Agronomy Research **21**(X), xxx–ccc, 2023
https://doi.org/10.15159/AR.23.064

Large building facilities towards energy transition

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Received: February 10th, 2023; Accepted: May 28th, 2023; Published: July 6th, 2023

Abstract. Large buildings complexes present significant amounts of energy consumption. Sport centers compose a more special case of large volume buildings, compared to other facilities. This is related not only to the specific requirements of the thermal environment regarding the type of activities taking place as well as the considerable loads enforced by the presence of people. The aim of this paper is to evaluate the energy consumption of a Sports center, through energy audits, extract energy baselines and propose energy-saving interventions and RES utilization. More precisely, a cost-benefit analysis will be carried out to assess the energy production and the relevant contribution of the potential energy interventions. As a result, the priority list of proposed measures will be extracted, with all the data regarding energy gains, capital costs, and cash flows. Particularly, a capital budgeting analysis of each measure will support the final decision of a holistic energy approach at the specific building facilities.

Key words: energy baselines, energy saving interventions, energy transition.

INTRODUCTION

Nearly or net zero energy buildings have become a demanding topic of research, as the building sector is the largest contributor of the total energy use in the European Union (EU). Approximately 40% of energy global consumption and almost 55% of electricity consumption are due to the building sector (Directorate-General for Energy, 2019). From 2021, the European Union (EU) requires its member states to guarantee that all new buildings will be nearly zero-energy buildings (Paspatis et al., 2022).. Improving energy efficiency and utilizing renewable energy in buildings is one of the paths to achieving climate and energy goals towards sustainable energy transition (Rhodes, 2008). According to the current energy usage and emission intensity, the carbon emission share of the building sector will be up to 50% by 2050 (Changchun et al., 2022).

Among all building typologies, sports centers comprise spaces of special interest, concerning the type of activities taking place, the presence of people of different type of activities, the building geometries (spaces of large volume), while critical is the thermal comfort level. For example, famous sports events, demands for indoor space heating, demand for hot water, swimming pools heating, extended opening hours of the facilities, etc. (Da Costa Duarte & Rosa-Jiménez, 2022), (Nguyen & Aiello, 2012), (Sheikhi, 2020), are factors that reflect onto energy consumption. Hence, the built environment consumes large amounts of energy from non-renewable energy sources, which are responsible for producing major global warming gases (Sheikhi, 2020) which is important to reduce. Moreover, as mentioned above, the energy consumption in the built environment is directly connected to the user behavior in the building. Human-induced activity is responsible for the warming of the atmosphere, ocean and land as states the release of the 2021 report from the Intergovernmental Panel on Climate Change (IPCC) (Global Status Report For Buildings and Construction, 2021). Therefore, knowing the detailed occupancy information in the building environment is an important parameter for efficient energy use.

The most effective available technologies with alternative energy sources and building energy strategies to restrain energy use and CO_2 emissions have become implemented through passive and active technologies. Some of those that have been highlighted for their application in energy saving are among others, the building orientation (Mina-Casaran et al., 2020), envelopes insulation (Faraj et al., 2022), phase change materials usage, green roofs (Pérez-Lombard et al., 2017), photovoltaics technology integration (Nguyen & Aiello, 2012; Zhitong et al., 2021).

In this paper, a sports center's energy evaluation is considered and its applicability towards a sustainable energy transition is emphasized. The case study investigates such an approach of Olympic Athletic Center of Athens, Greece. More specifically, the energy consumption is estimated through energy audits with the aim of extracting energy baselines, propose energy-saving interventions and RES utilization to introduce the self-sufficiency concept.

MATERIALS AND METHODS

The Olympic Athletic Center of Athens (OAKA) is one of the most complete European athletic complexes, with a total floor area of 1,000,000 m^2. OAKA is flanked by many sports facilities such as the Olympic Stadium, the Indoor Basketball Area and the Indoor Training Hall of the Olympic Indoor Sports Center, the Olympic Aquatic Center (indoor and outdoor), the Olympic Tennis Center and the Olympic Velodrome.

This section presents the energy profile analysis of the electrical and thermal needs of the facilities.

