MINARET

NETWORKING FOR THE FUTURE

ENERGY EFFICIENCY ASSESSMENT – TUNISIA

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1. Executive Summary

The Royal Scientific Society (RSS) / National Energy Research Center (NERC) conducted an energy assessment for the Monastir Municipality in Tunisia. The RSS / NERC team exerted huge efforts to compile and reconcile all the provided data, measurements and outcomes that took place during the audit stage, in order to come up with the final audit report, that will detail all identified energy saving measures with all its related analysis to demonstrate the benefit of having these measures.

2. Introduction

2.1 About MINARET Project

The MENA Region Initiative as a model of the NEXUS Approach to Renewable Energy Technologies (MINARET), is a project aimed to address the following three key issues:

renewable energy technology and energy efficiency, water management and food security with various cross cutting themes; gender equality, women empowerment and socio-economic dimension.

Many MENA countries, including Jordan, Lebanon and Tunisia are facing several challenges. These include a global economic downturn, regional upheavals and instability (such as the ongoing Syrian crisis), acute scarcity of energy and water resources, growing energy needs, and a fast-growing population that is demanding a better standard of living and adequate solutions to rising prices and unemployment. All of these challenges are significantly impacted by near total dependency on imported hydrocarbon energy sources as well as the arid and extremely variable climate, which are putting huge pressures on available energy, water and food resources.

2.2 Energy situation in Tunisia

Since 1990, the Tunisian primary energy consumption has increased in a roughly linear way, with approximately 4,500 k toe in 1990, 6,700 k toe in 2000 and 8,300 k toe in 2010 (without biomass). The gas sector represented 55 % of the primary energy supply in 2012. As a result, the share of oil, including crude oil and petroleum products, has slightly decreased. The share of coal and peat has always been minimal and now reached zero. The amount of biofuel and waste slightly increased (58 PJ in 2011), and currently represents 15 % of the primary energy supply. In 2014, primary energy consumption was about 107,000 GWh without biomass.

The Tunisian energy situation has drastically changed in the last two decades. Resulting from the economic development, primary energy demand has risen in a significantly steeper way than production. Consumption nearly doubled within 20 years between 1992 and 2012 from 4,500 k toe to 8,500 k toe. Between 1990 and 2000, consumption increased at a rate of 6.2%/year. Between 2000 and 2005, demand grew by 4.6%/year and between 2005 and 2009, annual demand growth slowed to 3.7%, mainly due to energy efficiency measures. In 2014, primary energy consumption was 9,200 k toe (without biomass), of which 46% was provided by oil products, 53% was provided by natural gas and 1% by renewable energies.

Oil production decreased between 1980 and 2012 from 120,000 to 67,000 barrels per day. Gas production, however, increased from 20 billion cubic feet in the early 1980s to 68 billion cubic feet in 2012. An overall increase in domestic primary energy production from 5,400 k toe in 1900 to 7,000 k toe in 2012 could not follow the sharp rise in demand.

Tunisia, a net energy exporter until 2000, has become a net importer. In 2014, 49% of natural gas consumption (2,300 k toe) was covered by domestic production. The remaining 51% (2,400 k toe) was imported from Algeria.

The energy sector is heavily subsidized in Tunisia. Subsidies for natural gas as well as electricity started a sharp increase in the early 2000s. In 2012, energy subsidies amounted to 5,600 million TND (3,100 million EUR), i.e. 20% of public budget or 9% of GDP. Whereas energy subsidies only represented 3% of GDP in 2005. This rise in subsidies is not sustainable for the State and has several negative effects on public spending such as a decreasing budget for public investments. Subsidizing procedures remain non-transparent. The subsidy system is composed of indirect and direct subsidies. Indirect subsidies are the differences between supply costs of crude oil and gas for the State, and the selling prices to the two public operators STIR for oil and STEG for natural gas. Direct subsidies are subsidies made directly by the State to STIR and STEG in order to offset their deficits.

Renewable energy

Currently, renewable energy plays a minor role in the energy supply. The use of solar energy for thermal purposes is widespread in Tunisia and can be regarded as a success story. Since its launch in 2005, the ANME program "Prosol Thermique", meant to promote the installation of solar water heaters, has led to an installed capacity of 487,853 m^2 in 2012.

Regarding grid-connected renewables, the total installed capacity of renewable energy was an estimated of 312 MW in early 2016 (245 MW of wind energy, 62 MW of hydropower and 25 MW of PV), that was 6% of the total capacity. In terms of electricity production, this meant 3% of this an annual production in 2013: 2.6% (357.8 GWh) from wind turbines and 0.4% (60.1 GWh) from hydropower.

There are two large wind parks in Tunisia, both operated by state utility STEG, one in the region of Bizerte in Metline and Kechabta with a capacity of 190 MW operational since 2012; and one in the region of Sidi Daoud, with a capacity of 55 MW, built in 3 phases between 2000 and 2009.

As for photovoltaics, there was a total capacity of 25 MW as of early 2016, mostly small-scale private installations most of whose capacity ranges between 1 kW and 10 kW. In low voltage, in the residential sector the capacities range from 1 kW to 17 kW and in the commercial sector capacities are between 10 kW and 30 kW. In medium voltage, capacities in commercial sector range between 25 kW and 100 kW. As of early 2015, there were only three operational PV installations with a capacity of at least 100 kW: a 149 kWp installation in Sfax, a 211 kWp installation operated by the Tunisian potable water supply company SONEDE and a 100 kWp installation in the region of Korba, both connected to the medium voltage, and realized by Tunisian installer companies.

The first large scale solar power plant of a 10 MW capacity, co-financed by the German Development Bank (KfW) and the EU's Neighborhood Investment Facility (NIF) and implemented by STEG, is due 2018 in Tozeur. Regarding the off-grid use of renewable energies, 11,000 decentralized PV systems have been installed.

2.3 Energy situation in Monastir

Monastir is a city on the central coast of Tunisia, in the Sahel area; it is 162 kilometers south of Tunis. Traditionally a fishing port, Monastir is now a major tourist resort. Its population is about 93,306. It is the capital of Monastir Governorate. Monastir enjoys a dry Mediterranean climate with hot summers, extremely mild winters, lots of sunshine and low rainfall year-round. The city sits in the northeast of Tunisia, on its central coast. It is milder than inland areas of Tunisia, forty percent of which is part of the Sahara. In the summer, while humidity is low, the soaring heat can still be hard to handle. The average high temperature of 29 °C in June skips past the 30 °C mark in the middle of the month and climbs up to 33 °C in July and August. As for education, the University of Monastir has more than 30,000 students and the largest colleges are: the Faculty of Science, followed by the Faculty of Economic Sciences and Management, and the Higher Institute of Biotechnology respectively. The University has five faculties, nine institutes and two schools.

3. RSS/NERC Energy Assessment Methodology

The energy assessment in Monastir municipality in Tunisia was conducted by the RSS/NERC team to evaluate the current situation for several municipality facilities and to identify the possible energy saving measures through the improvement of the energy efficiency in these facilities. The RSS/NERC team identified possible renewable energy systems that can be installed for these facilities.

Several meetings were conducted with different stakeholders and main entities within the municipality in order to collect the needed information to evaluate the energy situation of the municipality.

4. Analysis and Findings

The following facilities are under the municipality administration:

1. Main Municipality Building.
2. Mustapha Ben Jannet Monastir Stadium - Olympic Complex.
3. Salle Olympic Mohammad Mzali Monastir - Closed Basketball Arena.
4. Central Market.
5. Municipal Warehouse.
6. Public Lighting Grid.
7. Water Pumping Station.

4.1 Municipality Main Building

General description

The Monastir Municipality building is located in the middle of the Al-Monastir city. The building consists of two buildings and the utilized area equals to (1500 m^2) including two floors and 30 offices. Total number of employees working in the municipality is 80 and operating hours around eight. There are many facilities under the municipality's administration within its boundaries, including the municipality building, street lighting, pumping water station, wastewater treatment station, waste separation plant, central market and football playground.

Electrical System

Table 1 shows the details of the electric equipment in the main municipality building with its associated load. Table 2 shows the lighting system in the main building.

Table 1: Municipality main building equipment

Equipment	No.	Total Load (Kw)
PC	78	254.55
Printer	73	
Copier	6	

Tv (Screen)	2	
Water Cooler	7	
Ac (1 Ton)	120	
Server	4	
Fax	1	
Receiver	1	
Motor (0.5 Kw)	2	
Motor (5.5 Kw)	1	
Motor (11 Kw)	1	
Fan	4	

Table 2: Main building lighting system

Type	No. of Connected Lamps	Load (Kw)	Total Load (Kw)
Fluorescent T8 36w	202	10.1	32.1
Fluorescent T8 18w	418	10.5	
CFL	112	1.9	
Incandescent 60w	16	1.0	
Incandescent 40w	148	5.6	
HPS 280w	3	0.8	
Led Units	160	2.0	

Mechanical System

After site investigations and discussions with responsible staff at the Municipality; it was considered that the municipal building envelope has double wall construction, considering its composition as follows: air, plaster, 10 cm concrete, 5 cm insulation, air cavity, 15 cm concrete, 2 cm plaster and air, which is more efficient than the single wall construction (U-value for the double wall less than for the single wall). The windows in the building envelope are single glazed and some of the windows have cracks, which allows a big amount of heat loss from infiltration.

The building depends – mainly, on split units (all offices) for cooling and heating, where there are 120 split units that are of non-inverter technology types. The capacity of spilt units is 1 ton each.

Non-inverter technology: the non-inverter air conditioner system is a model that operates by simply being switched on or off and allows controlling of temperature. Rather than allowing the compressor to run at a full power all the time it is on, the compressor motor here controls the compressor as needed. A constant amount of energy is delivered to the compressor, which causes it to run at a fixed speed. Figure 1 shows a split unit installed in the building.

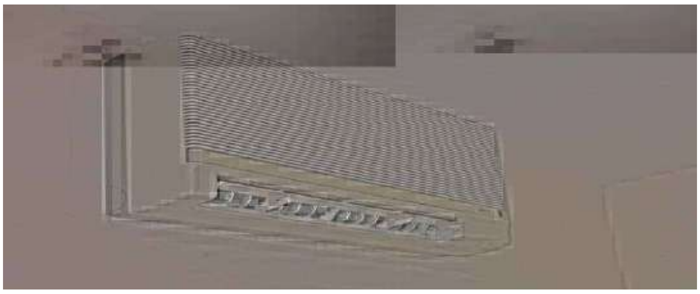

Figure 1: Air conditioning (split unit) from the site

Furthermore, the VRF system is used in the big halls in the municipality building to supply the halls with air-cooling. It is located on the roof of the building; it was observed that the insulation of the system was good, but the filter was very dirty and the external fans are directly facing the sun. Figures 2 and 3 show the VRF system for the municipality building. The VRF system is a multi-split type air conditioner, which uses variable refrigerant flow control to provide customers with the ability to maintain individual zone control in each room and floor of a building.

Figure 2: VRF system

Figure 3: VRF system from the site

Total annual energy consumption of split units is (161,925.12 kW) and the air volume of VRF system is (29,500 m^3/h), motor capacity is 11 kW, another VRF system is (29,500 m^3/h), and motor capacity is 5.5 kW.

4.2 Mustapha Ben Jannet Monastir Stadium - Olympic Complex

General description

The Mustapha Ben Jannet Monastir Stadium - Olympic complex was opened in 1958, it is a multi-use stadium in Monastir, Tunisia. The Olympic complex consists of three buildings: the football stadium, swimming pool and basketball stadium. The utilized area equals to (12280 m^2), the total number of employees working at the Olympic complex is 77 and the daily operating hours is around eight.

The Olympic complex is currently used by the Monastir Sports Federation and hosted some of the African Nations Cup games in 2004. The stadiums accommodate 20,000 spectators.

The Olympic complex includes three buildings: the football stadium; swimming pool and basketball stadium. Figure 4 hereunder shows the football stadium.

Figure 4: Football stadium

Electrical system

Football stadium

Table 3 shows the details of the lighting system at the football stadium in the Olympic complex. The breakdown of this system is shown in Figure 5 hereunder. It can be noticed that the highest share of the load is related to the high-pressure sodium lamps with power rating of 2000W.

