoor sport hall in the current state, on the assumption of full annual operation and coverage of all energy uses, is analysed in the following sections.

5.2.1. Indoor space conditioning

The thermal performance of the indoor sport hall for a whole annual period was computationally simulated with hourly average time steps. The overall sport facility was divided in two thermal zones: the main sport hall and the auxiliary building.

The main sport hall has been constructed with a metallic bearing structure. Its vertical surfaces have been constructed with bricks, for the first 3 m height, and polycarbonate semi-transparent panels for the rest 4 m, as clearly seen in Figure 1a. The main sport hall's roof is covered with synthetic polyurethane panels, practically destroyed due to their inadequate sealing, their physical wear due to ageing and the penetration of rainwater inside them. The auxiliary building is constructed with concrete and bricks, with no insulation. All existing openings in the overall facility have metallic frame and single glazing.

For the calculation of the indoor space heating and cooling load the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Transfer Function Method (TFM) [60,61] was applied through a relevant simulation developed with the TRSNSYS software.

The U-factors for all the opaque surfaces were calculated by using the essential relationship 1 from 3 W/m²·K for the vertical brick walls to 5 W/m²·K for the semi-transparent polycarbonate panels:

$$\frac{1}{U}=\frac{1}{h_i}+\sum_j \frac{d_j}{k_j}+\frac{1}{h_o}, \tag{1}$$

where d_j and k_j the thickness and the thermal conductivity factor of the structural material j of the opaque constructive element.

The heat transfer factor from the inner space h_i and towards the outer space h_o (or conversely in summer) were set equal to [62]:

- h_i = 10 W/m²·K and h_o = 25 W/m²·K for air flow over horizontal surfaces and for average wind speed of 5 m/s;
- h_i = 7.7 W/m²·K and h_o = 25 W/m²·K for air flow next to vertical surfaces and for average wind speed of 5 m/s.

The U-factors for the openings were set equal to 7 W/m²·K and the solar heat gain at 0.77, according to the TRNSYS library. The high solar radiation penetration from the semi-transparent panels increases considerably the solar gains in the main sports hall and creates an unpleasant environment, with too high indoor temperatures during the summer months. On the other hand, the high U-factor of the same structural elements leads to increased heat losses during winter and configuration of an unpleasant, cold indoor environment during winter.

The natural ventilation due to the openings' inadequate sealing was calculated by the relationship 2 [63,64], introduced by ASHRAE (ACH: air changes per hour):

$$ACH=K_1+K_2\cdot(T_{in}-T_{amb})+K_3\cdot u_w, \tag{2}$$

where u_w is the average wind velocity, T_{in} and T_{amb} are the indoor space and the ambient temperature (Figure 3, Section 4) and the parameters K_1, K_2 and K_3 are set equal to 0.100, 0.023 and 0.070 respectively for the existing, inadequate sealing condition.

The thermal comfort conditions were set at 22 °C / 50% in winter and 26 °C / 50% in summer [65,66]. The sport facility operates daily from 14:00 – 23:00 plus roughly 15 basketball games per year of the local team during weekends.

The annual heating and cooling load of the indoor sport facility in the existing condition was calculated at 79,144.6 kWh and 101,981.9 kWh respectively. Given the total covered area of 1426.7 m² of the indoor conditioned space, the specific annual heat consumption was calculated at 55.5 kWh/m² for heating and 71.5 kWh/m² for cooling.

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On the assumption of full coverage of this total annual heat demand with the existing oil burners for the main sport hall and the auxiliary building for heating and theoretical autonomous heat pumps for cooling with typical Energy Efficiency Ratio (EER) from 1.5 to 3.2, the annual diesel oil, electricity and the corresponding primary energy consumption are presented in Table 3. The electricity consumption for the indoor space cooling is calculated from the following fundamental relationship:

$$P_{el}=\frac{Q_c}{EER} \quad (3)$$

The efficiencies of the oil burners were taken equal to 83.5% for the two new ones and 75% for the old one. The hot water distribution hydraulic network efficiency was set equal to 80% and the efficiency of the hydronic terminal units was set at 91.8%. Finally, the diesel oil calorific value was set at 10.25 kWh/L [66]. According to the Greek Directive on Building's Energy Performance [66], the primary energy consumption due to electricity is calculated by multiplying the electricity consumption with the factor 2.9. Similarly, the primary energy which corresponds to a specific diesel oil consumption is calculated by multiplying the initial chemical energy contained in the consumed diesel oil with a factor of 1.1.

Table 3. Energy consumption analysis for indoor space conditioning in the existing operation.

Energy	Diesel oil	Electricity
Final heat demand (kWh)	79,144.6	101,981.9
Annual consumption (L / kWh)	11,845.5	28,993.8
Primary energy consumption (kWh)	121,416.8	28,993.8
Total primary energy consumption (kWh)	217,640.5	

5.2.2. Domestic hot water production

The domestic hot water consumption in the indoor sport hall exists in the changing rooms. The arisen annual heat demand for the production of the required domestic hot water amount is simply calculated with the following essential relationship:

$$\dot{Q}=\dot{m}_h \cdot c_p \cdot \Delta T=\dot{m}_h \cdot c_p \cdot (T_{hw}-T_{sw}), \quad (4)$$

where:

- $\dot{m}_h$ is the mass flow rate of the consumed hot water
- c_p = 4.187 kJ/kg·K the water specific heat capacity
- T_{hw} = 45° C the hot water required temperature
- T_{sw} the water temperature from the municipal water supply network. given by the Technical Directive 20701-1/2017 [67] (from 12.8 °C in February to 26.6 °C in August).

The hourly calculation of the consumed hot water was calculated, based on the information given by the management of the indoor sport hall, by assuming a varying number from 12 to 16 of showers users per hour, from 17:00 to 23:00 during the daily period, and 40 L hot water consumption per user.

Given the assumptions and data presented above, the annual time series of the final heat demand fluctuation for the coverage of the domestic hot water demand in the indoor sport hall was developed and is presented in Figure 8.

 doi:10.20944/preprints202308.1119.v1

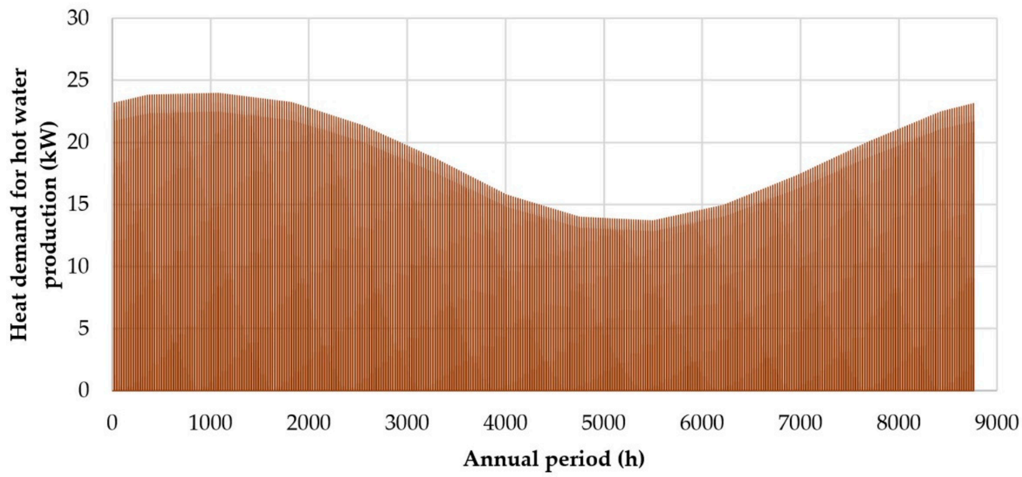

Figure 8. Annual fluctuation the heat demand for the domestic hot water demand coverage in the indoor sport hall.

The annual heat demand for the coverage of the hot water demand in the indoor sport hall is calculated equal to 41,327.3 kWh_{th}, by simply aggregating the hourly values of the annual time series presented in Figure 8.

For the calculation of the energy resources consumption for the coverage of this heat demand, it is assumed that:

- during the winter period, namely from 16/10 to 14/4, the existing oil burner for the indoor space heating of the auxiliary building will be used, practically concurrently with the indoor space heating, also for the production of domestic hot water
- during the summer period, namely from 15/4 to 15/10, the existing electrical boilers will be used.

Given the corresponding heat demand for hot water production during the aforementioned time periods, the electricity, diesel oi and primary energy consumptions are presented in Table 4. Regarding the efficiencies and the diesel oil calorific value, the values presented in the previous section for the old oil burner and the distribution network was also assumed.

Table 4. Energy consumption analysis for domestic hot water production in the existing operation.

Energy	Diesel oil	Electricity
Final heat demand (kWh)	23,829.6	17,497.7
Annual consumption (L / kWh)	3,262.9	19,388.1
Primary energy consumption (kWh)	36,789.5	56,225.4
Total primary energy consumption (kWh)	93,014.9	

5.2.3. Lighting

Lighting constitutes an important final energy use in the under study indoor sport hall. The following discrete lighting uses are found:

- indoor space lighting of the main sport hall, covered by 32 mercury and 4 halogen floodlights, with nominal electrical power 250 W and 400 W for each one of them respectively;
- indoor space lighting of the auxiliary building, covered by fluorescent lamps installed in 28 old plastic luminaires without reflective surfaces;
- outdoor perimeter lighting of the overall building facility, covered by 4 mercury floodlights with nominal electrical power 250 W each.

The annual electricity consumption for the full coverage of the lighting needs in the indoor sport hall is easily calculated by taking into account the installed electrical power of the existing lighting equipment and the daily operation schedule of each discrete space of the facility. The results are presented in Table 5. The presented nominal power consumptions have been read from the installed bulbs and floodlights.

 doi:10.20944/preprints202308.1119.v1

Table 5. Electricity consumption for lighting in the current operation state.

Lighting use / power / consumption	Installed electrical power (kW)	Electricity consumption (kWh)
Outdoor perimeter floodlights	1.25	4,627.6
Main indoor sport hall	12.86	11,313.9
Auxiliary building	3.91	1,467.7
Total installed power	18.02	
Total electricity consumption		17,409.2
Total primary energy consumption		50,486.7

5.2.4. Other electricity consumptions

Apart from the three main final energy uses (indoor space conditioning, domestic hot water production and lighting), electricity is additionally consumed in the indoor sport hall in the following equipment:

- the three in total circulators of the heating hydraulic network, two for the main sport hall with 150 W nominal electrical input power each and one for the auxiliary building with 100 W nominal electrical input power;
- the 22 fans of the hydronic terminal units of the main sport hall with 183 W nominal electrical input power for each one.