Internal Electrical Grid and Load Brief Analysis

The load demand of OAKA'S facilities is exclusively served by the Hellenic Electricity Distribution Network (HEDNO). Alternative energy sources like Renewable Energy Systems are a proposal we need to focus on, to absorb the no greenhouse gas emissions electricity produced from Renewables.

The electrical grid consists of three (3) central medium voltage (20 kV) substations D1, D2 and D3 that serve the electrical loads. More precisely, D1 serves the facilities of the central stadium, D2 serves part of the lighting of the main stadium, the tennis courts, and the lighting of the surrounding area, while D3 serves the indoor gym, the swimming pool, and the cycling track.

Fig. 1 depicts the network layout and the interconnection of these three (3) nodes.

The load demand at the level of 0.4 kV is served by twenty-two (22) 20 kV/0.4 kV substations, as is shown in Fig. 2. The main three (3) HV/MV substations are marked in red, and the MV/LV substations of the complex are marked in black.

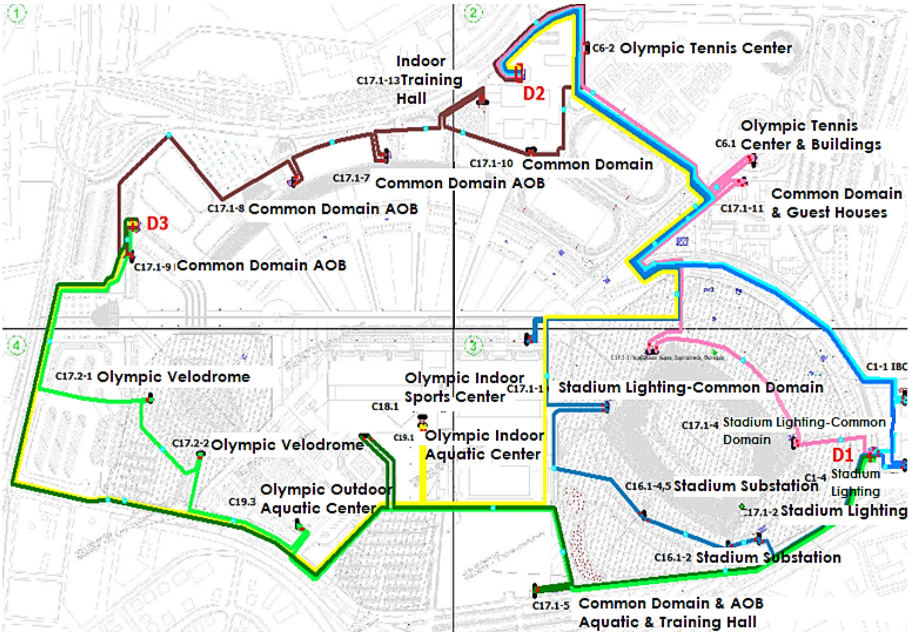

Figure 1. Layout Distribution Network.

The energy needs are mainly determined by lighting (indoor and outdoor) of the surrounding area of the complex, heating-cooling consumption (air conditioning), domestic hot water (pool water heating network) and electrical consumption from the inside of the facilities such as staff offices.

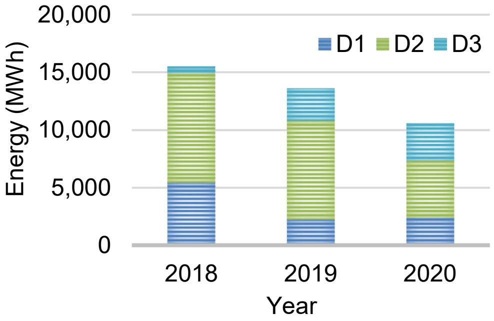

Figure 2. Annual Electricity Consumption.

Fig. 2 depicts the annual electricity consumption for the years 2018, 2019, and 2020, respectively. Obviously, substation D2 is the one with the highest consumption which serves the tennis courts and the lighting of the surrounding area of the stadium. The D3 substation under normal operating conditions serves facilities with particularly high energy usage. A significant decrease, 31.58% from 2018 and 22.01% from 2019 occurred in 2020 due to the COVID-19 restrictions applied in sports.