Table 3 Football stadium lighting system

Type	No. Of Connected Lamps	Load (Kw)	Total Load (Kw)
T8 Fluorescent 36w	248	12.4	580.94
T8 Fluorescent 18w	32	0.8	
Halogen Spot 15w	100	1.5	
High Pressure Sodium 250w	36	10.44	
High Pressure Sodium 400w	41	18.778	
High Pressure Sodium 1000w	25	27.025	
High Pressure Sodium 2000w	240	510	

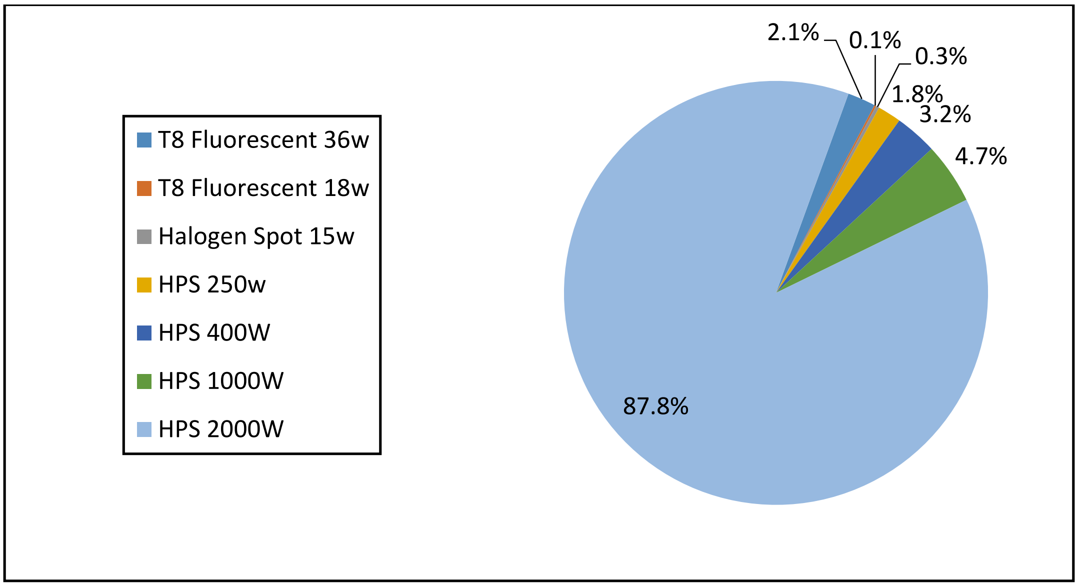

Figure 5: Football stadium lighting system breakdown

Mechanical system

Domestic hot water system

Domestic hot water (DHW) of the Olympic complex is provided from a central system located inside the gas boiler room (ground level). The DHW system is comprised of indirect-fired water heater. The heater is manufactured by Air-O-Smith Inc. with a capacity of 278 litres, and the Calorifier is 88.5 KW. The water is recirculated using a 2 kW recirculation pump. Figure 6 show the stadium gas boiler.

Figure 6: Stadium gas boiler

There are two swimming pools inside the Olympic complex; a small one (100 m^3) and another larger one (240 m^3). Pool water is heated through a heat exchanger using hot water supplied by the boiler plant and maintained at 25°C. The pool filtration and pumping equipment is located in the sub-basement pool equipment room. The equipment includes three filters, and three circulation pumps each of them of 5.5 HP. An indirect fired water heater located in the basement room heats the pool water, the capacity is 300 litres. The swimming pool water is renewed every five days.

Swimming pool

Table 4 shows the details of the lighting system for the swimming pool in the Olympic complex. The breakdown of this system is shown in Figure 7 hereunder. It can be noticed that the total load of the lighting system is not comparable with the load of the lighting system for the football stadium.

Table 4: Swimming pool lighting system

Type	No. of connected lamps	Load (kw)	Total load (kw)
T8 Fluorescent 36w	20	1	6.18
Incandescent 60w	10	0.6	
High Pressure Sodium 400w	10	4.58	

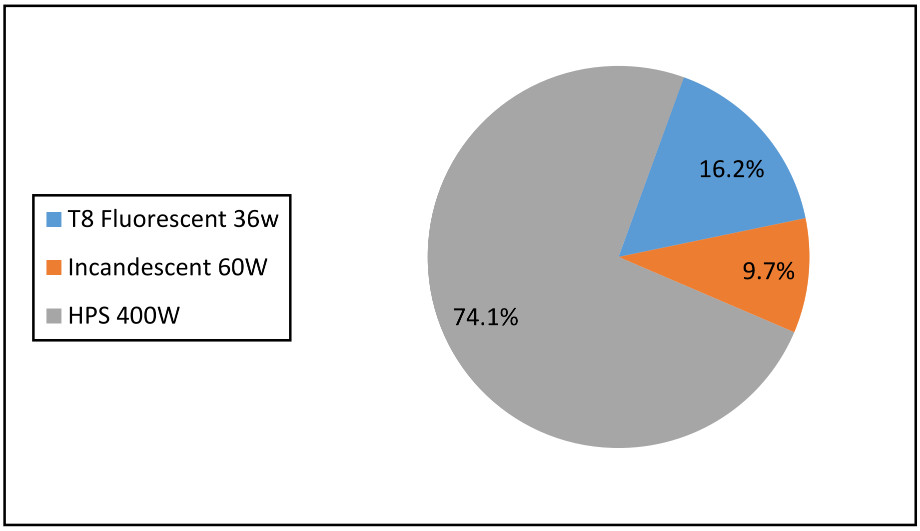

Figure 7: Swimming pool lighting system breakdown

Basketball stadium

Table 5 shows the details of the lighting system for the basketball stadium in the Olympic complex. The breakdown of this system is shown in Figure 8 hereunder. It can be noticed that the major consumer of the lighting system is high pressure sodium with power rating of 400W.

Table 5: Basketball stadium lighting system

Type	No. of connected lamps	Load (kw)	Total load (kw)
T8 Fluorescent 36w	20	1	28.21
T8 Fluorescent 18w	120	3	
High Pressure Sodium 250w	14	4.06	
High Pressure Sodium 400w	44	20.15	

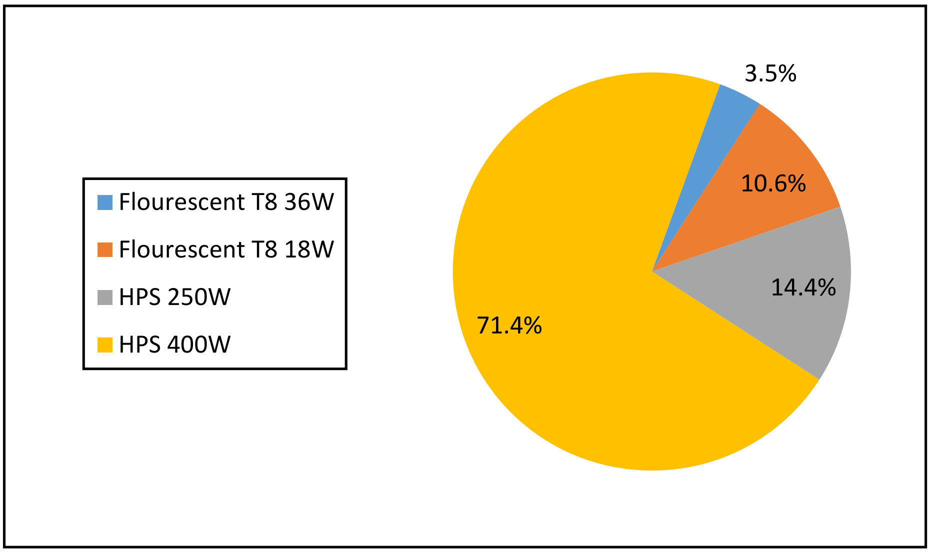

Figure 8: basketball stadium lighting system

4.3 Salle Olympic Mohammad Mzali Monastir - closed basketball arena

General description

The Olympic Hall Mohammed Mazali Monastir is a closed basketball arena, shown in Figure 9. It consists of the main building. The energy consumers in this building are: the ventilation and lighting system, the latter being the main consumer.

Figure 9: Salle Olympic Mohammad Mzali Monastir

The following is a summary of our observations on site; the roof and walls of the building are not insulated and the ventilation system's filters and ducts are dusty.

Lighting system

Table 6 shows the details of the lighting system of Salle Olympic Mohammad Mzali Monastir. The total load of the lighting system is **36.71 kW**. The breakdown of this system is shown in Figure 10.

Table 6: Salle Olympic Mohammad Mzali Monastir Lighting System

Type	No. of connected lamps	Load (kw)	Total load (kw)
T8 Fluorescent 36w	40	2	
T8 Fluorescent 18w	160	4	
Halogen Spot 15w	20	0.3	36.71
High Pressure Sodium 250w	18	5.22	
High Pressure Sodium 400w	55	25.19	

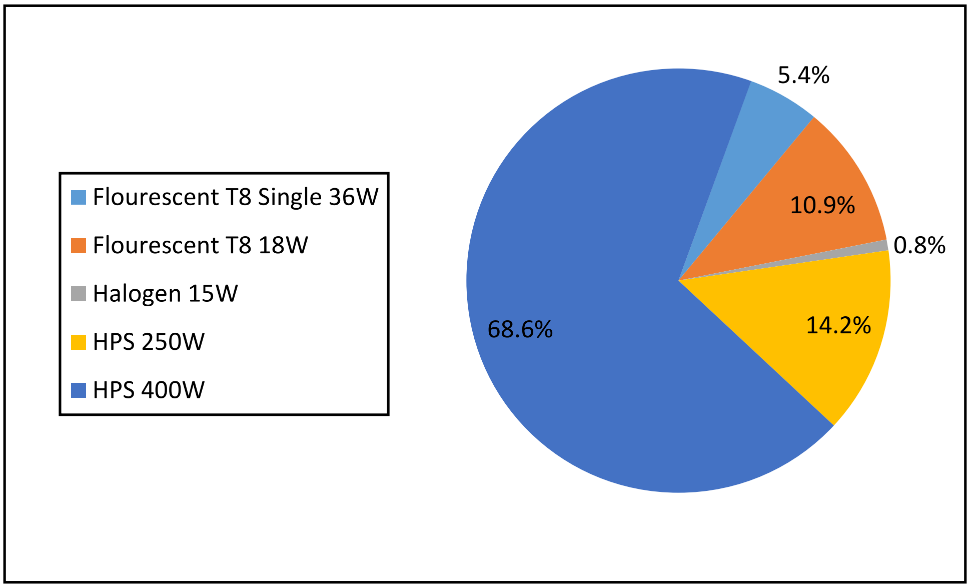

Figure 10: Closed basketball arena connected lighting load distribution

4.4 Central market and stores

General description

The central market and stores are considered as important utilities in providing facilitative services to the local community at Monastir. They have different areas that are around 18000 m^2 and 4000 m^2 for the market and stores, respectively. These utilities are administered by the municipality.

Electric system

The central market and stores mainly depend on the electric energy to meet their energy needs, where the electricity is completely fed by the public power network of the municipality. The annual electric energy consumptions are 28,148.1 kWh and 69,138 kWh, which cost around 5,052.88 T.D and 13,837.65 T.D for the market and stores, respectively. It is worth mentioning that the annual energy consumptions costs for both utilities are accounted under municipality administration’s responsibility.

On the other hand, it is noted that the electric system structure, which is applied for both utilities, is classified under low voltage (tension) category. The category is distributed into four tariffs depending on the monthly electric energy consumption.

Table 7 shows in details the electric tariff applied for low tension level for both utilities.

Table 7: Electricity tariff applied for low-tension level in non-residential sector

kWh	1-200	201-300	301-500	Above 500
T.D/ kWh	0.167	0.198	0.260	0.295
18% added for non-residential and irrigation purposes, and 0.005 added for each kwh.				

As mentioned above, the electricity fed by public electricity network is the only energy source for both utilities. The electricity consumption of the market is mainly by the consumption of the lighting system.

The electricity consumption for the municipality’s stores is broken down into their main energy consumers as shown in Figure 11.

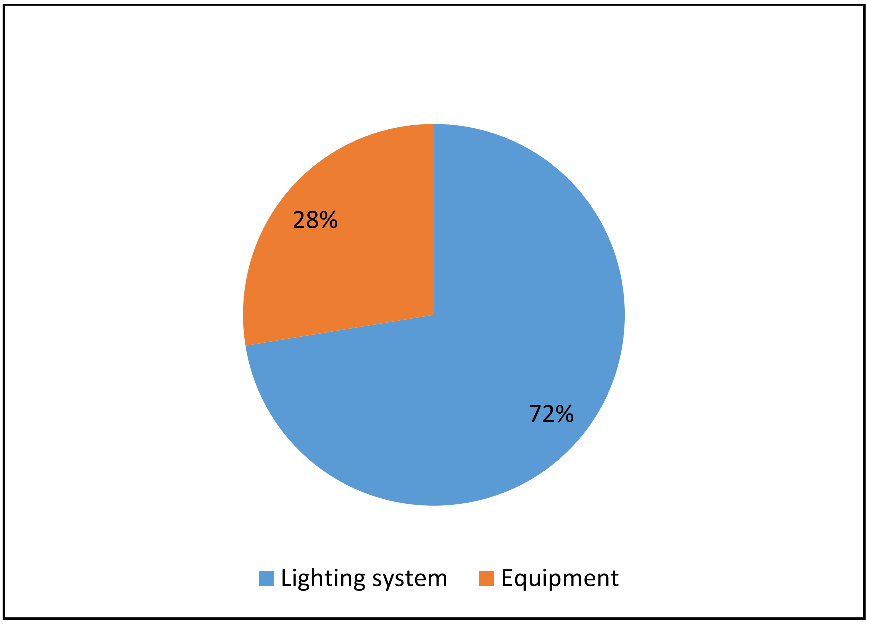

Figure 11: Electric load breakdown in Municipality's stores

The figure above shows that the electric consumption due to lighting system use represents the big portion, which is **72 %,** approximately.

Lighting system

The lighting system is considered the main energy consumer in all facilities under the Municipality's administration. In our case, the lighting system consumes around 72% of the total consumption of the stores and is the main energy consumer in the market, which are equivalent to **50,132.7 kWh** and **28,148.1 kWh** for the stores and the market, respectively.

This high consumption of the lighting system operation is attributed to the extensive use of conventional lighting units in each facility. Tables 8 and 9 hereunder show the lighting units and their respective loads in the stores and the market, respectively.