According to the heating load annual time series particularly for the thermal zone 1 (main sport hall) and the thermal zone 2 (auxiliary building), the total operating hours during the year of the heating system and, consequently, the corresponding circulators for these two thermal zones are calculated 2696 and 1456 respectively.

Given the aforementioned data, the total annual electricity consumption is calculated at:

- 808.8 kWh for the circulators of the main sport hall heating network
- 145.6 kWh for the circulators of the auxiliary building heating network
- 10.854,1 kWh for the hydronic unit fans.

The total electricity annual consumption from these additional equipment is calculated equal to 11,808.5 kWh, which corresponds to 34,244.6 kWh of primary energy.

5.2.5. Energy consumption synopsis in existing conditions

Summarizing the results from the calculations presented in the previous sections, the diesel oil and electricity total annual consumption and the corresponding primary energy consumptios are analyzed per different final energy use in Table 6.

Table 6. Annual energy consumption on the assumption of full operation of the municipal sport centre during the whole year under the current state.

Final energy use	Diesel oil (L)	Electricity (kWh)	Primary energy	
			(kWh)	(%)
Indoor space heating	11,845.5	0.0	133,558.0	33.8
Indoor space cooling	0.0	28,993.8	84,082.0	21.3
Hot water production	3,262.9	19,388.1	93,014.7	23.5
Lighting	0.0	17,409.2	50,486.7	12.8
Circulators and fans	0.0	11,808.5	34,244.7	8.7
Total	**15,108.4**	**77,599.6**	**395,386.1**	**100.0**

As seen in Table 6, the main energy consumptions in the municipal indoor sport hall are related with heat. Indeed, the sum of the primary energy consumption for indoor space heating and cooling and hot water production is calculated at 78.5%. The electricity consumption for lighting accounts also for a significant percentage (12.8%). By dividing the total primary energy annual consumption

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with the covered area of the indoor conditioned space, the specific annual primary energy consumption is calculated at 277.1 kWh/m².

5.3. Proposed energy saving measures

The energy performance upgrade of the under study indoor sport hall was approached with a wide cluster of the most mature, effective and economically competitive passive and active measures. Specifically, starting from the passive measures:

- Replacement of all existing semi-transparent polycarbonate panels from the vertical walls of the main sport hall with stone wool panels of 8 cm thickness, with total net surface of 579.4 m² and U-factor of 0.38 W/m²·K.
- Installation of outer insulation in all vertical opaque surfaces constructed with reinforced concrete or bricks, with 7 cm thickness stone wool sheets. The new U-factors are calculated equal to 0.40 W/m²·K for the bearing structure parts of the opaque surfaces and 0.34 W/m²·K for the brick walls. The total opaque net area under insulation is equal to 471.7 m².
- Replacement of all existing polyurethane panels on the main sport hall's roof, of 1230 m², with stone wool panels of 8 cm thickness. The new U-factor is calculated equal to 0.39 W/m²·K.
- Installation of outer insulation on the auxiliary building's roof of 304 m² total area, with 7 cm thickness stone wool sheets. The new U-factor is calculated equal to 0.40 W/m²·K.
- Replacement of all existing openings in the facility, with new, of low-e technology, with synthetic frame and double glazing. The new U-factors will be equal to 0.95 W/m²·K for the windows and 1.2 W/m²·K for the doors. In total 46 windows and 5 doors will be installed, with total areas equal to 44.6 m² and 16.6 m² respectively.
- Installation of 54 solar tubes on the main sport hall's roof, in a 6 × 9 layout, for the maximisation of the natural lighting during the daytime.

Additionally, the following active systems are proposed:

- Installation of an air-to-water heat pump with nominal capacity of 150 kW_{th} and 149 kW_{th} for heating and cooling respectively, for the indoor space conditioning of the main sport hall. The heat pump will exploit the existing hydraulic network and the 22 hydronic terminal units of 6.5 kW_{th} nominal capacity both for heating and cooling, already installed for this specific space. The oil burners will be removed.
- Installation of a second air-to-water heat pump with nominal capacity 11.2 kW_{th} and 10.0 kW_{th} for heating and cooling respectively, for the indoor space conditioning of the auxiliary building, together with a new hydraulic network and new hydronic, terminal units. In total 12 new hydronic units will be installed, with nominal capacities from 1.6 kW_{th} to 2.7 kW_{th} both for heating and cooling.
- Installation of a solar-combi system, with 24 solar collectors of 2.4 m² absorber surface each and two heat storage tanks of 2000 L each, divided in two discrete groups, supported by a third air-to-water heat pump, with nominal heating capacity 23 kW_{th}. The layout of this system is depicted in Figure 9. The solar collectors will be installed on the ground, at the south part of the outdoor available land in the facility, with an inclination of 30° with regard to the horizontal plane and southern orientation, so as to maximize the annual captured solar radiation.

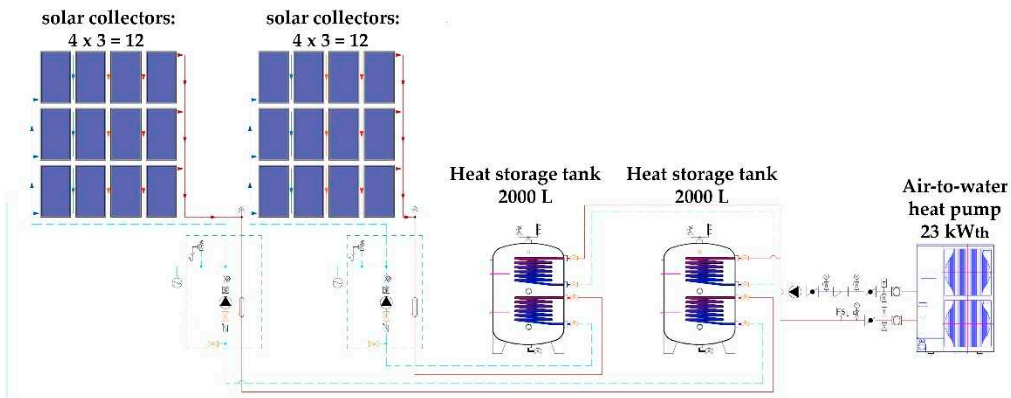

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Figure 9. The layout of the proposed system for the domestic hot water production.

- Replacement of all existing lamps and luminaires for indoor and outdoor lighting, with new with reflective surfaces and LED technology. In total 4 outdoor luminaires and 47 luminaires will be replaced in the auxiliary building, while 40 new LED floodlights will be installed in the main sports hall. The total installed lighting power will be reduced from 18.4 kW to 8.4 kW (54.4%).
- Finally, a photovoltaic plant will be installed on the main sports hall's roof for the compensation of the remaining electricity consumption. The use of diesel oil will be totally eliminated with the removal of the diesel oil burners.

5.4. Energy consumption with the proposed upgrade measures

In this section the anticipated energy saving and production results are presented, separately for each discrete final energy use, after the introduction and implementation of all the above presented passive and active energy upgrade measures.

5.4.1. Indoor space conditioning

Firstly, the indoor space heating and cooling load is calculated, assuming that all the proposed passive measures have been applied in the overall building's envelope. The same process presented in Section 5.2.1 is followed again. With the introduction of the proposed passive measures, the achieved U-factors of the building's envelope discrete structural elements are presented in Table 7. All these achieved new U-factors are significantly lower than the upper acceptable limits in the Greek Directive of Building's Energy Performance [66]: 0.5 W/m^2·K for opaque surfaces (walls and roofs) and 2 W/m^2·K for openings.

Table 7. U-factors of the building's envelope discrete structural elements after the introduction of the proposed passive measures.

Structural element	U-factor (W/m^2·K)	Structural element	U-factor (W/m^2·K)
Main sport hall vertical surface: stone wool 8 cm panels	0.38	Auxiliary building vertical surface: brick walls with 7 cm stone wool insulation sheet	0.34
Main sport hall vertical surface: reinforced concrete with 7 cm stone wool insulation sheet	0.40	Auxiliary building vertical surface: reinforced concrete with 7 cm stone wool insulation sheet	0.0
Main sport hall roof: stone wool 8 cm panels	0.39	Auxiliary building roof: reinforced concrete with 7 cm stone wool insulation sheet	0.40
Windows	0.95	Doors	1.2

Relationship 2 is employed again for the calculation of the natural ventilation from the new openings, yet, this time with improved values for the parameters K_1, K_2 and K_3 equal to 0.100, 0.011 and 0.034 respectively, assuming adequate air sealing of the new openings. The TRNSYS software was used again for the computational simulation of the overall building's thermal performance.

The annual fluctuation of the total heating and cooling load for both thermal zones (whole building) is presented in Figure 10, firstly in the current operating condition (Figure 10a) and secondly after the integration of the proposed passive measures (Figure 10b).