Moreover, Fig. 3 depicts the monthly consumption of the three examined years. During the winter months and in the summer period electricity load reached the highest as the demand peaks, cause of the need of heating and cooling respectively and due to the frequency of sporting events. In 2018 the month with the highest consumption was July while in 2019 it was January. A significant decrease in the total energy consumption is observed in March 2020, when the outbreak of COVID-19 was started. However, a decrease is also observed in the annual (12.27% Fig. 2) and monthly (18.5% highest in October Fig. 3) electrical energy consumption for the year 2019 compared to the corresponding 2018.

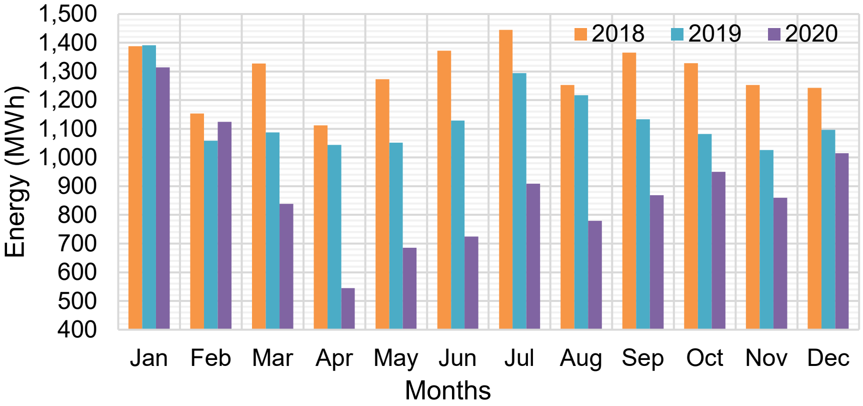

Figure 2. Annual Electrical Energy Consumption for the years 2018–2020.

Energy Base Lines Extraction

The Olympic stadium also has a central natural gas substation, which both serve space and water heating of the complex's swimming pools. The following Table 1 shows the annual heat and electrical consumption.

Table 1. Heat and Electrical Energy Consumption for the years 2018–2020

Months	Natural Gas			Electricity		
	2018	2019	2020	2018	2019	2020
1	2,965,994.44	3,349,132.64	3,230,879.19	1,388,110.80	1.290,752.80	1,315,142.00
2	2,438,092.36	2,072,005.76	2,871,674.20	1,154,196.00	858,696.40	1,123,972.80
3	2,212,129.01	2,191,529.57	1,498,372.85	1,326,572.40	1,087,336.50	838,017.60
4	1,491,382.22	1,885,611.58	939,020.57*	1,072,557.20	1,044,373.20	544,932.00
5	1,020,688.44	1,235,845.63	802,029.66	1,272,919.20	1,051,177.20	685,978.80
6	728,728.53	603,903.10	665,038.76	1,372,318.80	1,129,221.60	583,632.06
7	365,781.28	502,829.33	446,809.66	1,445,930.40	1,295,994.00	908,628.00
8	65,451.49	153,982.81	151,510.341	1,252,384.80	1,215,304.80	779,102.40
9	883,588.20	676,160.49	752,983.624	1,365,526.80	1,133,431.20	869,697.60
10	1,516,200.31	1,082,683.52	1,077,426.275	1,328,104.80	1,082,157.60	949,893.60
11	2,063,563.90	1,473,522.02	1,735.623.228	1,253,139.20	1,025,863.80	860,011.20
12	2,932,301.48	2,493,998.31	1,884,119.179	1,242,014.40	1,096,716.00	883,514.40*

According to comparison electrical energy consumption fluctuates at almost the same levels every month in compare with the corresponding natural gas, which is increased, mainly in the winter months, a fact which is also reflected in the subsequently exported energy baselines. Hence, a general conclusion is that the consumption of natural gas depends entirely on the ambient temperature, while the electrical loads mainly depend on the lighting. Consequently, it is considered appropriate to extract two (2) baselines of the existing situation, one for thermal loads and one for electrical loads.