Table 8: Lighting units' types and loads used in the stores

Unit/ Type	Number of units	Total loads (kW)
Incandescent	6	0.36
Mercury-Hid 400w	22	9.68
Fluorescent T8-120cm 18w	40	2
Fluorescent T8-60cm 36w	64	1.6
Led Floodlight	4	1.04
HPS-Street Lighting 400w	9	3.96
CFL 16w	14	0.224
Led Spotlight 6w	9	0.054

Table 9: Lighting units' types and loads used in the market

Unit/ Type	Number of units	Total loads (kw)
Incandescent 60w	120	7.20
Fluorescent T8-120cm 36w	40	2.00
CFL 27w	17	0.46

In Table 8, it is clearly noted that the wide use of conventional lighting units exists where there are high loads used in the lighting system. As shown the highest electric load is due to the use of Mercury 400 W.

In Table 9, it is also shown that conventional lighting units are being used, which in turn affect the energy consumption and cost. It is noted that the highest electric load came from or using incandescent units at 7.2 kW.

Figures 12 and 13 hereunder show the breakdown of the electricity consumptions of using lighting system in the stores and market, respectively.

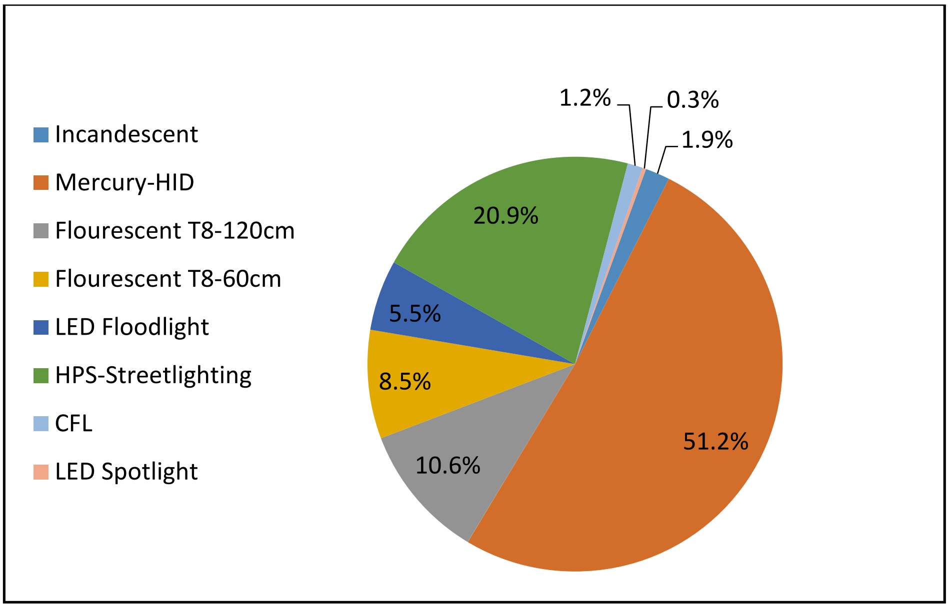

Figure 10: Electricity load breakdown of lighting system in the stores

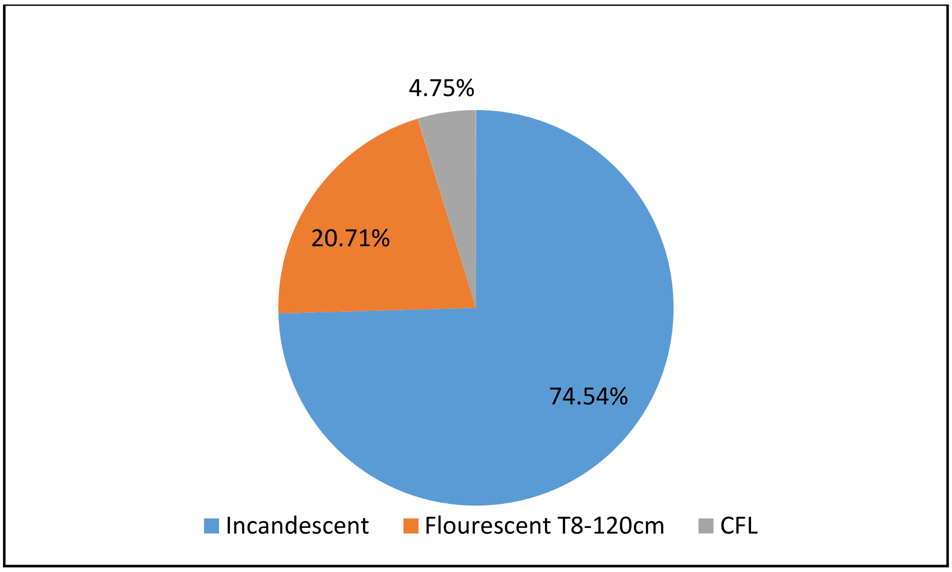

Figure 13: Electricity load breakdown of lighting system in the Stores

4.5 Municipal slaughter house

General description

The slaughterhouse was established in 2009; it consists of a moderate building that has an area about 1500 m^2 and receives several types of animals such as cows, sheep and camels to be slaughtered. The numbers of daily slaughtered livestock are not high because the residents in Al-Monastir depend on fish instead of livestock meat. Figure 14 shows the slaughterhouse.

Figure 11: The slaughterhouse in Monastir

Electrical system

The Slaughterhouse uses electrical energy to operate. The electrical energy is covered by the national electricity grid. The energy bills for the slaughterhouse were not provided by the Municipality due to some logistics problems in the electricity meter.

Lighting is one of the main energy consuming systems at the Slaughterhouse. There are two types of lighting systems that are needed to meet lighting requirements during working hours. Table 10 hereunder illustrates the number of lamps and connected load. Figure 15 shows the breakdown of the lighting system load for this facility.

Table 10: Slaughter House Lighting System

Type	No. of connected lamps	Load (kw)	Total load (kw)
T8 Fluorescent 36w	10	1	2.16
HPS 250w	4	1.16	

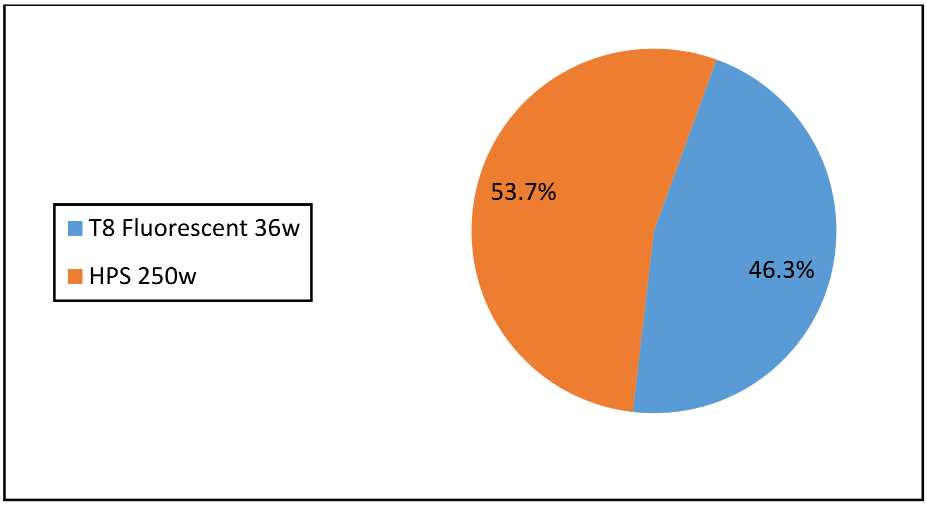

Figure 12: Slaughter house lighting system

Mechanical system

The process in the factory is a simple manual process to slaughter the livestock, but it uses a small air compressor in the process.

The Slaughterhouse includes an initial aerobic treatment unit to treat the bio-waste, produced from the slaughterhouse. The unit includes centrifugal pumps used to operate the unit. Figure 16 hereunder is the bio-waste treatment unit.

Figure 16: Bio-waste treatment unit

Energy saving opportunities in the equipment are negligent because the bio-waste treatment process does not work.

4.6 Public grid lighting

A study of the public lighting grid (street and squares) was performed in 2016 by the municipality of Monastir to assess the situation of the lighting grid and determine the required resources and budget to improve this grid.

The following Table 11 shows the details of the public lighting grid in 2005 and 2016. It contains the type of lamps, number of each type, and final load of connected fixtures.

Table 11: Public lighting grid

Type	Rating (W)	No. Of Lamps (2005)	Load (Kw)	Percentage (%)	No. Of Lamps (2016)	Load (Kw)	Percentage (%)
Mercury Vapor	250	2,300	667	34.12	1,900	551	27.62
Mercury Vapor	125	3,440	478	51.03	3,100	431	44.75
High Pressure Sodium	250	1,000	290	14.83	2,840	824	22.09
High Pressure Sodium	150	0	0	0.00	750	128	4.14
High Pressure Sodium	70	0	0	0.00	100	8	1.38
Total Load (Kw)	**1,435**				**1,942**		
Consumed Energy (Kwh/Year)	**6,430,000**				**5,377,670**		
Cost of Consumed Energy (T.D./Year)	**630,524**				**1,227,366**		

Form the table above, it can be noticed that the public lighting grid has been expanded about 35% from 2005 to 2016. This is due to the expansion of the lighting grid itself to cover new streets and locations, plus newly established public areas and squares.

According to this study, the total length of electric cables of the public lighting grid is 610 km (260 km underground cables and 350 km aerial cables).

Table 12 shows the distribution of the pubic lighting grid according to the demographic density. It contains the information for the First City, Al-Hyliah, Saqanes and the Second City, within the Monastir Municipality, in addition to the required cost to cover the shortage from the public lighting grid, as listed hereunder in Table 12.

Table 12: Distribution of public lighting grid

Location	No. of Citizen	No. of Families	Percentage of Beneficiaries (%)	Cost to Cover Shortage (T.D.)
First City	6,106	4,812	70	240,000
Al-Hyliah	11,619	9,260	75	335,000
Saqanes	11,397	8,249	45	500,000
Second City	5,481	4,146	55	216,000
Total	**34,603**	**26,467**	-	**1,291,000**

4.7 Water pumping station

The water pumping station in Monastir is located five kilometers from the city center. This station delivers on average of 9.2 million liters per day (MLD) or 0.27 million cubic meters per month to the network, while consuming about 41 MWh of electricity per month.

The pumping station is running by operations and maintenance engineers supported by technical staff comprised of electrical technicians and mechanical technicians.

Process

The National Water Exploitation and Distribution Company (SONEDE) is the governmental entity that is responsible for supplying water to the city of Monastir and its suburbs; it caters for approximately 95,500 residents.

The water influx comes from outsourced dams and flows into Monastir's receptive tanks, where it is treated by chlorine and pumped to boost supply to the zones that cannot be supplied with water by gravity. Figure 17 shows a schematic of the pumping process and configuration at the station.

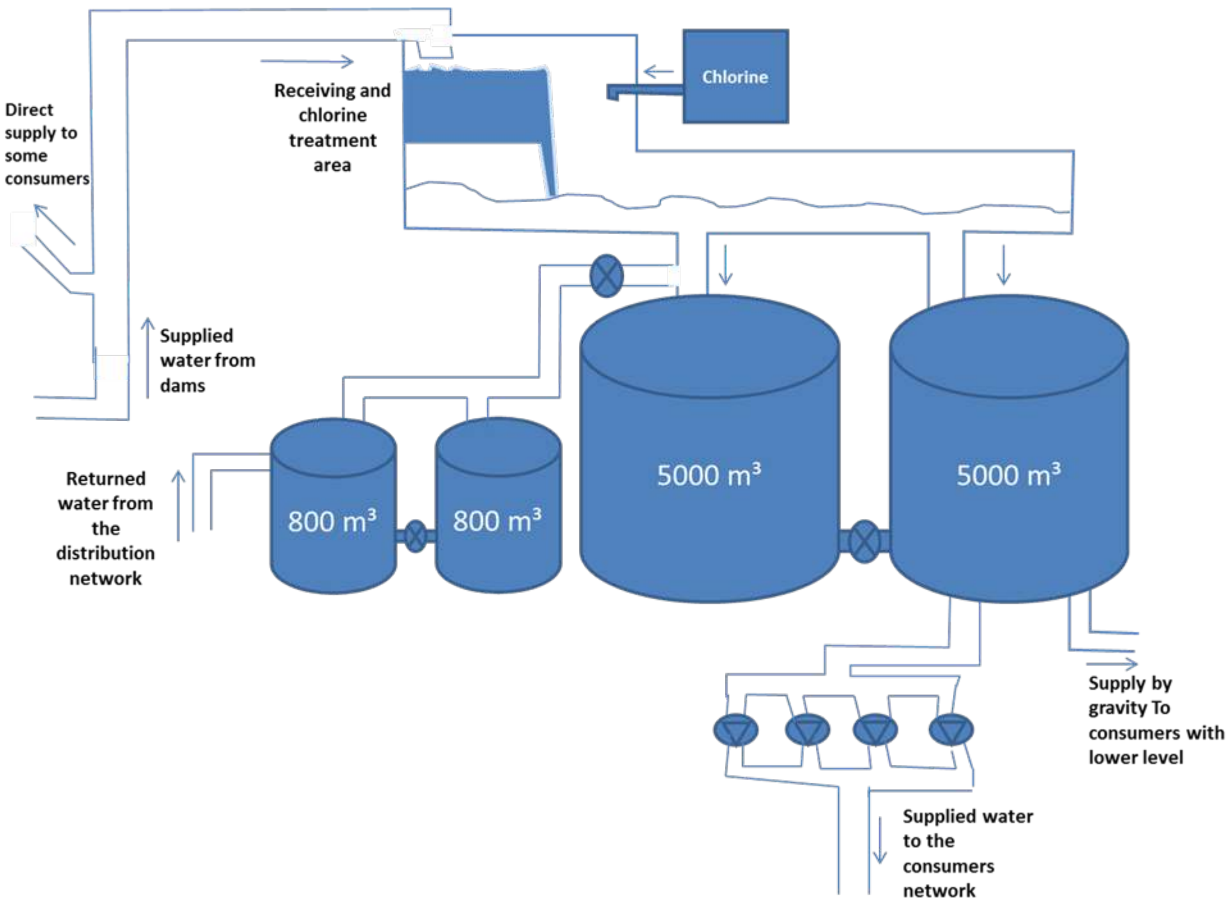

Figure 17: Water pumping station

The water pumping system at the Monastir plant consists of two reservoir tanks with a capacity of 5,000 cubic meters each, where four centrifugal pumps (two of them are standby) operate alternatively to transfer water to the water distribution network, where there are some areas supplied with water by gravity due to the lower level.