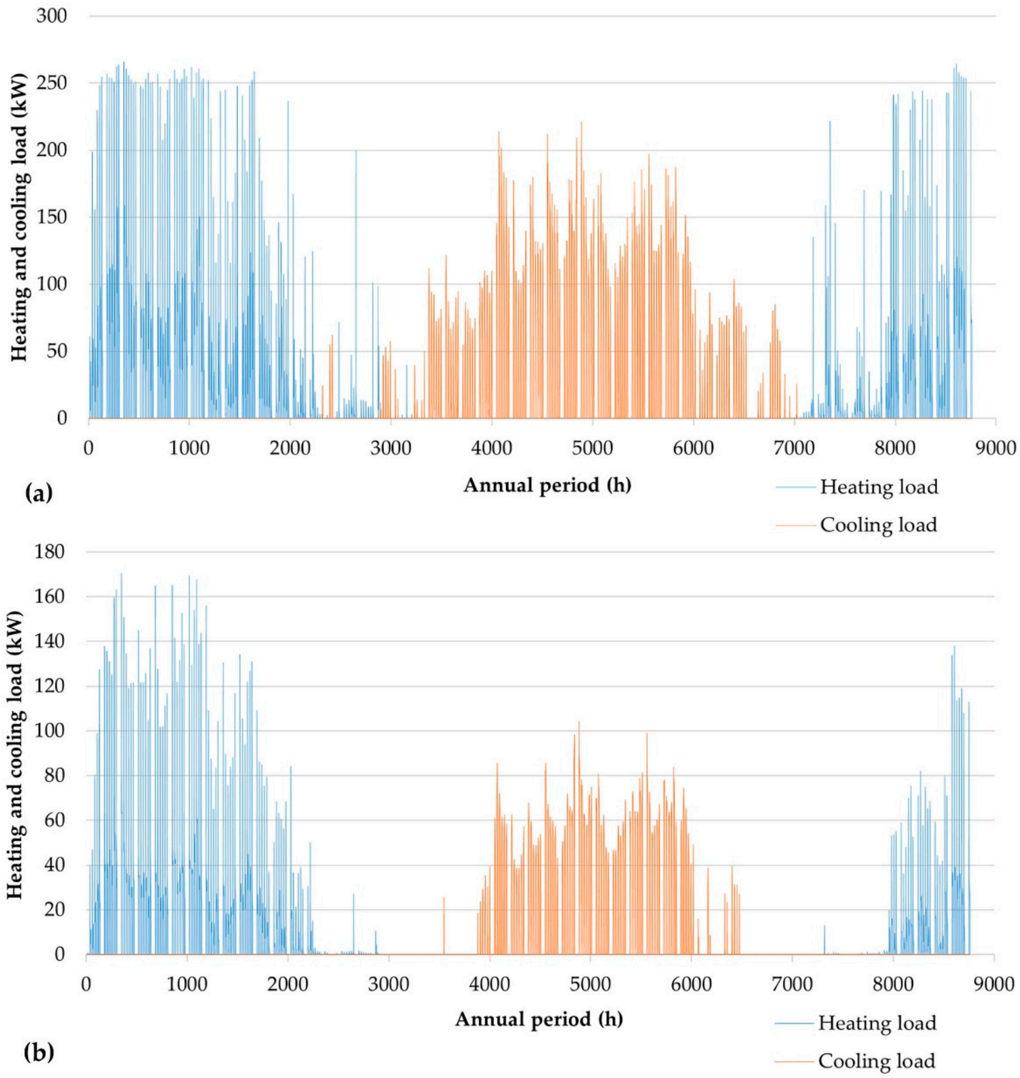

Figure 10. Annual fluctuation of the indoor space heating and cooling load for the indoor sport hall overall building facility, (a) before and (b) after the application of the proposed passive measures.

The annual heating and cooling load of the overall building facility is analysed in Table 8 before and after the implementation of the proposed passive measures. The achieved heating and cooling load annual drop is also presented. As seen in Table 8, annual reduction on heating and cooling load at the range of 60% is achieved, a result that should be sensibly expected, given the considerably ineffective current thermal performance of the existing facility.

Table 8. Reduction of indoor space conditioning load of the overall sport facility due to the application of the proposed passive measures.

Indoor space	Annual load		Annual load reduction	
conditioning mode	Existing operation	Proposed Operation	(kWh)	(%)
Heating	79,145	32,154	46,991	59.4
Cooling	101,982	39,181	62,801	61.6
Total	181,127	71,335	109,792	60.6

The heating and cooling load of the indoor sport facility in the new proposed operation state will be covered by two air-to-water heat pumps, as described in Section 5.3. The first, large size pump (nominal capacity 150 kW_{th} for heating and 149 kW_{th} for cooling) will cover the main sport hall, while the second one, small size pump (nominal capacity 11.2 kW_{th} and 10.0 kW_{th} for heating and cooling respectively) will cover the auxiliary building. The installation of a second small pump will serve the

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need for autonomous coverage of the auxiliary building's conditioning, in potential periods during which the main sport hall will not be in use. At the same time, through hydraulic automation and electronic control, it will be possible for the large size pump to undertake the conditioning of the overall facility, in case the total heating or cooling load does not exceed its nominal capacity.

The existing hydraulic network with the 22 hydronic terminal units will be used for the main sport hall. For the auxiliary building, a new hydraulic network with polypropylene (PPR) pipelines and 12 new hydronic terminal units will be installed.

New COP (Coefficient of Performance) and EER curves versus the ambient air temperature were introduced for both new heat pumps, presented in Figure 11.

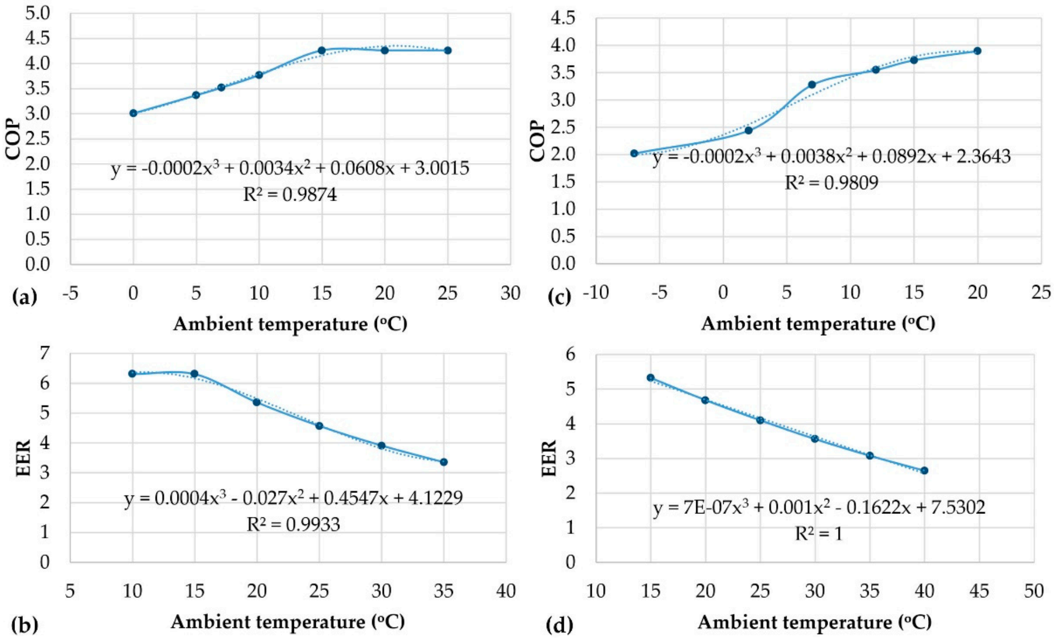

Figure 11. COP and EER curves versus ambient temperature of the large size (a and b) and the small size (c and d) heat pump introduced for the indoor space conditioning of the sport facility.

The electricity consumption from these heat pumps is calculated from the relationship 5 (Q_h the new indoor space heating load) for heating and from the relationship 3 for cooling.

$$P_{el}=\frac{Q_h}{COP} \quad (5)$$

The achieved energy resources saving for the indoor space conditioning of the sport facility is analyzed in Table 9. As seen in Table 9, the diesel oil consumption is eliminated, while the outstanding annual saving percentage of 77.4% of the consumed primary energy is achieved for the overall indoor space conditioning of the sport facility.

Table 9. Energy resources saving results for indoor space conditioning in the sport facility after the implementation of the proposed passive and active measures.

Energy	Load – consumption		Saving	
	Existing operation	Proposed Operation	(kWh)	(%)
Main sport hall (thermal zone 1)				
Heating & cooling load (kWh)	143,484.6	56,515.2	86,969.4	60.6
Diesel oil (L)	7,928.8	0.0	7,928.8	100.0
Electricity (kWh)	25,273.8	13,122.1	12,151.7	48.1
Primary energy (kWh)	162,691.2	38,054.1	124,637.1	76.6
Auxiliary building (thermal zone 2)				

Heating & cooling load (kWh)	37,641.9	14,819.7	22,822.2	60.6
Diesel oil (L)	3,916.7	0.0	3,916.7	100.0
Electricity (kWh)	3,720.0	3,871.3	-151.3	-4.1
Primary energy (kWh)	54,949.4	11,226.9	43,722.4	79.6
All indoor space				
Heating & cooling load (kWh)	181,126.5	71,334.8	109,791.7	60.6
Diesel oil (L)	11,845.5	0.0	11,845.5	100.0
Electricity (kWh)	28,993.8	16,993.4	12,000.4	41.4
Primary energy (kWh)	217,640.5	49,281.0	168,359.5	77.4

5.4.2. Domestic hot water production

A solar-combi system is proposed for the production of domestic hot water in the indoor sport hall. The overall layout of the proposed system has been presented in Figure The domestic hot water is proposed to be produced by the solar-combi system presented in Figure 9, Section 5.3. Practically, the system is formulated with two replicated parts. Each part consists of 12 solar collectors, connected in three parallel groups with 4 in-series connected collectors in each one of them and a heat storage tank with 2000 L storage capacity. The system is integrated with an air-to-water heat pump with nominal heating capacity 23 kW_{th}, which is connected as a back-up unit with both storage tanks. The aforementioned sizing was the result of the dimensioning procedure which will be briefly described below.

The operation algorithm of the proposed system is simple and it is analysed in the following steps (see also Figure 9):

- if $T_{sol} > T_{st}$, the circulator of the solar collectors' primary closed loop turns on and heat is transferred from the solar collectors to the heat storage tanks;
- if $T_{sol} \leq T_{st}$, then the heat produced by the solar collectors cannot be transferred to the heat storage tanks and the circulator of the solar collectors' primary closed loop remains off;
- if $T_{st} < T_{hw}$, then the back-up unit (the heat pump) is turned on,

where:

T_{sol} : the supplied water temperature from the solar collectors;
T_{st} : the stored water temperature in the heat storage tanks;
T_{hw} : the required hot water temperature.

Another important issue regarding the efficiency of the proposed solar-combi system is the installation inclination of the solar collectors. An iterative calculation of the total incident solar radiation on inclined flat surface with southern orientation was performed for different inclinations with regard to the horizontal plane and for the geographical coordinates of the installation site. These results are presented in Table 10.

Table 10. Calculation of the total incident annual cumulative solar radiation on a flat surface versus its inclination at the geographical location of the municipal sport centre.