Thus, the energy baselines were extracted from the processing of the recorded energy data consumption. The analysis of the energy consumption of the stadium was carried out by using hourly data available from HEDNO.

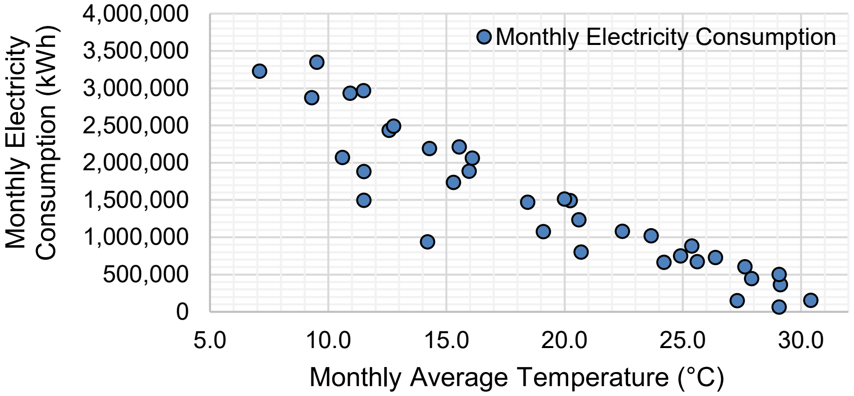

Figure 4. Correlation of Temperature and Natural gas.

When warmest days occurs and daily temperatures start to climb, July and August which are the hottest months statistically, the energy demand is low, as shown in Fig. 4 and Fig. 5, because there is no need for heating.

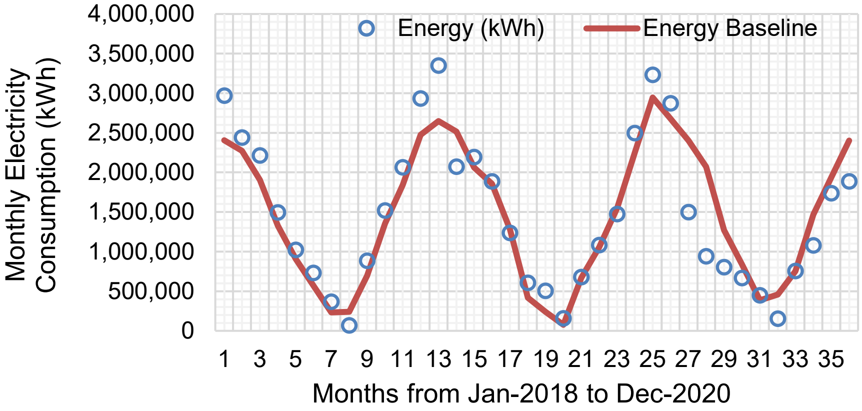

Figure 5. Natural Gas Baseline Consumption.

Cold weather (low temperatures) increases demand for heating, consequently the energy demand is high. Subsequently, the electrical energy demand of such high energy consumers like sports centers is steadily high during the examining period, as shown in Fig. 6 and Fig. 7, and does not show any strong correlation with the respective temperature, nor does the correlation improve by including the rest of the meteorological data. The values of the final extracted baselines are presented in Table 2.

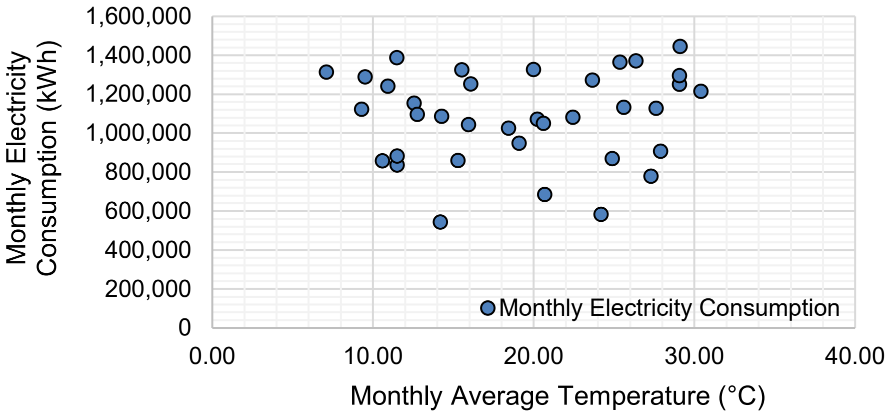

Figure 6. Correlation of Temperature and Electricity Energy Consumption.