The Monastir pumping station is a high-energy intensity facility with high inductive motor loads. The station runs on a 24-hour basis throughout the year and was commissioned in 1980.

Pumping operations

The pumping stations at Monastir use four Centrifugal pumps that operate alternatively, driven by four (1470 rpm) electric motors with rated nominal output of 37 kW each, designed to operate at 50 Hz and 380 V supply voltage. The pumps and their components' nameplates are shown in Figures 18, 19, 20 and 21.

Figure 138: Water supply pumps as assembled with components

Figure 19: Motor-pump coupling

Figure 20: Motor nameplate

Figure 21: Pump Name Plate

The used flow meter at the Monastir pumping station is of the ultrasonic type, where movements of ultrasonic sound waves through flowing water particles are converted to digital signals that indicate the flow rate in the pipeline. Also, analogue sub-meters are positioned at the pumps control switchboard for operational use. Pumping station flow meter and the analog sub-meters are shown in Figure 22.

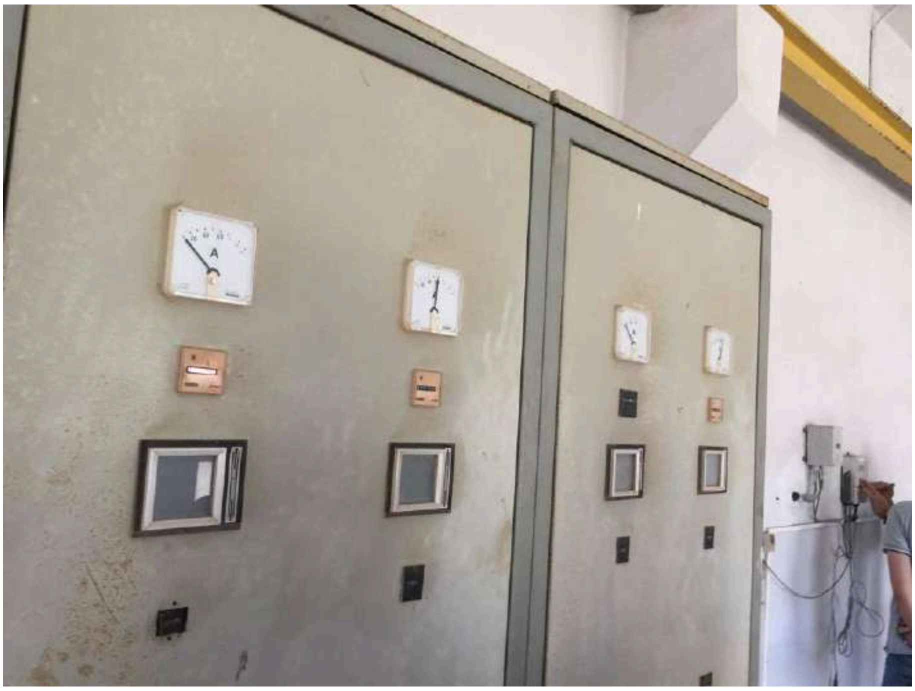

Figure 22: The existing flow meter (right) and the electricity sub-meters in the pumping station

The station supply pipeline has two surge vessels located 10 meters away from the discharge point. Its purpose is to control potentially harmful surge pressures from damaging the piping when the pumps are switched off and the non-return valve closes. This action produces water hammer when the water flows back and slams the non-return valve, causing the surge pressures. One-air compressors (1.5 kW) to maintain the air gap in the surge vessels at required levels support the surge vessels. The surge vessels have a working pressure of two bars. Surge vessels are shown in Figure 23.

Figure 23: The existing surge vessels in the Monastir pumping station

Total electricity consumption and flow rate at the pumping station

Flow rate data was taken from an ultrasonic flow meter installed at the pumping station. Table 13 shows the total energy and flow data for 2016, with electrical consumption in kilowatt per hour (kWh) and corresponding flow rate in cubic meters (m^3).

Table 13: Electrical energy and flow data 2016

Year	Month	Flow (M3)	Electrical Consumption (kWh)	Cumulative (M3)	Cumulative (kWh)	Energy Cost (Td)
2016	Jan	246,400	38,017	246,400	38,017	8,131
	Feb	248,270	37,570	494,670	75,587	7,852
	Mar	258,895	41,733	753,565	117,320	8,523
	Apr	271,735	38,378	1,025,300	155,698	8,240
	May	290,585	41,726	1,315,885	197,424	8,553
	Jun	303,065	48,919	1,618,950	246,343	11,533
	Jul	308,960	41,741	1,927,910	288,084	10,309
	Aug	317,115	37,782	2,245,025	325,866	9,031
	Sep	279,520	43,282	2,524,545	369,148	9,055
	Oct	292,270	42,849	2,816,815	411,997	8,730
	Nov	262,095	46,409	3,078,910	458,406	9,250
	Dec	251,710	34,005	3,330,620	492,411	6,982
Sum		**3,330,620**	**492,411**			**106,188**

Individual and combination pump motor energy running hours

Tables 14 and 15 show the monthly pump motor running hours and energy consumption for combination and individual pumps running respectively, for 2016.

Table 14: Combination pump motor running hours and energy usage

Year 2016	Pump1and2	Pump1and3	Pump1and4	Pump2and3	Pump2and4	Pump3and4
Running Hours	631	1,157	1,897	1,225	2,026	520
Energy Consumption (kWh)	38,807	86,391	129,979	79,837	119,564	37,580

Table 15: Individual Pump Motor running hours and Energy Usage

Year 2016	Pump1	Pump2	Pump3	Pump4
Running Hours	3,685	3,882	2,901	4,445
Energy Consumption (kWh)	130,818	100,932	113,739	146,669

Energy performance and trending indices of pumping operations

In this section, the graphic representation of energy consumptions, trending and analyses are shown. Figure 24 shows the relation between water flow outputs and consumed energy in 2016.

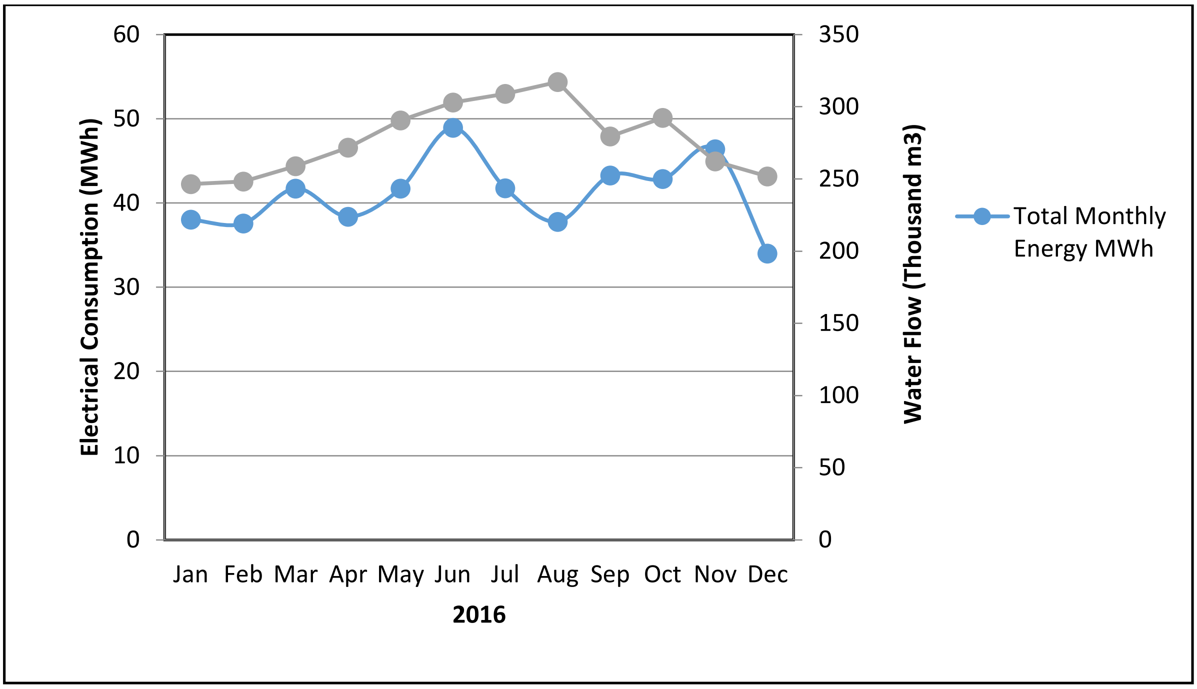

Figure 24: Electricity consumption and flow 2016

In Figure 24, electricity consumption is somewhat proportional to the flow output of the pumping station. This trend somewhat met the expectation, (so that) the higher the flow output is, the higher the electricity consumption gets, while for some other points (July and August), it does not meet the expectation, and this may be attributed to the variation of efficiencies in running pumps.

Figure 25 shows the cumulative energy versus flow graph for 2016.

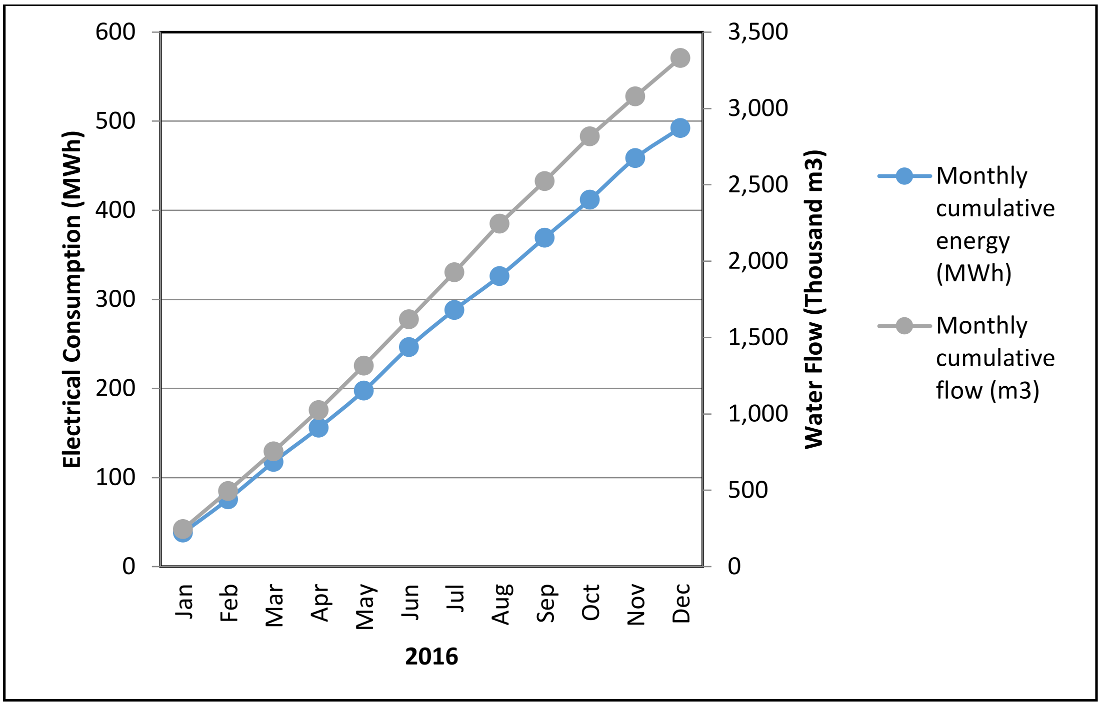

Figure 25: Electricity consumption and flow for 2016 period

The cumulative graph of monthly electricity consumption versus flow output indicates an abnormal trend with the lines diverging. This trend was inconsistent with the expectation for the cumulative electricity consumption and flow output values, that were generally expected to be parallel.

Figure 26 shows the relationship between flow output and electricity consumption for 2016, where months July and August were excluded in order to avoid a large dispersion in the trend line.

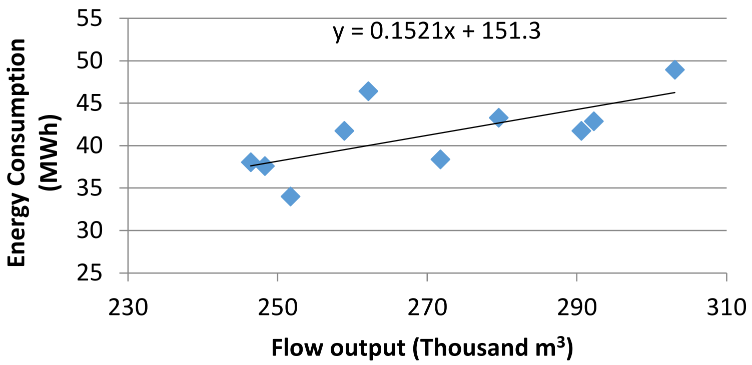

Figure 26: Relationship between electricity consumption and flow -2016

Figure 26 indicates that the slope is positive. The electricity consumption increases with an increase in flow output. Because of the narrow flow output range, the extrapolation of the Y-Axis shows that there is an energy consumption of **151.4 kWh** at zero flow output. The energy intensity of **0.152 kWh/m^3** is also near to the period average of **0.1484 kWh/m^3**.