Solar radiation	Surface inclination with regard to the horizontal plane								
	20°	**25°**	**30°**	**35°**	**40°**	**45°**	**50°**	**55°**	**60°**
Annually cumulative incident solar radiation (kWh/m²)									
Direct	1060	1078	1088	1089	1083	1068	1045	1014	975
Diffused	696	684	670	653	634	613	590	566	539
Reflected	13	20	29	39	51	64	78	93	109
Total	1769	1783	1787	1782	1768	1744	1712	1672	1623
Cumulative incident solar radiation from 15/10 to 15/3 (kWh/m²)									
Direct	320	340	357	371	382	390	396	398	397

Diffused	203	200	196	191	185	179	172	165	157
Reflected	4	6	8	11	14	17	21	25	29
Total	527	545	560	572	581	586	589	588	584

According to Table 10, the maximum annual received cumulative solar radiation is achieved for 30° inclination. However, for the specific case, it is more crucial to achieve maximisation of the incident cumulative solar radiation during the winter months (from 15/10 to 15/3). Given this criterion, the optimum inclination is found for 50°. In order to achieve an average approach, aiming at the maximum possible operation during winter without affecting considerably the overall annual heat production, the inclination of 40° was finally adopted. Figure 12 presents the annual fluctuation of the incident solar irradiance on a flat surface with 40° inclination at the geographical site of the indoor sport hall.

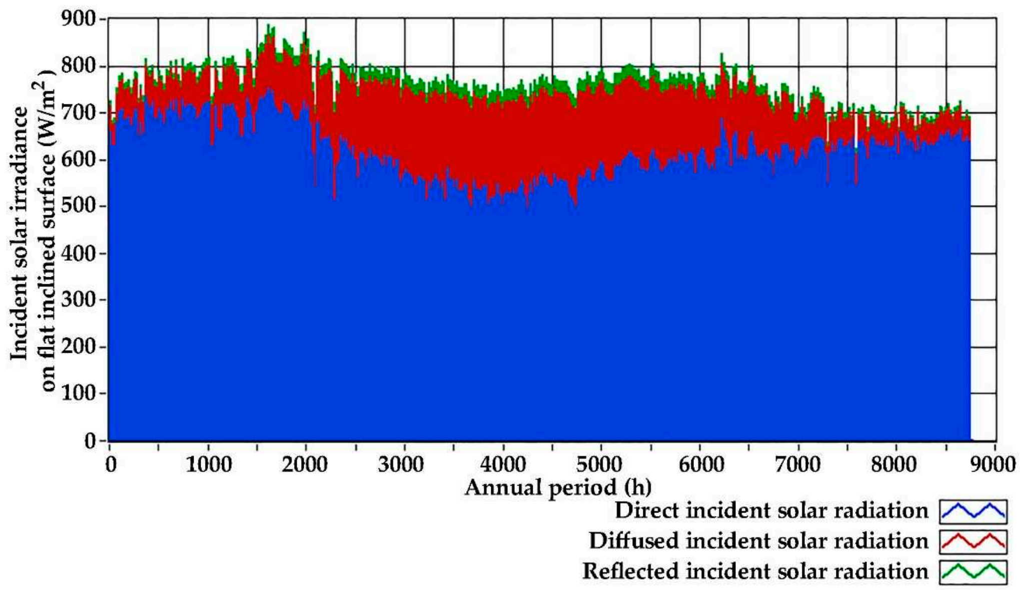

Figure 12. Annual fluctuation of the incident solar irradiance on a flat surface with 40° inclination at the geographical site of the indoor sport hall.

The sizing of the proposed solar-combi system was accomplished through the computational simulation of the system's annual operation, following the aforementioned simple operation algorithm. The process is presented in the Part A of this overall work. Nevertheless, it is presented here again for integrity reasons.

The computational simulation of the proposed solar-combi is based on the following data:

- the annual times series of the total incident solar irradiance on the 40° inclined surface (Figure 12);
- the annual time series of the heat demand for domestic hot water production (Figure 8, Section 5.2.2);
- the annual time series of the ambient temperature (Figure 3, Section 4);
- the annual time series of the wind velocity (Figure 5, Section 4);
- the water specific heat capacity (4.187 kJ/kg·K);
- the domestic hot water minimum required temperature T_{hw}, set equal to:
    - from the 1st of January to the 30th of April: 40 °C
    - from the 1st of May to the 30th of June: 35 °C
    - from the 1st of July to the 15th of September: 30 °C
    - from the 16th of September to the 15th of November: 35 °C
    - from the 16th of November to the 31st of December: 40 °C;

 doi:10.20944/preprints202308.1119.v1

- typical geometrical and thermo-physical features of a collective plate, flat solar collector's model [42];
- typical geometrical and thermo-physical features of a heat storage tank with 2000 L storage capacity (2.4 m height, 1.3 m diameter, 10 mm insulation thickness and total U-factor 0.22 $W/m^2{\cdot}K$).

The computational simulation of the system's annual operation was iteratively executed for different numbers of solar collectors and heat storage tanks. The optimization criterion was the minimization of the heat production specific cost from the solar-combi system, which was approached by the following relationship:

$$c_{th}=\frac{N_{sc}\cdot C_{sc}+N_{ST}\cdot C_{ST}}{E_{SC}\cdot T_{LP}}, \quad (6)$$

where:

N_{SC} : the solar collectors' total number in the system;

C_{SC} : the procurement price of one solar collector, adopted equal to 450 €;

N_{ST} : the heat storage tanks' number in the system, with storage capacity of 2000 L;

C_{ST} : the procurement price of one 2000 L heat storage tank, adopted equal to 6000 €;

E_{SC} : the annual heat demand coverage for domestic hot water production from the solar-combi system;

T_{LP} : the solar-combi system's life period, adopted equal to 15 years.

Additionally, the annual coverage of at least 45% of the final heat demand by the solar collectors was also set as a dimensioning requirement.

It is conceivable that the above presented specific cost is not accurate, since it does not contain other components of the solar-combi system set-up cost, such as the required hydraulic network or any automation devices, as well as any component of the annual operation cost (for example the maintenance of the heat pump or the glazing cleaning of the solar collectors). Yet, the accurate calculation of this magnitude is not crucial, because it is introduced only as a comparative evaluation criterion between the different investigated dimensioning scenarios.

The mathematical background for the calculation of the thermal power production from the solar collectors and the heat storage in the tanks are in detail described in [42,68].

After the iterative execution of the aforementioned sizing process, the results summarized in Table 11 are received. The annual heat demand for the domestic hot water production is 41.327,3 kWh.

Table 11. Iterative process results for the dimensioning of the solar-combi system.

Collectors' number	Tanks' number	Initial heat production from solar collectors (kWh)	Heat storage (kWh)	Rejected heat percentage (%)	Heat coverage from collectors (kWh)	Heat demand coverage percentage from collectors (%)	Collectors-tanks cost (€)	Heat production specific cost (€/kWh)
12	1	31.399,4	13.247,6	57,8	9.658,6	23,4	11.400	0,0787
16	1	39.826,9	15.161,7	61,9	11.100,7	26,9	13.200	0,0793
16	2	39.826,9	23.533,6	40,9	16.230,2	39,3	19.200	0,0789
20	2	47.899,2	26.699,0	44,3	18.506,2	44,8	21.000	0,0757
24	2	55.796,6	28.368,0	49,2	19.692,7	47,6	22.800	0,0772
24	3	55.796,6	34.285,2	38,6	21.846,9	52,9	28.800	0,0879
28	2	63.572,3	29.844,8	53,1	20.764,6	50,2	24.600	0,0790

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28	3	63.572,3	36.496,9	42,6	23.354,8	56,5	30.600	0,0873
32	3	71.276,3	38.098,0	46,5	24.418,2	59,1	32.400	0,0885
36	3	78.941,3	39.571,9	49,9	25.449,0	61,6	34.200	0,0896
40	3	86.579,5	40.661,9	53,0	26.166,5	63,3	36.000	0,0917
40	4	86.579,5	46.808,9	45,9	27.129,1	65,6	42.000	0,1032

Given the results presented in Table 11, the minimum heat production specific cost with annual heat demand percentage coverage from the solar collectors higher than 45% is given by 24 collectors and two heat storage tanks of 2000 L each.

Figure 13 presents the annual fluctuation of the heat demand coverage from the solar collectors and the heat pump.

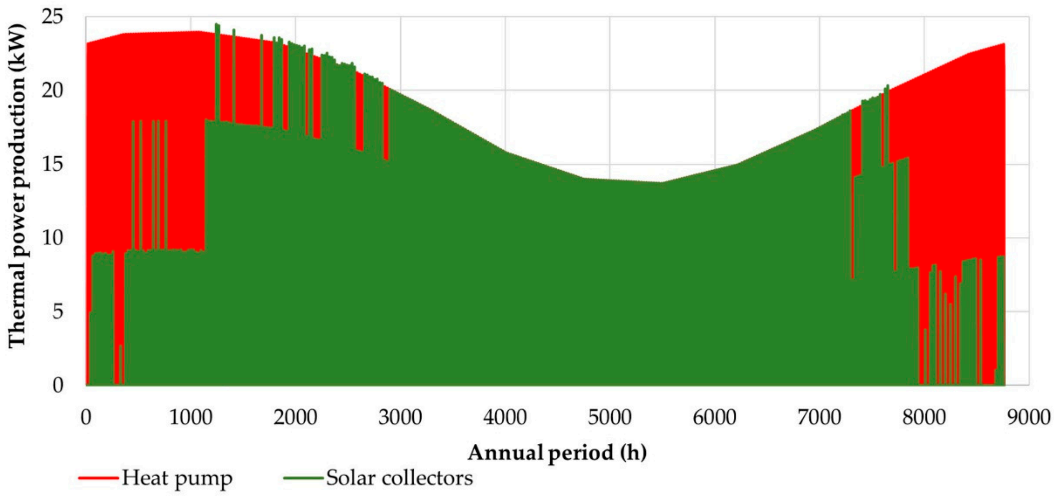

Figure 13. Annual fluctuation of the heat demand coverage from the solar collectors and the heat pump for domestic hot water production in the indoor sport hall.

The annual fluctuation of the supplied hot water temperature from the solar collectors' primary loop to the heat storage tanks is also presented in Figure 14.