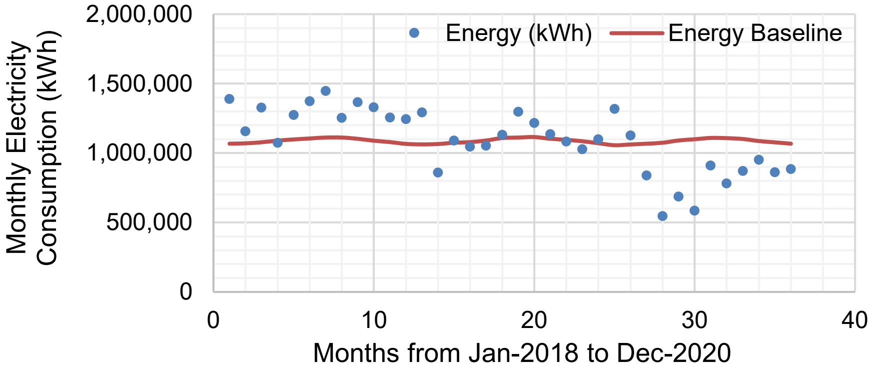

Figure 7. Electrical Energy Baseline Consumption.

Energy saving interventions and RES utilization

Effective energy management requires the use of tools and methodologies that support the strategic decision making process of selecting energy saving measures, which are viable and environmental friendly. In this section, since energy consumption is one of the main components of the energy balance of the existing and newly designed buildings complexes energy saving interventions and RES utilization will be proposed. Based on the number of existing buildings and the related opportunities to improve energy efficiency, an important issue is to propose effective and low cost interventions that allow to reduce heat and electrical energy consumption.

The proposed energy interventions initially concern an energy upgrade of large electromechanical (ELMCH) equipment such as replacement of conventional lamps (indoors and outdoors) with LEDs technology lamps, which can significantly reduce operating costs, by use less energy and they last remakrably longer. LED are considered as the sustainable alternative solution to achieve energy savings objectives in the lighting sector and offers outstanding prospects for progress, especially for smart control. Subsequently, replacement of central air conditioning units (CHUs) and replacement of existing pumps results in high energy efficiency.

Table 2. Natural gas and Electricity Consumption Baseline for the years 2018–2020