Electrical energy intensity of pumping operations – specific energy

Table 16 shows the energy intensities and the corresponding flow output for 2016.

Table 16: Intensity and flow output figures for 2016 period

Year	Month	Flow (M^3)	Electrical Consumption (kWh)	Energy Intensity kWh/M^3)
2016	Jan	246,400	38,017	0.1543
	Feb	248,270	37,570	0.1513
	Mar	258,895	41,733	0.1612
	Apr	271,735	38,378	0.1412
	May	290,585	41,726	0.1436
	Jun	303,065	48,919	0.1614
	Jul	308,960	41,741	0.1351
	Aug	317,115	37,782	0.1191
	Sep	279,520	43,282	0.1548
	Oct	292,270	42,849	0.1466
	Nov	262,095	46,409	0.1771
	Dec	251,710	34,005	0.1351
	Average energy intensity			**0.1484**

Figure 27 shows the relationship between the flow output and specific energy for 2016 (excluding July and August for the same above reason). The graph indicates that there is no relationship between flow output and specific energy as seen from the horizontal line. The energy intensity of approximately **0.152 kWh/m^3** as seen from the graph remains constant for the entire range of flows.

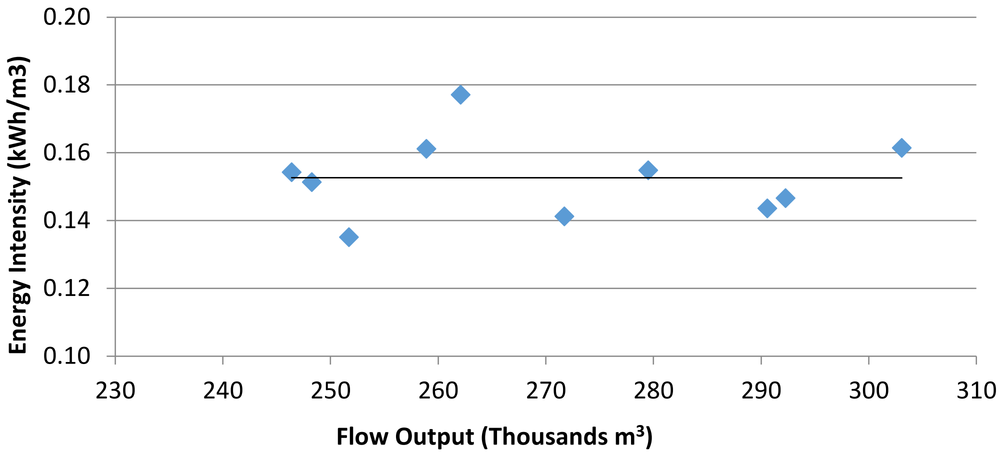

Figure 27: Specific energy consumption and flow output – 2016

5. Recommendations

After the assessment of the energy status of Monastir Municipality main facilities, this section includes the recommendations to improve the energy efficiency of the main systems within these facilities.

5.1 Municipality Main Building

Table 17 shows the details of the lighting system of the municipality main building. This Table shows the types of the lighting lamps and their quantities in the building, the electric load in kW, the annual energy consumption in kWh and the share of each type of the total annual energy consumption of the lighting system.

Table 17: Municipality main building lighting baseline

Lighting Unit Type	No. Of Connected Lamps	Total Connected Load (Kw)	Annual Total Electric Energy Consumption (kWh)	Share Of Overall Electric Energy Consumption (%)
Fluorescent T8 36w	202	10.1	26542.8	31.44%
Fluorescent T8 18w	418	10.5	27462.6	32.53%
CFL	112	1.9	4998.45	5.92%
Incandescent 60w	16	1.0	2522.88	2.99%
Incandescent 40w	148	5.9	15557.76	18.43%
HPS	3	0.8	2207.52	2.61%
Led	160	2.0	5129.85	6.08%
Total		**32.1**	**84421.9**	**100%**

Table 18 shows the recommendations to replace each type of the existing lighting types in the municipality main building including the annual expected energy saving, annual cost saving, the required investment cost, the expected lift time for the system and the simple payback period for these recommendations. Figure 28 shows the share of each lighting type of the total electric load.

Table 18: Municipality main building lighting retrofitting

Ecms	No. of Lamps to be Replaced	Total Connected Load (Kw)	Annual Energy Saving (Kwh)	Annual Cost Saving (Td)	Investment (Td)	Expected Lifetime (Yr.)	Simple Payback Period (Yr.)
Replacing with LED T8 18W	202	3.6	16,987.4	5,096	6,060	25	9.51
Replacing with LED T8 9 W	418	3.8	17,576.1	5,273	9,753	25	9.84
Replacing with LED Round Panel 12 W	112	1.5	3,484.7	1,045	10,667	25	1.95
Replacing with LED Bulbs 6 W	16	0.9	14,695.8	4,409	2,467	25	8.23
Replacing with LED Floodlight 100	148	0.3	1,419.1	426	700	25	0.79
Total		**12.1**	**54,163**	**16,249**	**29,647**		**1.82**

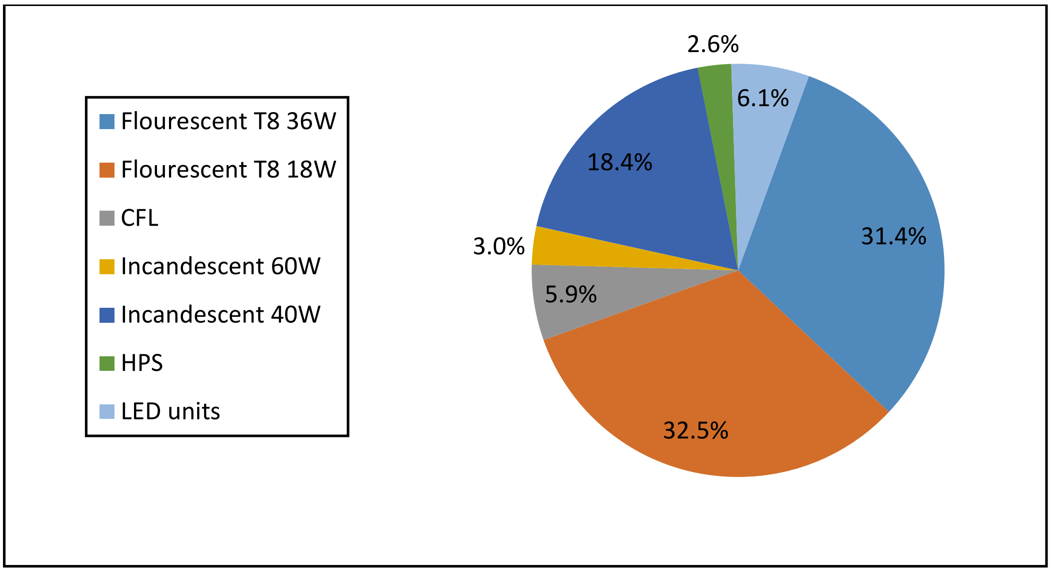

Figure 28: Municipality main building lighting system breakdown

Figure 29 shows the share of the electric energy consumption of each one of the lighting types to the total annual energy consumed by the building. Figure 30 shows the annual energy consumption of the lighting system before and after applying these recommendations.

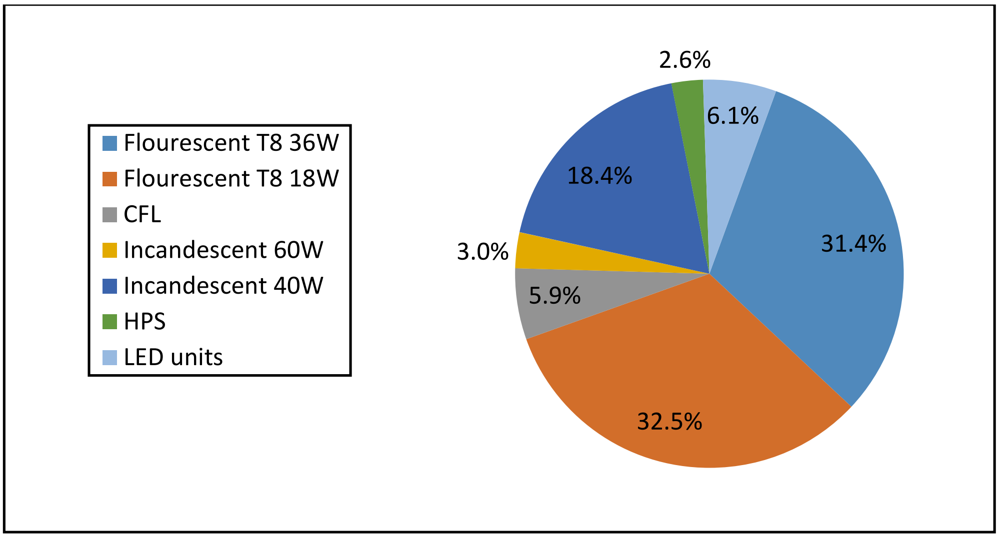

Figure 29: Electrical energy consumption of the municipality main building

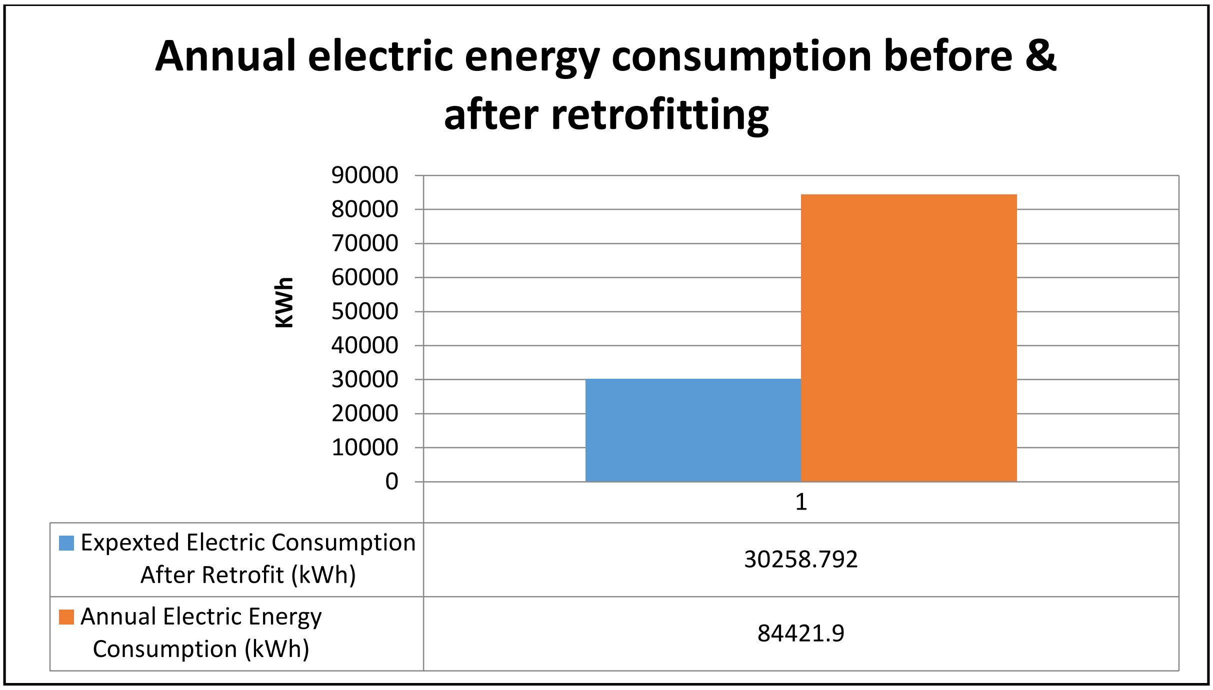

Figure 30: Main building lighting energy consumption before and after retrofit

Recommendations for the mechanical system

It is recommended to replace all the spilt units with more efficient ones (using the inverter technology). The inverter air conditioner unit, which is considered more sophisticated, is made up of a variable-speed compressor rather than a fixed-speed one. Although this process is more complicated than it sounds, the essence of the variable speed is not to allow the compressor to run at full power all the time while operating, but rather to have control over their operation as needed. This compressor is meant to constantly regulate the temperature as desired. Therefore, when the old split units are replaced with inverter technology, the result would be a reduction in energy consumption and increase in the efficiency of the split unit.

The VRF system is recommended to clean the filter, and cover the external fans to improve the efficiency and increase the life operation. Furthermore, some of the ducts need to be insulated to decrease energy loss.

Concerning the building envelope, it is recommended to replace all the windows from single glass to double glass to reduce the heat loss due to infiltration.

Table 19 represents the energy saving after replacing the on-off split unit with an inverter split unit at the main municipality building.

Table 19: Energy saving after replacing split units

System	Annual Energy Consumption (kWh/Yr.)	Annual Energy Saving (kWh/Yr.)	Annual Energy Saving (Tnd)	Investment Cost (Tnd)	Payback Period (Year)
Split Unit	161,925.12*	95,562.37	19,112.47	144,000**	7.5
* Average operating hours are 4 hours/day ** Depending of budgetary prices from suppliers					

Furthermore, after applying the above recommendation on the use of the VRF system, the energy efficiency of the system will increase about **2-3%,** leading to a reduction in the electricity consumption of the VRF system by **1-1.5%**. (According to the practical experience).