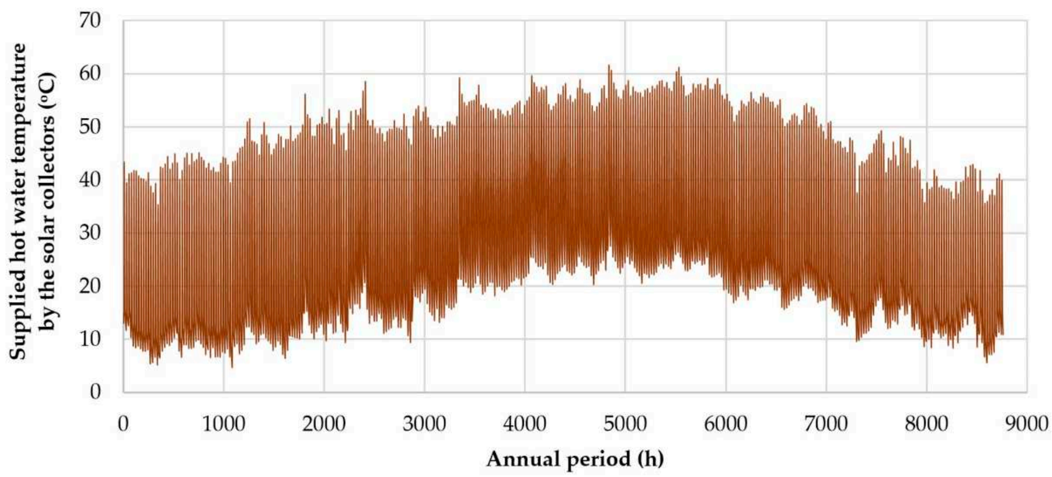

Figure 14. Annual fluctuation of the supplied hot water temperature from the solar collectors' primary loop to the heat storage tanks.

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With the proposed solar-combi system energy saving for the production of domestic hot water in the indoor sport hall is achieved in two levels:

- the 47.6% contribution of the solar collectors to the annual heat demand coverage;
- the consumption of electricity instead of diesel oil, which is totally eliminated for the specific use.

The electricity consumption from the heat pump for the domestic hot water production is calculated using the relationship 3. The COP curve versus the ambient temperature presented in Figure 11c is employed. The ambient temperature curve presented in Figure 3 is used, while the heat demand Q_h for hot water production has been supplied in Figure 8. The energy resources saving results for domestic hot water production in indoor sport hall are summarized in Table 12.

Table 12. Energy resources saving summary for domestic hot water production in indoor sport hall.

Energy	Load – consumption		Saving	
	Existing operation	Proposed Operation	(kWh)	(%)
Heat demand for hot water production (kWh)	41.327,3	41.327,3	0,0	0,0
Diesel oil (L)	3.262,9	0,0	3.262,9	100,0
Electricity (kWh)	19.388,1	7.323,4	12.064,7	62,2
Primary energy (kWh)	93.014,9	21.237,8	71.777,1	77,2

5.4.3. Lighting

The interventions for the improvement of the lighting operation in the indoor sport hall contain both passive and active measures:

- The passive measures include the installation of 54 solar tubes on the main sport hall's roof, arranged in nine parallel rows along the long side of the hall, with six tubes in each one of them, as shown in Figure 15. In the same figure the photometric results in the main sport hall at 1 m height above ground, obtained only from natural lighting penetration through the proposed solar tubes, are also presented for a typical summer day at 12:00 a.m. The same results are given in Figure 16, this time for a typical sunny day in winter, again at 12:00 a.m. The minimum required illuminance at 1 m height above height for an indoor sport hall according to the Greek Directive on Building's Energy Performance is set at 300 lux, so, as seen in Figures 15 and 16, with the proposed solar tubes number and layout, the required lighting conditions are achieved for both winter and summer and for sunny days.
- With these solar tubes it is anticipated that natural lighting will fully cover the lighting needs of the main sport hall during daytime for most days during the year. With this measure, the natural lighting loss due to the replacement of the existing semi-transparent and energy ineffective polycarbonate panels with the opaque stone wool panels will be also fully compensated.
- With regard to the active measures, practically all existing mercury and halogen floodlights for the main sport hall and the outdoor space lighting, as well as all the fluorescent lamps with the old and ineffective luminaires will be fully replaced, with LED floodlights and lamps and with luminaires with reflective surfaces. Specifically, the existing 32 mercury and 4 halogen floodlights in the main sport hall will be replaced with 40 LED floodlights, arranged in 8 rows with 5 units each, with nominal electrical power input of 147 W and nominal luminous flux of 22,000 lumens. The photometric results in the main sport hall with this proposed artificial lighting equipment is given in Figure 17. As seen in this figure, the illuminance requirements are also fully satisfied with this proposed floodlights arrangement. All photometric calculations presented in this section were executed with the DIALux evo 11 [69].

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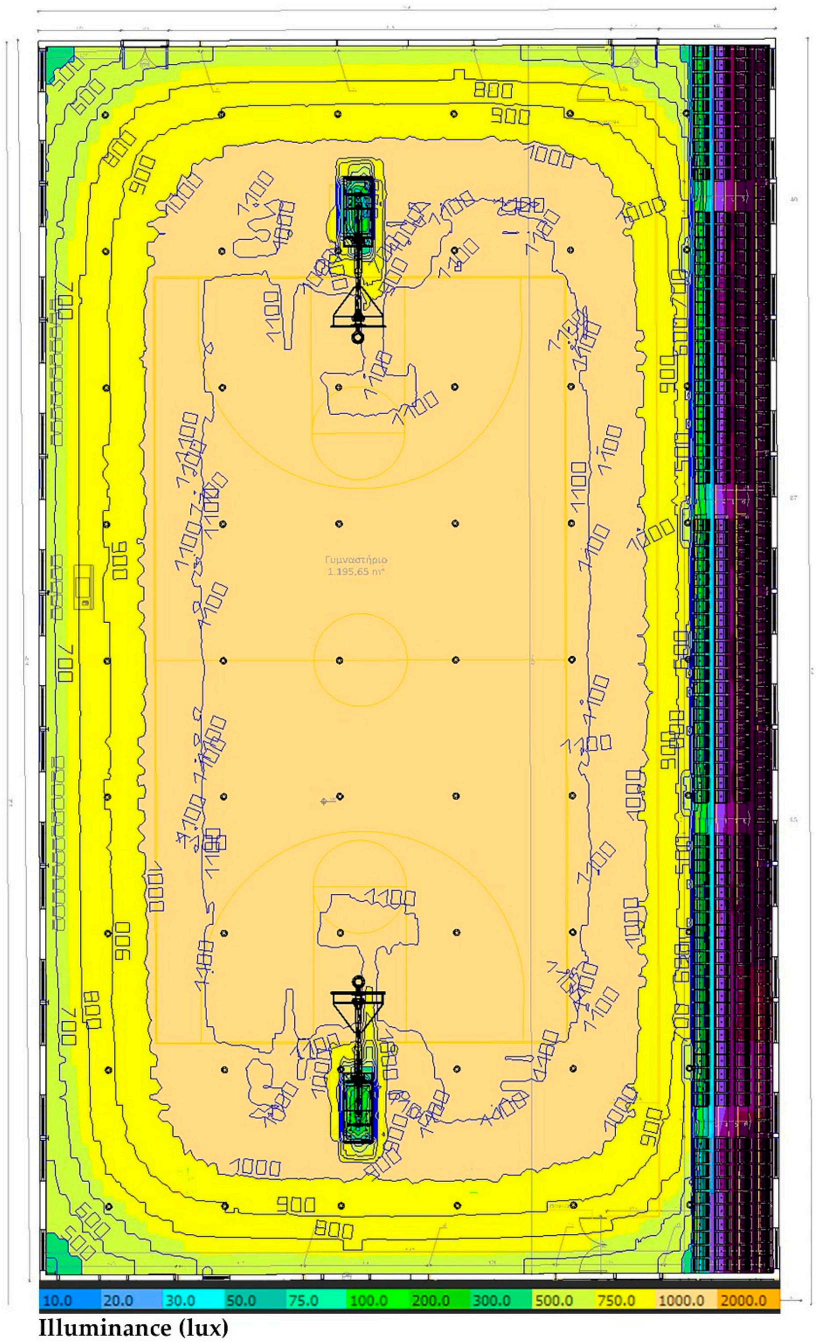

Figure 15. Solar tubes arrangement and photometric results from natural lighting in the main sport hall in typical sunny summer day at 12:00 a.m.

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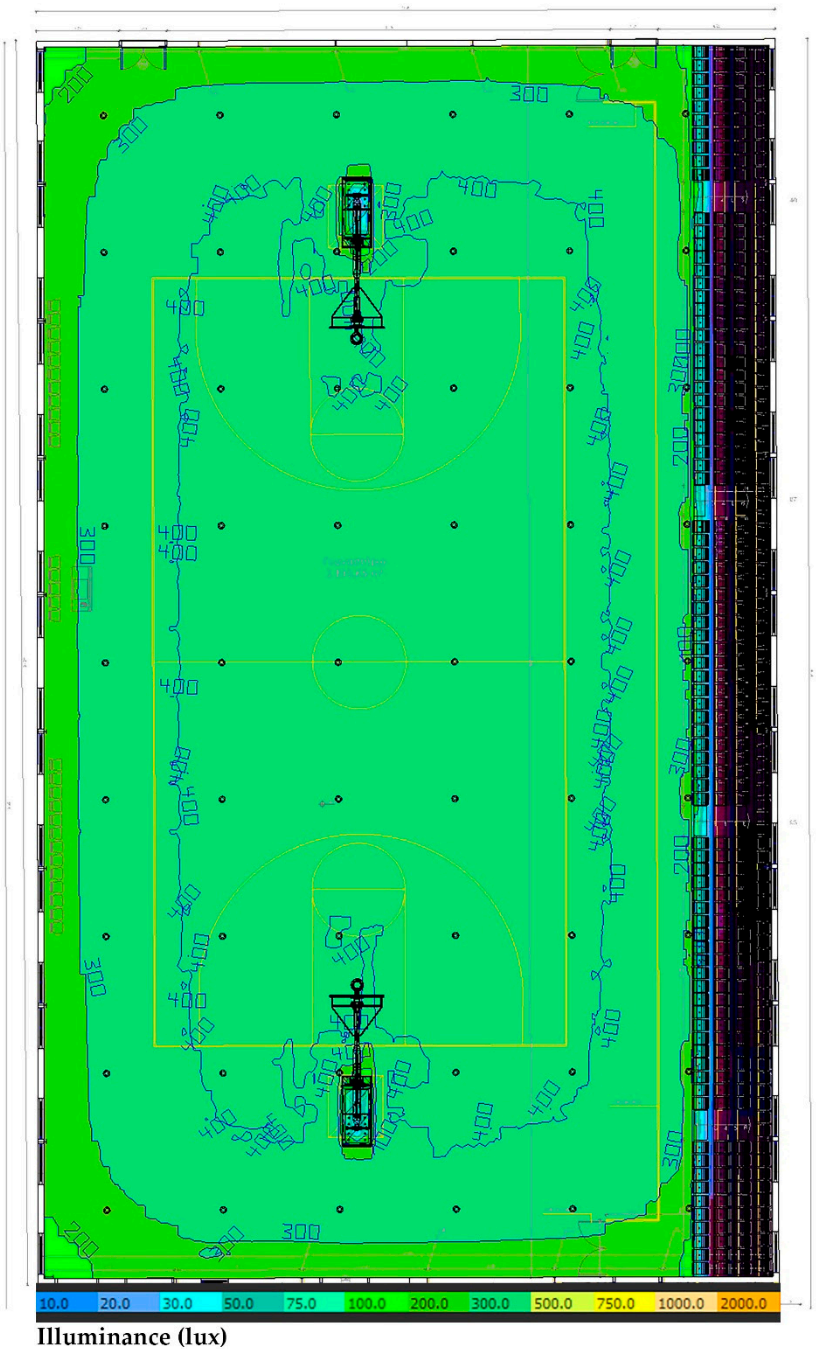

Figure 16. Solar tubes arrangement and photometric results from natural lighting in the main sport hall in typical sunny winter day at 12:00 a.m.