			A		B	
Months/ Years	A/A	Temperature (°C)	Energy (kWh)	Energy baselines	Energy (kWh)	Energy baselines
Jan-18	1	11.5	1,388,110.80	1,067,450.30	2,965,994.44	2,405,117.30
Feb-18	2	12.6	1,154,196.00	1,070,177.10	2,438,092.36	2,272,024.50
Mar-18	3	15.5	1,326,572.40	1,077,658.70	2,212,129.01	1,906,847.40
Apr-18	4	20.2	1,072,577.20	1,089,522.00	1,491,382.22	1,327,796.40
May-18	5	23.7	1,272,919.20	1,098,144.50	1,020,688.44	906,931.40
Jun-18	6	26.4	1,372,318.80	1,105,006.50	728,728.53	571,997.60
Jul-18	7	29.1	1,445,930.40	1,111,921.10	365,781.28	234,495.40
Aug-18	8	29.1	1,252,384.80	1,111,811.20	65,451.49	239,857.40
Sep-18	9	25.4	1,365,526.80	1,102,467.10	883,588.20	695,946.20
Oct-18	10	20.0	1,328,104.80	1,088,912.70	1,516,200.31	1,357,539.00
Nov-18	11	16.1	1,253,139.20	1,079,049.10	2,063,563.90	1,838,981.50
Dec-18	12	10.9	1,242,014.40	1,066,038.50	2,932,301.48	2,474,029.10
Jan-19	13	9.5	1,290,752.80	1,062,482.50	3,349,132.64	2,647,599.40
Feb-19	14	10.6	858,696.40	1,065,208.50	2,072,005.76	2,514,542.10
Mar-19	15	14.3	1,087,336.50	1,074,489.20	2,191,529.57	2,061,551.30
Apr-19	16	16.0	1,044,373.20	1,078,725.40	1,885,611.58	1,854,782.90
May-19	17	20.6	1,051,177.20	1,090,442.50	1,235,845.63	1,282,868.00
Jun-19	18	27.6	1,129,221.60	1,108,142.90	603,903.10	418,908.90
Jul-19	19	29.1	1,285,994.00	1,111,803.10	502,829.33	240,254.60
Aug-19	20	30.4	1,215,304.80	1,115,163.80	153,982.81	76,216.70
Sep-19	21	25.6	1,133,431.20	1,103,059.90	676,160.49	667,011.20
Oct-19	22	22.4	1,082,157.60	1,095,064.50	1,082,683.52	1,057,266.30
Nov-19	23	18.4	1,025,863.80	1,084,964.60	1,473,522.02	1,550,247.10
Dec-19	24	12.8	1,096,716.00	1,070,676.80	2,493,998.31	2,247,633.00
Jan-20	25	7.1	1,315,142.00	1,056,379.40	3,230,879.19	2,945,488.90
Feb-20	26	9.3	1,123,972.80	1,061,929.10	2,871,674.20	2,674,608.00
Mar-20	27	11.5	838,017.60	1,067,478.80	1,498,372.85	2,403,727.10
Apr-20	28	14.2	544,932.00	1,074,289.80	939,020.57	2,071,282.40

Table 2 (continued)

	May-20	29	20.7	685,978.80	1,090,686.60	802,029.66	1,270,962.40
	Jun-20	30	24.2	583,632.06	1,099,515.70	665,038.76	840,005.60
	Jul-20	31	27.9	908,628.00	1,108,849.20	446,809.66	384,433.10
	Aug-20	32	27.3	779,102.40	1,107,335.70	151,510.34	458,309.70
	Sep-20	33	24.9	869,697.60	1,101,281.50	752,983.62	753,816.20
	Oct-20	34	19.1	949,893.60	1,086,650.50	1,077,426.28	1,467,956.70
	Nov-20	35	15.3	860,011.20	1,077,064.70	1,735,623.23	1,935,841.90
	Dec-20	36	11.5	883,514.40	1,067,478.80	1,884,119.18	2,403,727.10
A	b1	b0	Mean	1,086,870.06	1,084,678.30		
	2,522.60	1,038,469.10	RMSE	234,844.10	Minimum Target		
	0.44	8.94	<-tStud/R2->	0.006	21.65%		
B	b1	b0	Mean			1,457,239	1,564,220.20
	-123,127.70	3,819,695.50	RMSE			234,844.10	Minimum Target
	-13.52	20.59	<-tStud/R2->			0.843	23.98%

Furthermore, the installation of Combined Heat and Power (CHP) through photovoltaic (PV) and solar thermal systems (STE) and more specifically 1 MWe CHP, 3 MW photovoltaic park and solar thermal power 832 kWh will provide additional benefits. Also, the installation of electrical storage systems such as a battery system with 4.25 MW power and a storage capacity of 10 MWh allows better use of renewable energy, ensure that you can use power whenever you need it and reduce the carbon footprint. As well as the operation of a smart microgrid through the conversion and use of existing gensets to support the planned microgrid.

All the above-mentioned interventions must be accompanied by the automated and optimized operation of the sports center ELMCH equipment through the installation of a new Building Management System (BMS), by the development and operation of a SCADA system that will have the responsibility of supervising and controlling all the electricity and thermal energy production units of the proposed microgrid.

Finally, the development of a network of electric vehicle chargers at about forty (40) chargers and eighty (80) seats parking that will serve the data future needs of OAKA.