On the other hand, the energy savings that comes from the replacement of the existing single glass windows to double glass windows is up to **44%**, where the U-values of single and double (glazing) glass windows are 4.8 W/m^2.K and 2.7 W/m^2.K, respectively.

5.2 Olympic complex

Football stadium

Table 20 shows the details of the lighting system for the football stadium in the Olympic complex. This Table shows the types of the lighting lamps and their quantities in the stadium, the electric load in kW, the annual energy consumption in kWh and the share of each type of the total calculated annual energy consumption of the stadium.

Table 20: Football stadium lighting baseline

Lighting Unit Type	No. Of Connected Lamps	Total Connected Load (Kw)	Annual Total Electric Energy Consumption (kWh)	Share Of Overall Electric Energy Consumption (%)
Fluorescent T8 36w	248	12.4	22320	7.15%
Fluorescent T8 18w	32	0.8	1440	0.46%
Halogen 15w	100	1.5	2700	0.86%
HPS 250w	36	10.44	10022.4	3.21%
HPS 400w	41	18.778	18026.88	5.77%
HPS 1000w	25	27.025	12972	4.15%
HPS 2000w	240	510	244800	78.39%
Total		**580.943**	**31,2281.28**	**100%**

Table 21 shows the recommendations to replace each type of the existing lighting types in the football stadium including the annual expected energy saving, annual cost saving, the required investment cost, the expected lift time for the system and the simple payback period for these recommendations. Figure 31 shows the share of each lighting type of the total electric load.

Table 21: Football stadium lighting retrofitting

Ecms	No. Of Lamps To Be Replaced	Total Connected Load (Kw)	Annual Energy Saving (kWh)	Annual Cost Saving (Td)	Investmen t (Td)	Expected Lifetime (Yr.)	Simple Payback Period (Yr.)
Replace Fl 36 W With Led 20 W	248	4.84	13608.0	2721.6	6050	25	2.2
Replace Fl18w With Led10 W	32	0.32	864.0	172.8	480	25	2.8
Replace Halogen 15w With Led 5 W	100	0.5	1800.0	360.0	1000	25	2.8
Replace HPS 250w With Led 100w	36	3.6	6566.4	1313.3	18000	25	13.7
Replace HPS 400W with LED 150 W	41	6.15	12122.9	2424.6	28700	25	11.8

TOTAL		**15.41**	**34961.3**	**6992.3**	**54230**		**7.8**

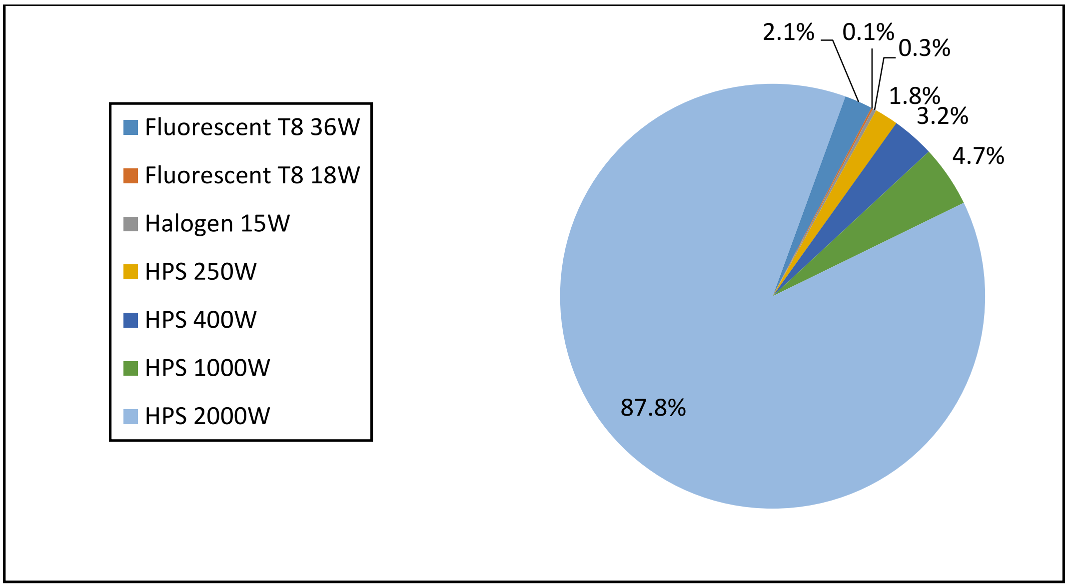

Figure 31: Football stadium lighting breakdown

Figure 32 shows the share of the electric energy consumption of each one of the lighting types to the total annual energy consumed by the stadium. Figure 33 shows the annual energy consumption before and after applying these recommendations.

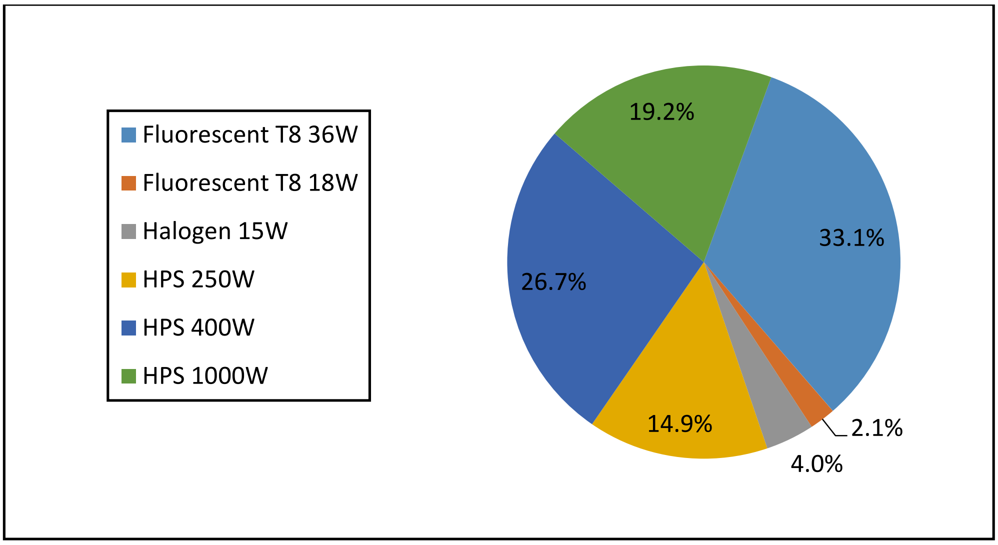

Figure 32:14 Football stadium lighting consumption

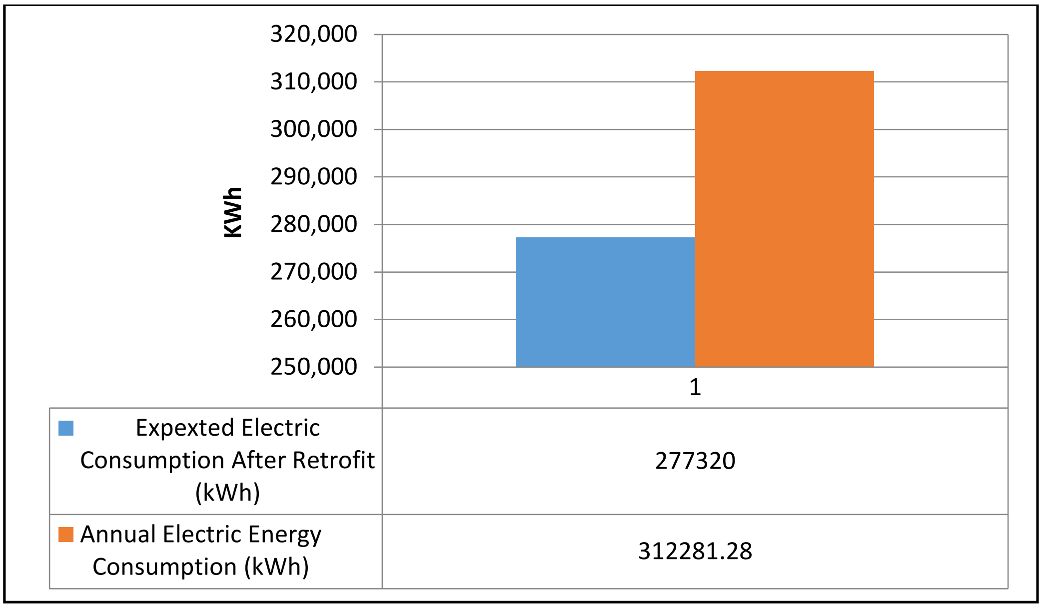

Figure 33: Football stadium lighting energy consumption before and after retrofit

Swimming pool

Table 22 shows the details of the lighting system of the swimming pool in the Olympic complex. This Table shows the types of the lighting lamps and their quantities, the electric load in kW, the annual energy consumption in kWh and the share of each type of the total calculated annual energy consumption of the pool.

Table 22: Swimming pool lighting baseline

Lighting Unit Type	No. Of Connected Lamps	Total Connected Load (Kw)	Annual Total Electric Energy Consumption (kWh)	Share Of Overall Electric Energy Consumption (%)
Fluorescent T8 36w	20	1	1800	24.74%
Fluorescent T8 18w	10	0.6	1080	14.84%
HPS 400w	10	4.58	4396.8	60.42%
Total		**6.18**	**7276.8**	**100%**

Table 23 shows the recommendations to replace each type of the existing lighting typess in the swimming pool including the annual expected energy saving, annual cost saving, required investment cost, expected life time of the system, and the simple payback period of these recommendations. Figure 34 shows the share of each lighting type of the total electric load.

Table 23: Swimming pool lighting retrofit

ECMS	No. of Lamps to be Replaced	Total Connected Load (Kw)	Annual Energy Saving (kWh)	Annual Cost Saving (Td)	Investment (Td)	Expected Lifetime (Yr.)	Simple Payback Period (Yr.)
Replace Fl 36w With LED 20 W	20	0.4	1080.0	216.0	500	25	2.3
Replace Fl 18w With LED 10 W	10	0.1	900.0	180.0	150	25	0.8
Replace HPS 400w With LED 150 W	10	1.5	2956.8	591.4	7000	25	11.8
Total		**2**	**4936.8**	**987.4**	**7650**		**7.7**

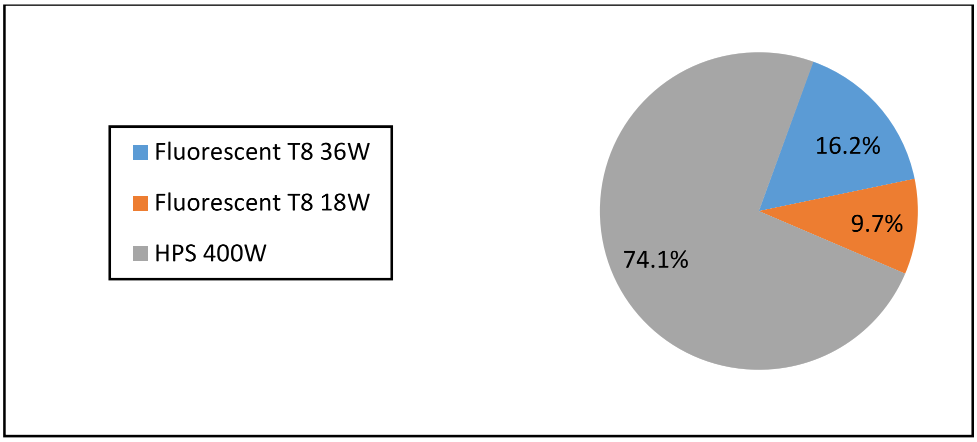

Figure 34: Swimming pool lighting load

Figure 35 shows the share of the electric energy consumption of each one of the lighting types to the total annual energy consumed by the stadium. Figure 36 shows the annual energy consumption before and after applying these recommendations.