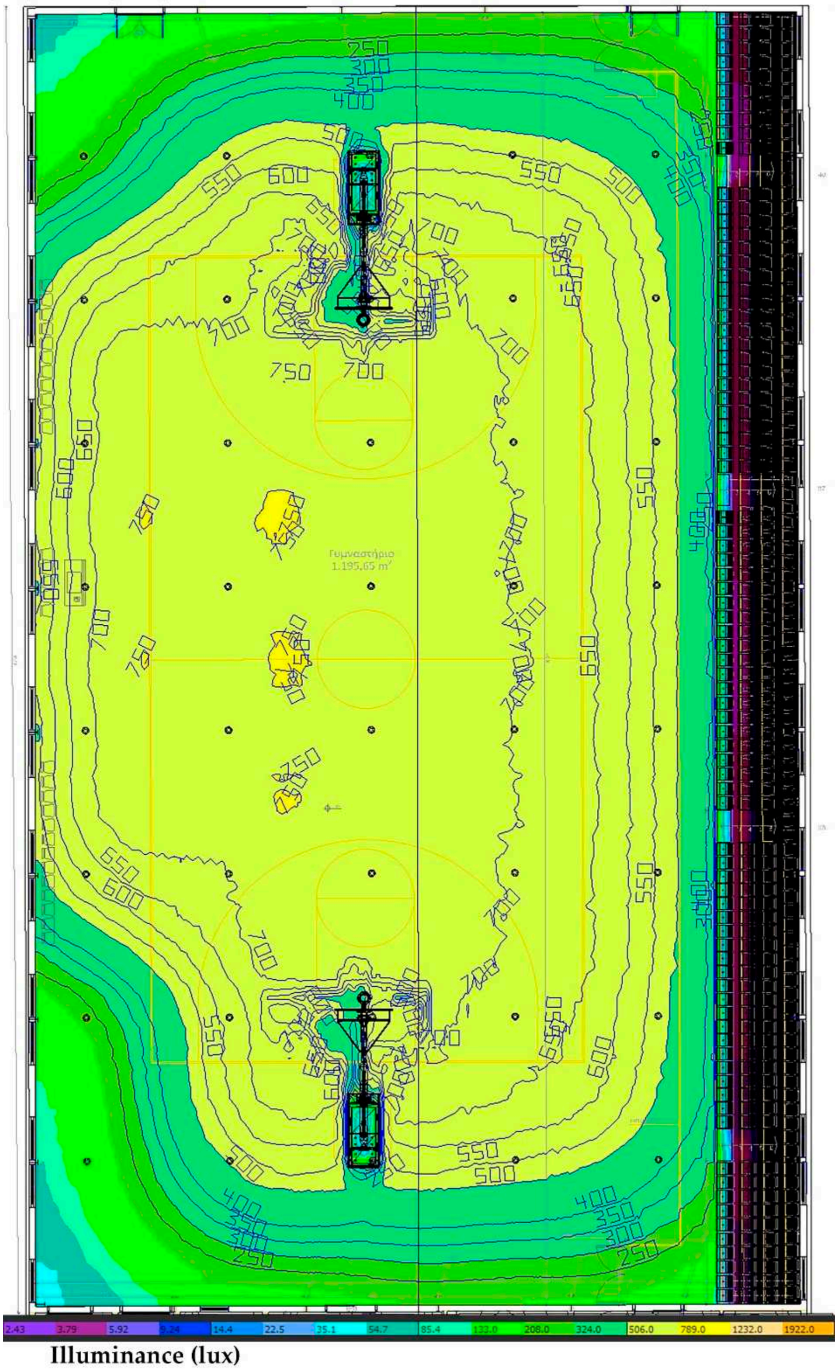

Figure 17. LED floodlights arrangement and photometric results from artificial lighting in the main sport hall.

Additionally, in total 47 fluorescent luminaires and lamps will be replaced with LED lamps and luminaires with reflective surfaces in the discrete rooms of the auxiliary building.

The achieved electrical power reduction for all lighting equipment in the indoor sport hall and the achieved annual electricity saving are summarized in Table 13.

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Table 13. Summary of the achieved results on the installed electrical power drop and electricity saving for lighting in the municipal indoor sport hall.

	Existing operation		Proposed operation		Power drop		Electricity saving	
	Power (W)	Electricity (kWh)	Power (W)	Electricity (kWh)	(W)	(%)	(kWh)	(%)
Outdoor perimeter lighting	1,648	4,627.6	500	1,334.9	1,148	69.7	3,292.7	71.2
Main sport hall lighting	12,864	11,313.9	5,880	5,171.5	6,984	54.3	6,142.4	54.3
Auxiliary building indoor lighting	3,914	1,467.7	2,028	760.5	1,886	48.2	707.2	48.2
Total	18,426	17,409.2	8,408	7,266.9	10,018	54.4	10,142.3	58.3

The achieved corresponding primary energy annual saving is calculated at 29,412.7 kWh.

5.4.4. Remaining electricity consumption – summary of new consumptions

Except the aforementioned thoroughly described consumptions for indoor space conditioning, domestic hot water and lighting, electricity will be also consumed in the sport facility for the operation of the circulators in the hydraulic networks for the indoor space facility and the hot water distribution, and in the fans of the hydronic units. The overall calculation of these additional consumptions, with the essential required parameters, such as the annual operating hours and the nominal electrical power inputs, are summarized in Table 14.

Table 14. Remaining electricity consumption analysis.

Circulators of the indoor space conditioning hydraulic network			
	Main sport hall	Auxiliary building	Total
Nominal electrical power input (W)	81.7	143.0	
Annual operating time (h)	1738	1317	
Annual electriciy consumption (kWh)	142.0	188.3	330.3
Hydronic units fans			
	Main sport hall	Auxiliary building	Total
Nominal electrical power input (W)	4026	306	
Annual operating time (h)	1738	1317	
Annual electriciy consumption (kWh)	6997.2	403.0	7400.2
Circulators of the domestic hot water distribution hydraulic network			
	Solar collectors	Heat pump	Total
Nominal electrical power input (W)	49	81.7	
Annual operating time (h)	1289	731	
Annual electriciy consumption (kWh)	63.2	59.7	122.9

The total electricity consumption from the above presented equipment is calculated at 7853.4 kWh, which corresponds to 22,774.9 of primary energy.

The total electricity consumption for all final energy uses in the proposed operation state is summarized in Table 15.

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Table 15. Summary of the total electricity consumption in the proposed operation state of the indoor sport hall.

Energy use	Electricity consumption (kWh)
Indoor space conditioning	16,994
Hot water production	7,323
Lighting	7,267
Circulators of the conditioning system	330
Hydronic units' fans	7,400
Circulators of the hot water production system	123
Total	39,437

5.4.5. Photovoltaic station

For the compensation of the remaining annual electricity consumption, a photovoltaic plant is proposed to be installed on the main sport hall roof. The photovoltaic panels will be installed following the inclination (5° with regard to the horizontal plane) and the orientation (western) of the western part of the hall's roof. With these installation parameters, the annual fluctuation of the total incident solar irradiance on the photovoltaic panels is depicted in Figure 18.

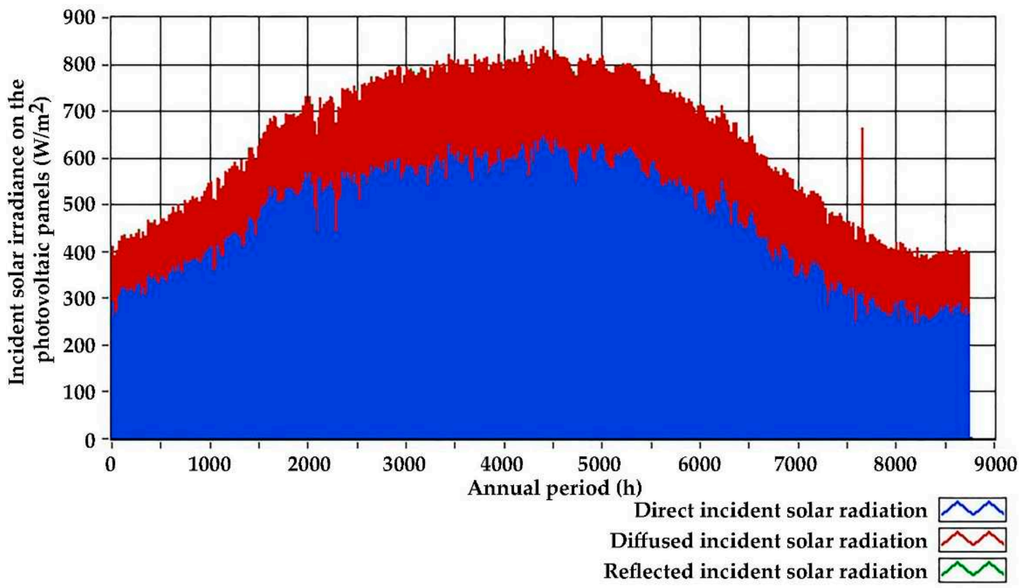

Figure 18. Annual fluctuation of the incident solar irradiance on the photovoltaic panels for 4° inclination and western orientation.