RESULTS AND DISCUSSION

The integrated management plan propose to upgrade a significant part of the existing electromechanical (ELMCH) equipment, the exploitation of RES for thermal and electricity production, smart energy management and saving, as it is shown in Table 3. Taking into account the consumptions of the year 2021, the energy upgrade of ELMCH effects an immediate reduction in electricity consumption by 39.4% with improving energy efficiency by replacing the high energy consuming ELMCH facilities of the OAKA, saving 5,139 MWh. The corresponding reduction in emissions exceeds 850 tons of CO_2. The improvement of the energy efficiency of the respective mechanical facilities of the sport center and the envelope upgrade of the main stadium, directly results in a reduction in consumption and thermal energy of more than 23% and consequently in natural gas consumption equal to 3,846 MWh.

Regarding the total production of the electric power units of electric power, that have an installed capacity equal to 18.81 MW, including battery inverters (4.25 MW), they add up to 19 GWh. The self-sufficiency of electrical and thermal energy through the installation of a photovoltaic park (PV) with a capacity of 3 MW, a cogeneration system (CHP) with a capacity of 1 MW, an electric storage system with batteries of a nominal capacity of 10 MWh, a solar thermal field of 832 kWh as well as the exploitation of the existing sport center power plants 7.56 MW is a key target.

CONCLUSIONS

The study goal is to measure energy consumption in large type buildings such as sport centers and examine energy efficiency measures towards energy transition. The study aims at determining the amount of energy consumed both per month and per year in order to propose an innovative intelligent decision support model for the identification of the need for intervention and further evaluation of energy saving measures in an existing large-scale building, based on data like loads, demands and user requirements.

The results show that upgrading the lighting system with new LED technology lighting systems can reduce the lighting electricity consumption by 50–75% compared

Table 3. Energy Saving Interventions

a/a	Intervention Description	Energy saving (%)	Thermal energy saving (%)	Thermal energy reduction	Electrical energy saving (%)	Electrical energy reduction
1	Power Elecriticity Heat Trigeneration System 1 MWe & 1 MWth	14.0%	14.0%	2,333 MWh	14.0%	1,834 MWh
2	Replacement of conventional lighting in playing fields with new LED technology	8.8%			8.8%	1,147 MWh
3	Buldings Energy Management Systems (BEMS)	2.5%	2.5%	415 MWh	2.5%	327 MWh
4	Interventions in the Domestic Hot Water (DHW) production facilities of the Swimming pool (heating) and Basketball courts	4.8%	4.8%	793 MWh		
5	Interventions in the DHW facilities for Indoor Training	0.6%	0.6%	95 MWh		
6	Interventions in the DHW facilities for Dopping	0.1%	0.1%	10 MWh		
7	Interventions in the Air Conditioning facilities of the Indoor Basketball courts	0.2%			0.2%	20 MWh
8	Interventions in the Air Conditioning facilities of Dopping Control	0.2%			0.2%	24 MWh
9	Interventions in the Air Conditioning facilities of the main center	0.2%			0.2%	31 MWh
10	Replacement of existing pumps with new high energy efficiency	2.0%			2.0%	261 MWh
12	Replacement of conventional lamps (indoors and outdoors) with LEDs technology lamps	3.9%			3.9%	513 MWh
13	Interventions in the Air Conditioning facilities of indoor Swimming pool and Basketaball court	7.5%			7.5%	983 MWh
			23.1%	3,846 MWh	39.4%	5,139 MWh

to old lighting systems. The improvement of Domestic Hot Water (DHW) production facilities will ensure more efficient operation of the installation and the ability to cover partial or total loads with hydraulic isolation or reconnection of part of the available boilers. The improvement of central air-conditioning-heating facilities will ensure a better level of efficiency of the installation, since modern equipment will show better EER coefficients (> 3.2), better operation in partial loads and satisfactory back-up in case of failure of one or more of the five installed coolers. The replacement of energy-consuming pumps-circulators with corresponding ones of new technology is expected to bring about a spectacular result of reducing installed power with direct effects on the total energy consumption.

Proper energy planning is essential to optimize the implementation of EE measures considering the resources available and the potential energy savings. Combining renewable energy integration with the implementation of EE measures is a good strategy for municipalities to improve the environmental performance of their public buildings and to overcome barriers.

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