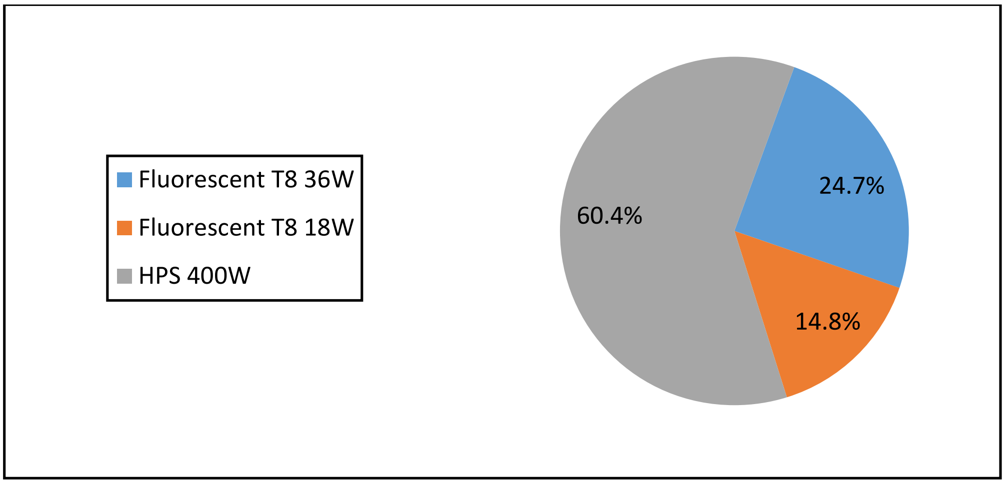

Figure 35: Swimming pool lighting consumption

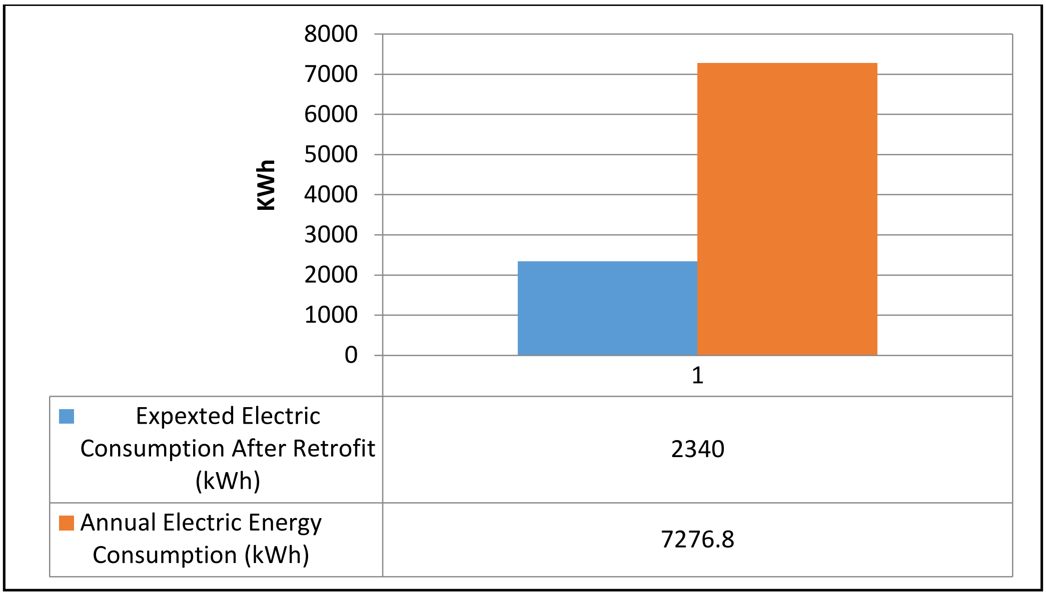

Figure 36: Swimming pool lighting consumption before and after retrofit

Basketball stadium

Table 24 shows the details of the lighting system for the basketball stadium in the Olympic complex. This Table shows the types of the lighting lamps and their quantities, the electric load in kW, the annual energy consumption in kWh and the share of each type of the total calculated annual energy consumption of the basketball stadium.

Table 24: Basketball stadium lighting load

Lighting Unit Type	No. of Connected Lamps	Total Connected Load (Kw)	Annual Total Electric Energy Consumption (kWh)	Share Of Overall Electric Energy Consumption (%)
Fluorescent T8 36w	20	1	1800	5.91%
Fluorescent T8 18w	120	3	5400	17.74%
HPS 250W	14	4.06	3897.6	12.80%
HPS 400W	44	20.152	19345.92	63.55%
Total		**28.212**	**30443.52**	**100%**

Table 25 shows the recommendations to replace each type of the existing lighting typess in the basketball stadium including the annual expected energy saving, annual cost saving, the required investment cost, the expected lift time of the system and the simple payback period for these recommendations. Figure 37 shows the share of each lighting type of the total electric load.

Table 25: Basketball stadium retrofit

Ecms	No. of Lamps to be Replaced	Total Connected Load (Kw)	Annual Energy Saving (Kwh)	Annual Cost Saving (Td)	Investmen t (Td)	Expected Lifetime (Yr.)	Simple Payback Period (Yr.)
Replace Fl 36w With LED 20 W	20	0.4	1080.0	216.0	500	25	2.3
Replace Fl 18w With LED 10 W	120	1.2	3240.0	648.0	1800	25	2.8
Replace HPS 250w With LED 100w	14	1.4	2553.6	510.7	7000	25	13.7
Replace HPS 400w With LED 150 W	44	6.6	13009.9	2602.0	30800	25	11.8
Total		**9.6**	**19883.5**	**3976.7**	**40100**		**10.1**

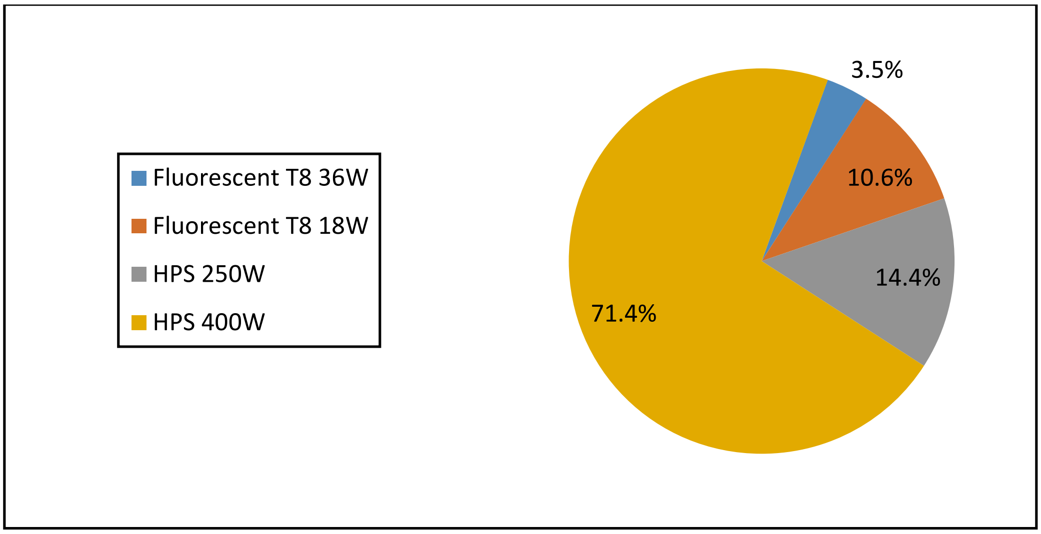

Figure 37: Basketball stadium lighting load

Figure 38 shows the share of the electric energy consumption of each one of the lighting types to the total annual energy consumed by the stadium. Figure 39 shows the calculated annual energy consumption before and after applying these recommendations.

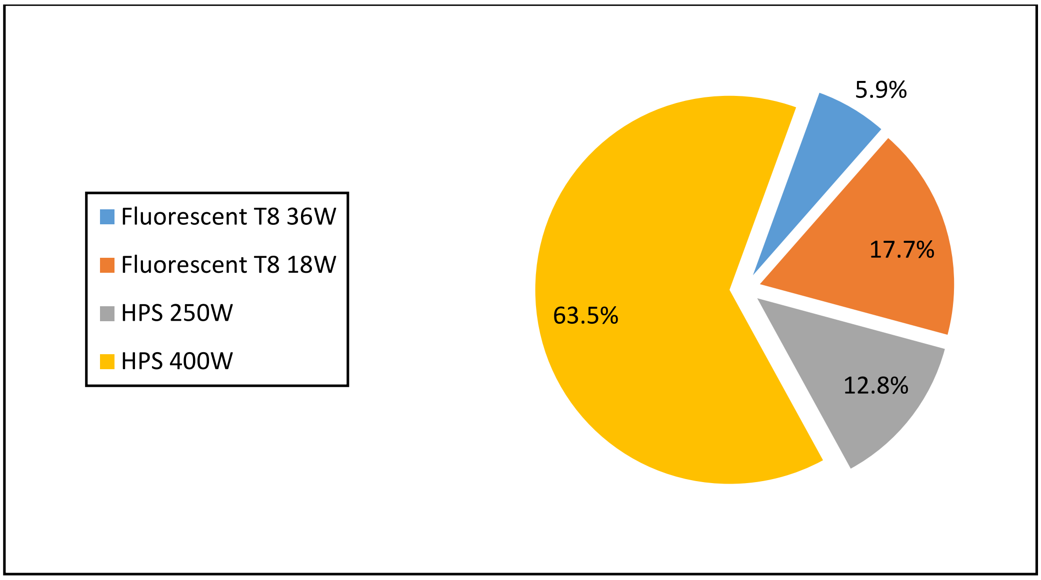

Figure 38: Basketball stadium consumption

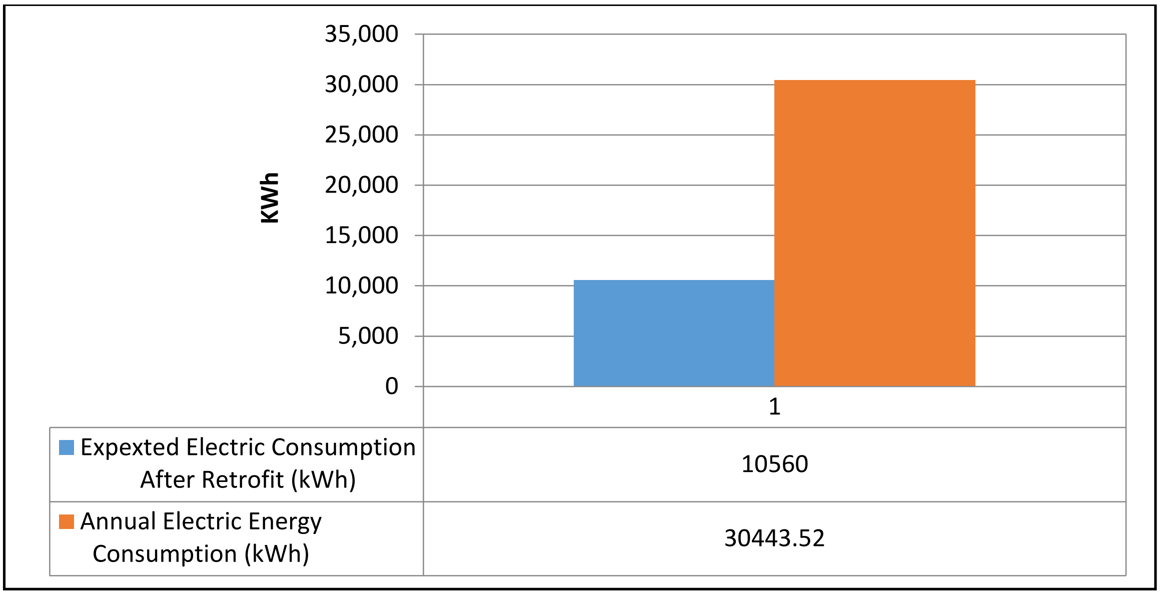

Figure 39: Basketball stadium consumption before and after retrofit

5.3 Salle Olympic Mzali Monastir - closed basketball arena

Table 26 shows the details of the lighting system for the basketball Arena. This table shows the types of the lighting lamps and their quantities, the electric load in kW, the annual energy consumption in kWh and the share of each type of the total calculated annual energy consumption of the basketball stadium.

Table 26: Basketball arena lighting load

Lighting Unit Type	No. Of Connected Lamps	Total Connected Load (Kw)	Annual Total Electric Energy Consumption (kWh)	Share Of Overall Electric Energy Consumption (%)
Fluorescent T8 36W	40	2	3600	8.88%
Fluorescent T8 18W	160	4	7200	17.76%

Halogen 15W	20	0.3	540	1.33%
Hps 250W	18	5.22	5011.2	12.36%
Hps 400W	55	25.19	24182.4	59.66%
Total		**36.71**	**40533.6**	**100%**

Table 27 shows the recommendations to replace each type of the existing lighting types in the basketball arena including the annual expected energy saving, annual cost saving, the required investment cost, the expected life time for the system and the simple payback period for these recommendations. Figure 40 shows the share of each lighting type of the total electric load.

Table 27: Basketball arena lighting retrofitting

Ecms	No. of Lamps to be Replaced	Total Connected Load (Kw)	Annual Energy Saving (kWh)	Annual Cost Saving (Td)	Investment (Td)	Expected Lifetime (Yr.)	Simple Payback Period (Yr.)
Replace Fl 36W With LED 20 W	40	0.8	2160.0	432.0	1000	25	2.3
Replace Fl 18W With LED 10 W	160	1.6	4320.0	864.0	2400	25	2.8
Replace Halogen 15w With LED 5W	20	0.1	360.0	72.0	200	25	2.8
Replace HPS 250W With LED 100W	18	1.8	3283.2	656.6	9000	25	13.7
Replace HPS 400w With LED 150 W	55	8.25	16262.4	3252.5	38500	25	11.8
Total		**12.55**	**26385.6**	**5277.1**	**51100**		**9.7**

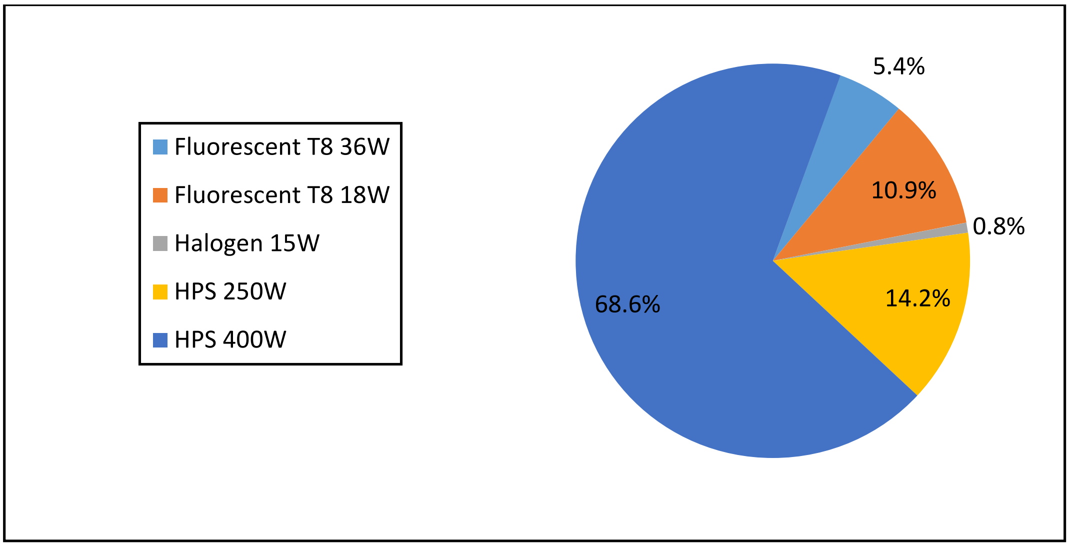

Figure 40: Basketball arena lighting load

Figure 41 shows the share of the electric energy consumption of each one of the lighting types to the total annual energy consumed by the stadium. Figure 42 shows the annual energy consumption before and after applying these recommendations.