The required installed photovoltaic power, for the full coverage of the annual electricity remaining consumption in the facility, given the available solar potential in the specific geographical region and the installation characteristics, was calculated at 31.8 kW, following the essential calculation process for the electricity produced by a photovoltaic plant [70]. This total power can be achieved with the installation of 108 panels of 300 W nominal power each. Two inverters of 20 kW each will be used for their interconnection with the local grid. The siting of the photovoltaic plant on the main sports hall's roof is depicted in Figure 19, together with the solar tubes grid.

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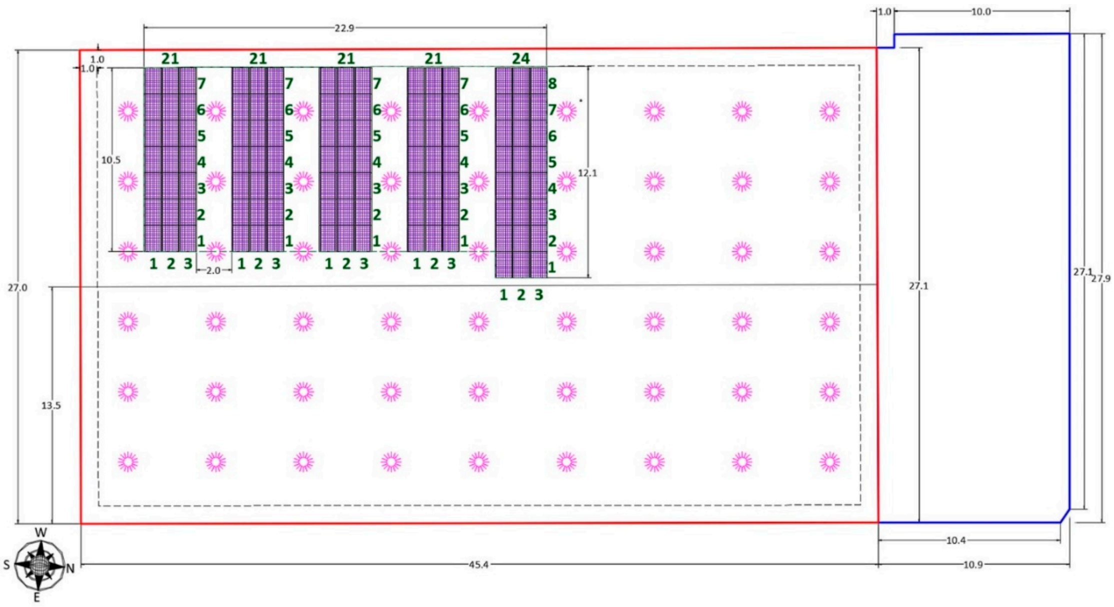

Figure 19. Photorealistic panels and solar tubes siting on the main sport hall's roof.

The 31.8 kW photovoltaic plant will annually produce 40,195 kWh of electricity, which corresponds to 116,565.5 kWh of primary. This annual electricity production leads to a final, total capacity factor of 14.4%. The produced electricity by the photovoltaic plant is 758 kWh higher than the expecting annual remaining electricity consumption, which, practically means, that the indoor sport hall is upgraded to a zero energy facility.

5.5. Summary of energy saving results and key performance indicators

The achieved primary energy saving results are summarized in Table 16. The remaining primary energy negative consumption simply means that there is an electricity production annual surplus from the photovoltaic plant, compared to the annual electricity production in the sport facility. This, in turn, leads to a total annual primary energy saving equal to 100.6%, which, practically, means, that the indoor sport hall is upgraded to a zero energy facility.

Table 16. Primary energy saving results achieved with the proposed energy performance upgrade of the indoor sport hall.

Load / energy use	Load / Primary energy consumption (kWh)		Saving	
	Existing operation	Proposed operation	(kWh)	(%)
Indoor space conditioning load	181,127	71,335	109,792	60.6
Primary energy for indoor space conditioning	217,640.5	49,281.0	168,359.5	77.4
Primary energy for domestic hot water production	93,014.9	21,237.8	71.777,1	77,2
Primary energy for lighting	50,486.7	21,074.0	29,412.7	58.3
Primary energy in circulators and fans	34,244.7	22,774.9	11,469.8	33.5
Photovoltaic plant primary energy production	0	-116,565.5	116,565.5	-
Total annual primary energy consumption	395,387	-2,198	397,585	100.6

In Table 17 the annual diesel oil and electricity saving are presented. The diesel oil consumption is totally eliminated, while, although all the final energy uses are fully transferred to electricity, a 9.3% electricity consumption annual drop is also achieved.

Table 17. Diesel oil and electricity annual saving in the municipal sport centre.

Energy sources	Consumption (L or kWh)		Annual saving	
	Existing operation	Proposed operation	(L or kWh)	(%)
Diesel oil	15,108	0	15,108	100.0
Electricity	77,600	39,437	38,163	49.2

In Table 18 the project's total set-up cost is presented in a comprehensive approach, analyzed for each different proposed category of energy performance upgrade measure.

Table 18. Budget comprehensive analysis of the proposed energy performance upgrade project.

Budget component	Cost (€)
Insulation and stone wool panels	299,495
Installation of new openings	35,697
Indoor space active conditioning systems	226,654
Solar-combi system	101,970
Natural and artificial lighting interventions	123,195
Building Energy Management System (BEMS)	33,656
Reactive power compensation panel	4,487
Photovoltaic plant	127,846
Total	953,000

The annual economic benefit from the implementation of the proposed energy performance upgrade is calculated by accounting the annual electricity and diesel oil saving and by introducing indicative procurement prices. The results are analysed in Table 19.

Table 19. Analysis of the achieved annual economic benefit due to the implementation of the energy performance upgrade.

Energy source	Procurement price (€/kWh - €/L)	Existing theoretical operation		New expecting operation		Economic saving	
		Annual consumption (kWh - L)	Annual procurement cost (€)	Annual consumption (kWh - L)	Annual procurement cost (€)	(€)	(%)
Electricity	0.25	77,600	19,400	39,437	1,479	17,921	92.4
Diesel oil	1.2	15,108	18,130	0	0	18,130	100.0
Total			37.530,0		1.478,9	36.051	96.1

In Table 19 it is clearly seen that it is assumed that currently the sport facility operates on full annual basis and all final energy needs are fully covered. In this way, a common basis will be available for the comparison between the existing and the proposed operation state, which will be configured after the implementation of all the proposed passive and active measures. It should be also clarified that none of the proposed measures has been so far implemented. Additionally, it be also explained that with the annual electricity consumption compensation, achieved by the photovoltaic station operation, the electricity procurement cost is approximately 85% reduced. A remaining 15% procurement cost with regard to the initial amount, which corresponds to the electrical grid use rates, taxes etc, will not be avoided. Conclusively, by accounting all these assumptions and parameters, the energy sources annual procurement cost is impressively 96.1% reduced.

Finally, with the above calculated results, the following typical KPIs can be calculated:

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- Payback period:

It is calculated equal to 26.4 years, by dividing the project's total budget over the annually achieved economic benefit.

- Annual primary energy saving:

As documented in Table 16, the annual primary energy achieved saving is 397,585 kWh, namely 100.6% with regard to the existing annual primary energy consumption.

- Annual Renewable Energy Sources (RES) penetration:

The total contribution of the involved RES technologies to the annual energy demand coverage comes from:

- the production of 40,195 kWh of electricity from the photovoltaic plant, which corresponds to 116,565.5 kWh of primary energy
- the production of 19.692,7 kWh of heat from the solar collectors, which corresponds to 35.804,9 kWh of primary solar radiation, by assuming a typical average efficiency of 55% for the solar collectors.

The total primary energy penetration from the RES technologies is calculated at 152.370,4 kWh. The remaining electricity consumption in the facility is 39.437,1 kWh which corresponds to 114.367,6 kWh of primary energy. By dividing these two primary energy amounts, the RES annual penetration in the facility is calculated at 133.2% with regard to the remaining electricity consumption (before its compensation from the photovoltaic plant).

- CO2 emissions saving:

The annual CO_2 emissions saving is due to the elimination of the diesel oil consumption and the electricity saving and demand compensation with the photovoltaic plant. According to the Greek Directive on the Buildings' Energy Performance [66], the following factors are introduced as the specific CO_2 emissions:

- 0.989 kg CO_2/kWh of electricity
- 0.264 kg CO_2/kWh of primary energy corresponding to diesel oil consumption.

Given the aforementioned factors, the CO_2 emissions annual saving are calculated as shown in Table 20.

Table 20. Calculation of the annual CO_2 emissions saving.

Energy source	CO_2 specific emissions (kg/kWh)	Existing operation		Proposed operation		Electricity & primary energy annual saving (kWh)	CO_2 emissions drop	
		Annual consumption (kWh – L)	Primary energy (kWh)	Annual consumption (kWh – L)	Primary energy (kWh)		(kg)	(%)
Electricity	0.989	77,600	225,038.8	-758	-2,197.3	227,236.2	77,495.4	101.0
Diesel oil	0.264	15,108	170,347.2	0	0,0	170,347.2	44,971.7	100.0
Total			395,386.1		-2,197.3	397,583.4	122,467.0	100.6

6. Discussion

The construction of the under study indoor sport hall was completed in 1995 and since then it constitutes the unique indoor sport facility in the broad area of the Municipality of Minoa Pediadas, hosting a wide cluster of indoor sport municipal activities, with hundreds of participating students - athletes. Additionally, it also hosts the official basketball games of the local sport club in the 2nd national category. It is so conceivable how important this facility is for the local community.

The necessity for the energy performance upgrade of this sport hall is revealed by several facts:

- the use of diesel oil boilers for the heating of the main sport hall and the auxiliary building;
- the lack of any kind of active system for the indoor space cooling of the main sport hall;
- the availability of only one air-to-air heat pump for the cooling of only one specific room (the administrative office) in the auxiliary building;

- the considerably high U-factor values of all constructive elements, which, resulting, particularly for the main sport hall, to the configuration of a very cold indoor environment in winter;
- the high solar gain factor of the semi-transparent polycarbonate panels in the main sport hall, which, in combination with their large surfaces, contribute to the considerable increase of the indoor space temperature in summer;
- the absence of the kind of active system for the production or electricity or heat from renewables;
- the use electrical resistances and diesel oil for domestic hot water production;
- the use of ineffective lighting equipment.

Despite these facts, the local Municipality of Minoa Pediadas had not taken the initiative to proceed to the beginning of the required process for the implementation of the necessary energy performance upgrade, which, sensibly, should be initiated with the accomplishment of the final, application studies.

This opportunity was offered by the first call for the funding of studies for energy transition projects, posted in 2020 by the Consortium of the European Commission's Horizon 2020 project entitled "New Energy Solutions Optimized for Islands" (NESOI). The applicant of the proposal "Sustainable Actions for Viable Energy" (SAVE) was the Minoan Energy Community, currently the largest energy community in Greece. The proposal was among the 30 approved among the 120 submitted. Apart from the work presented in this current article, within the SAVE project the energy performance upgrade study was also accomplished for the municipal sport centre in the town of Arkalochori, which practically includes an outdoor swimming pool centre, an outdoor 8 × 8 football court, tennis and basketball courts. This work is presented in a former article, entitled as Part A, with the same title with the current one. The SAVE project was integrated with the application study of the first smart grid in Crete, with decentralized storage and electricity production from photovoltaics and DSM strategies.

The results of the SAVE project can constitute a pilot for similar cases worldwide. Firstly it highlights the importance of energy saving and the Rational Use of Energy, especially regarding indoor space conditioning and domestic hot water production, where annual energy saving percentages higher than 77% are achieved in the specific study. Secondly, the SAVE project constitutes a success story regarding the collaboration of local municipalities and community-based schemes, such as energy communities, to treat in common significant issues and upgrade important municipal facilities for the local population. It also creates a successful pathway for the implementation of energy transition projects funded by the European Commission, with the active participation of the local communities and authorities. Finally, it constitutes a lively proof that energy transition projects can be optimized, leading to the maximum possible social and economic benefits for the citizens, only through the active involvement of the local stakeholders in their design and implementation phase.

Regarding specifically the technical and economic results of the proposed energy performance upgrade measures, firstly and above all the quite high energy saving percentages on indoor space conditioning and hot water production should be highlighted. Obviously, these percentages are configured as a resultant of both the current, ineffective operation state and the effectiveness of the proposed passive and active measures. The high U-factors of all constructive elements of the building's envelope offers the chance for considerable reduction of the indoor space heating and cooling load. Indeed, the achieved drop in the overall indoor space conditioning load was at the range of 60%.

Additionally, the use of diesel oil, for example, for indoor space heating and hot water production creates high potential for energy saving. The high solar radiation availability offers the favorable environment for the coverage of the heat demand for hot water production with solar thermal collectors. Finally, the introduction of high-efficiency air-to-water heat pumps, together with the proper design of the heating and cooling distribution system, leads to considerable electricity drop for indoor space conditioning. Cumulatively, given all the aforementioned favorable facts and proposed solutions, the achieved primary energy saving for indoor space conditioning and hot water production exceeds 77%.

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Regarding lighting, the innovative feature, given the existing state and the standards in the specific geographical area, is the introduction of the solar tubes for natural lighting. Through extensive photometric calculations, it was proved that the supplied natural lighting through these solar tubes can fully meet the illuminance standards for the indoor sport for most days during the year, even during winter. Additionally, the replacement of all existing and ineffective luminaires and lamps with new LED lamps and floodlights leads to the also impressive annual primary energy saving percentage of 58%.

Finally, having achieved a total primary energy saving for all final energy uses in the sport facility above 70%, the remaining electricity consumption is fully compensated on annual basis with the production of the proposed photovoltaic plant. In this way, the indoor sport hall is upgraded to a zero energy facility.

At this point it should be clarified that this work was accomplished on the assumption that the indoor sport hall, in its current state, operates for the full annual period, covering fully all the imposed final energy needs for the indoor space conditioning, the domestic hot water production, the lighting etc. This assumption was necessary in order to obtain a common reference for the comparison of the existing and the proposed operation.

The SAVE project was awarded by the European Commission with the public award of the "Islands Gamechanger" competition, organized by the NESOI Consortium and the Secretariat of the "Clean Energy for EU Islands" initiative.

7. Conclusions

The work accomplished for the energy performance upgrade of the indoor sport hall in the small town of Arkalochori, Crete, Greece was presented in this article. This work constitutes a part of the energy transition studies accomplished for the project entitled "Sustainable Actions for Viable Energy" (SAVE), which was funded by the European Commission's Horizon 2020 project "New Energy Solutions Optimized for Islands" (NESOI).

All most technically feasible and economically competitive energy upgrade measures were proposed in this work. The current ineffective and energy-consuming operation of the sport facility, together with the effectiveness, the proper design and selection of the proposed passive and active measures, led to considerably high anticipated energy saving percentages. Specifically, all synthetic constructive materials for vertical surfaces and walls are proposed to be replaced with 8 cm thickness stone wool panels. External insulation of 7 cm thickness stone wool sheets is proposed for all reinforced concrete and brick walls vertical and horizontal surfaces. New low-e openings, with synthetic frame and double glazing are proposed. All new U-factors are considerably lower than the upper limit introduced in the Greek Directive on Buildings Energy Performance, leading to roughly 60% drop of the annual indoor space conditioning load. With the introduction of two air-to-water heat high-efficiency pumps and the appropriate design of the hydraulic heating and cooling system, the diesel oil use is eliminated and the primary energy saving for indoor space heating exceed 77% with regard to the current operation state. A solar-combi system, supported with a heat storage tank and a heat pump as a back-up unit is proposed for the production of domestic hot water, leading also to 77% primary energy saving for this particular final energy need, compared to the current state. A solar tubes arrangement ensures natural lighting in the main sport hall during daytime and for the whole year, while the replacement of all the existing ineffective luminaires and lamps with new of LED technology is estimated to lead to a primary energy annual saving of 58% for the lighting needs coverage of the facility. The remaining electricity consumption is fully compensated with the proposed photovoltaic plant, so the indoor sport hall is upgraded to a zero energy facility.

The SAVE project was effortlessly initiated by a community based scheme, the Minoan Energy Community, which configured an integrated proposal for the beginning of energy transition in the local municipal facilities. The Minoan Energy Community adequately traced the real needs of the community and formulated an effective cluster of discrete works, with high added value, energy saving results and social benefits for the local community. For all these reasons, the SAVE project as

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a total constitutes a pilot, lighthouse global example, indicating excellent collaboration between local authorities and community-based, private initiatives.

Abbreviations (alphabetically)

ANN :	Artificial Neural Network
ASHRAE :	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BEMS :	Building Energy Management System
COP :	Coefficient Of Performance
DSM :	Demand Side Management
EER :	Energy Efficiency Ratio
EU :	European Union
GHE :	Geothermal Heat Exchangers
GHP :	Geothermal Heat Pumps
HVAC :	Heating, Ventilation, and Air Conditioning
KPIs :	Key Performance Indicators
NESOI	New Energy Solutions Optimized for Islands
PPR :	polypropylene
RES :	Renewable Energy Sources
RHC :	Radiant Heating and Cooling
RUE :	Rational Use of Energy
SAVE :	Sustainable Actions for Viable Energy
TFM :	Transfer Function Method
VRV :	Variable Refrigerant Volume
W-SAHP :	Water Solar assisted Heat Pump
ZEB :	Zero Emission Building

Nomenclature (in order of appearance)

T_{amb} :	the ambient temperature
U:	the thermal heat transfer factor (the so-called U-factor) (in $W/m^2 \cdot K$)
h_c :	the heat convection factor for ambient air horizontal flow with average velocity of 5 m/s (10 $W/m^2 \cdot K$)
h_{rw} :	the heat radiation factor
c_p :	the water specific heat capacity (4.187 kJ/kg·K)
T_{sw} :	the water temperature in the water supply network
h_{fg} :	the specific latent heat of water (2,441.7 kJ/kg at 25 ^oC)
d_j :	the thickness of the structural material j of the opaque constructive element
k_j :	the thermal conductivity factor of the structural material j of the opaque constructive element
h_i :	the heat transfer factor from the inner space and towards the outer space h_o (or conversely in summer)
h_o :	the heat transfer factor towards the outer space (or conversely in summer)
ACH :	air changes per hour
T_{in} :	the indoor space temperature
$\dot{m}_h$:	the domestic hot water consumed mass flow rate
T_{hw} :	the hot water required temperature
P_{el} :	the electrical power consumption in the heat pump
Q_h :	the indoor space heating load
h_w :	the thermal convection factor of still water, equal to 50 $W/(m^2 \cdot K)$
Q_c :	the indoor space cooling load
T_{sol} :	the supplied water temperature from the solar collectors
T_{st} :	the stored water temperature in the heat storage tanks

 doi:10.20944/preprints202308.1119.v1

T_{hw} : the required hot water temperature
N_{SC} : the solar collectors' total number in the system
C_{SC} : the procurement price of one solar collector, adopted equal to 450 €
N_{ST} : the heat storage tanks' number in the system, with storage capacity of 2000 L
C_{ST} : the procurement price of one 2000 L heat storage tank, adopted equal to 6000 €
E_{SC} : the annual heat demand coverage for domestic hot water production from the solar-combi system
T_{LP} : the solar-combi system's life period, adopted equal to 15 years
c_{th} : the heat production specific cost from the solar-combi system

Author Contributions: Conceptualization, Katsaprakakis, D.A.; methodology, Katsaprakakis, D.A. and Giannopoulou, E.; software, Katsaprakakis, D.A. and Zidianakis, G.; validation, Katsaprakakis, D.A. and Kartalidis, A; formal analysis, Katsaprakakis, D.A. and Kartalidis, A; investigation, Katsaprakakis, D.A., Papadakis, N., Giannopoulou, E.; Dakanali, E. and Yiannakoudakis, Y.; resources, Katzagiannakis, G.; data curation, Stavrakakis, G.; writing—original draft preparation, Katsaprakakis, D.A. and Papadakis, N.; writing—review and editing, Katsaprakakis, D.A. and Papadakis, N.; visualization, Katsaprakakis, D.A. and Papadakis, N.; supervision, Katsaprakakis, D.A.; project administration, Katsaprakakis, D.A. and Dakanali, E.; funding acquisition, Katsaprakakis, D.A. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the European Commission's Horizon 2020 project entitled "New Energy Solutions Optimized for Islands" (NESOI), under the grant number EL-056-2021-006– and the sub-project entitled "Sustainable Actions for Viable Energy" (SAVE).

Data Availability Statement: Data sharing not applicable. No new data were created or analyzed in this study. Data sharing is not applicable to this article.

Acknowledgments: The authors and the working team of this project are grateful to the NESOI Consortium for the approval of the SAVE proposal and for their overall constribution and support for the implementation of the project.

Conflicts of Interest: The authors declare no conflict of interest.

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