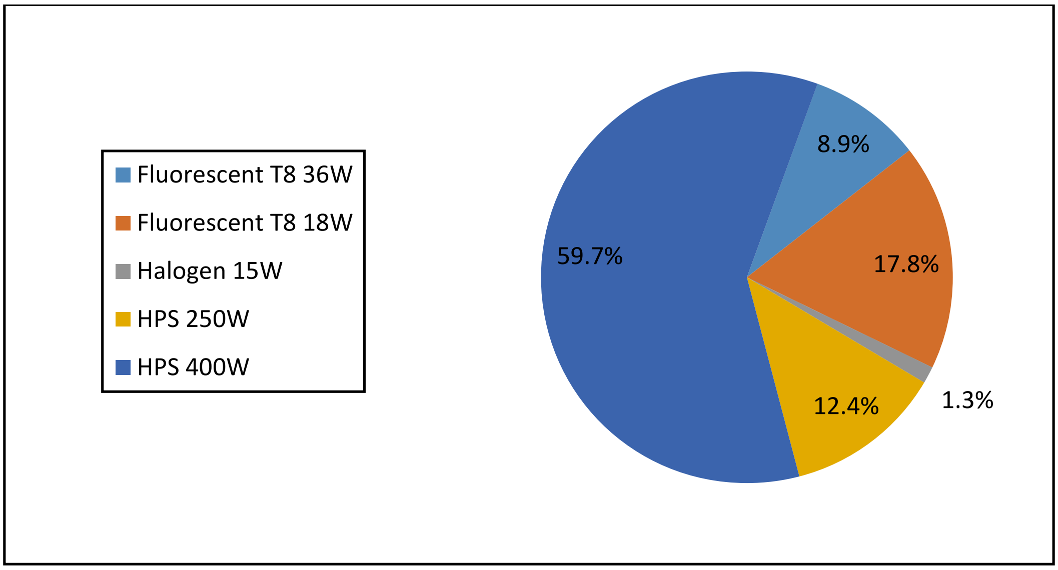

Figure 41: Basketball arena lighting consumption

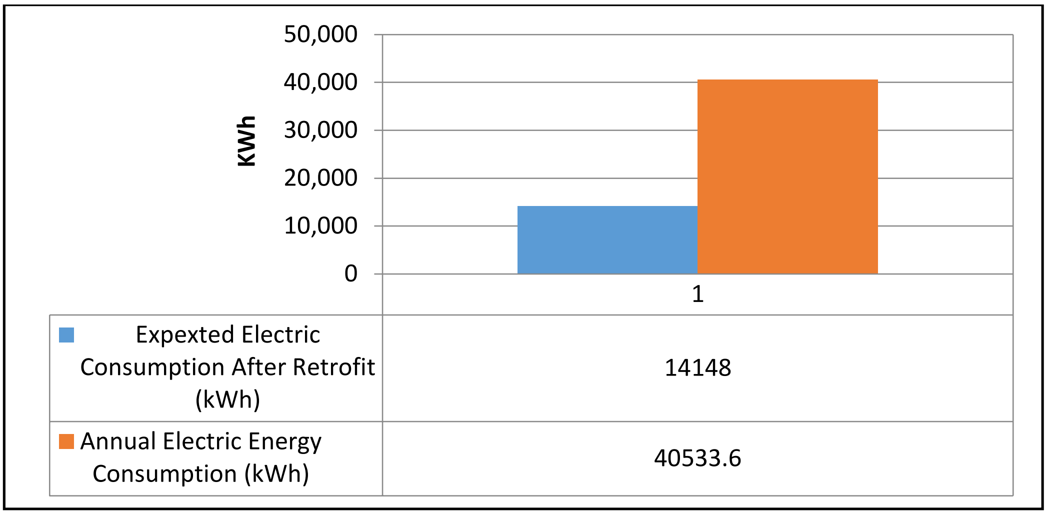

Figure 42: Basketball arena consumption before and after retrofitting

5.4 Municipal market and stores

In Table 28 hereunder, the energy and cost savings, simple payback period (SPB) for replacement of the lighting units in the stores and the market are shown.

Table 28: Energy saving opportunities in the market and the stores at Monastir's Municipality

ECMS	Current Energy Consumption (kWh)	Energy Saving (kWh)	Cost Saving (Td)	Investment (Td)	Pbp (Yr.)
The Store					
Replacing Incandescent 60 W with LED Bulb 10 W	954.0	795	159.00	140.0	0.88
Replacing Merc 400 W with LED Flood 180 W	25,652.0	15,158	3,031.60	6600.0	2.18
Replacing Fluorescent 36 W with LED Tube 18 W	5,300.0	3,392	678.40	1200.0	1.77
Replacing Fluorescent 18 W with LED Tube 9 W	4,240.0	2,714	542.72	1493.3	2.75
Replacing HPS-Street Lighting 400w With LED -Street 180 W	10,494.0	6,201	1,240.20	2700.0	2.18
Replacing CFL 16 W with LED Bulb 6 W	593.6	371	74.20	233.3	3.14
Total	**47,233.6**	**28,631**	**5,726.12**	**12,366.6**	**4.32**
The Market					
Replacing Incandescent 60 W with LED Bulb 10 W	21,024	17,520	3,154	2,800	0.9
Replacing Fluorescent 36 W with LED Tube 18 W	5,840	3,738	673	1,200	1.8
Replacing CFL 27 W with LED Bulb 6 W	1,340	1,042	188	283	1.5
Total	**28,204**	**22,300**	**4,014**	**4,283**	**1.1**

5.5 Municipal slaughter house

Table 29 shows the details of the lighting system for the municipal Slaughterhouse. This table shows the types of the lighting lamps and their quantities, the electric load in kW, the annual energy consumption in kWh and the share of each type of the total calculated annual energy consumption of the slaughterhouse.

Table 29: Lighting system for municipal slaughterhouse

Lighting Unit Type	No. of Connected Lamps	Total Connected Load (Kw)	Annual Total Electric Energy Consumption (kWh)	Share Of Overall Electric Energy Consumption (%)
Fluorescent T8 36W	10	1	480	46.3%
HPS 250w	4	1.16	556.8	53.7%
Total		**2.16**	**1036.8**	**100%**

Table 30 shows the recommendations to replace each type of the existing lighting typess in the slaughterhouse including the annual expected energy saving, annual cost saving, the required investment cost, the expected life time for the system and the simple payback period for these recommendations. Figure 43 shows the share of each lighting type of the total electric load.

Table 30: Lighting system for municipal slaughterhouse

ECMS	No. Of Lamps To Be Replaced	Total Connected Load (Kw)	Annual Electric Energy Saving (kWh)	Annual Cost Saving (Td)	Investment (Td)	Expected Lifetime (Yr.)	Simple Payback Period (Yr.)
Replace Fl 36w with LED 20 W	10	0.2	384.0	76.8	250	25	3.3
Replace Hps 250w with LED 100w	4	0.4	364.8	73.0	2000	25	27.4
Total		**0.6**	**748.8**	**149.8**	**2250**		**15.0**

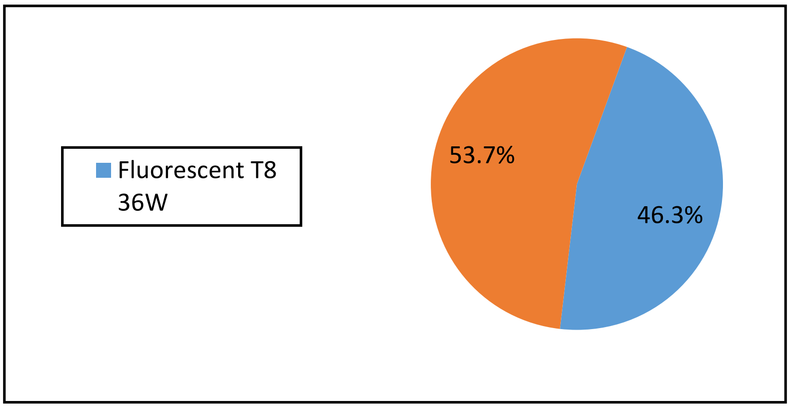

Figure 43: Slaughter house lighting load

Figure 44 shows the share of the electric energy consumption of each one of the lighting types to the total annual energy consumed by the slaughterhouse. Figure 45 shows the annual energy consumption before and after applying these recommendations.

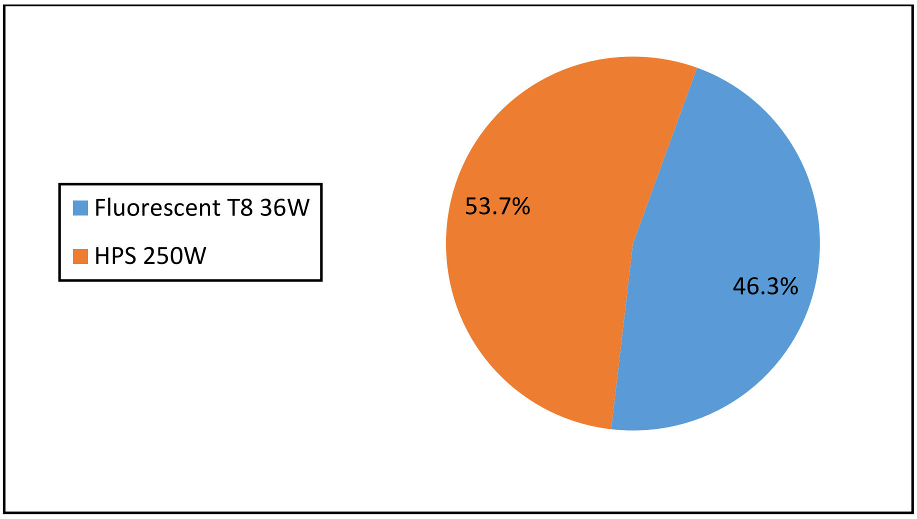

Figure 44: Slaughter house lighting energy consumption

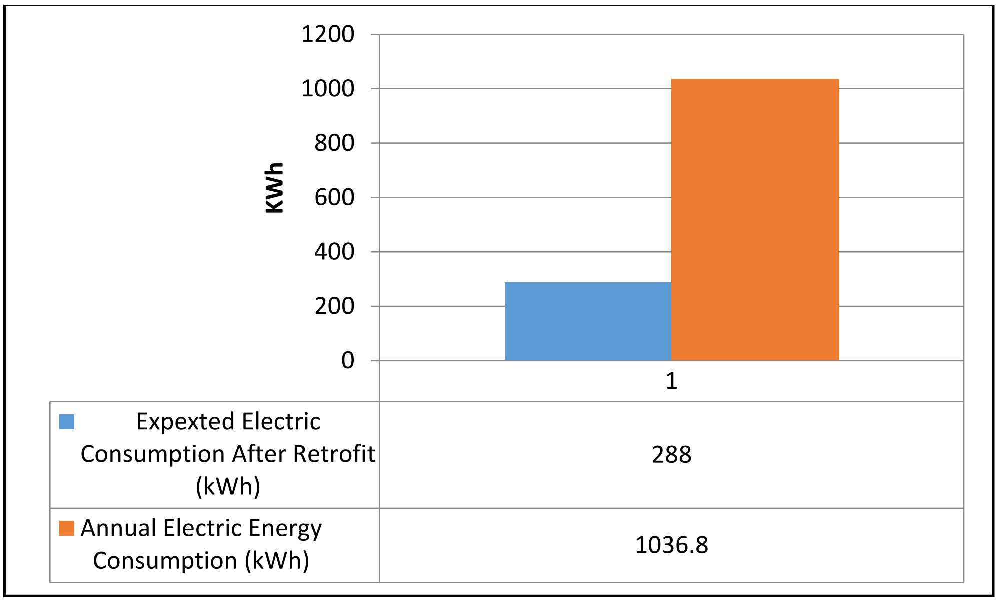

Figure 45: Slaughterhouse lighting system consumption before and after retrofit

5.6 Public grid lighting

Table 31 shows the details of the lighting system for public grid lighting system. This Table shows the types of the lighting lamps and their quantities, the electric load in kW, the annual energy consumption in kWh and the share of each type of the total annual energy consumption of the public grid lighting.

Table 31: Public Grid Lighting Load

Lighting Unit Type	No. of Connected Lamps	Total Connected Load (Kw)	Annual Total Electric Energy Consumption (kWh)	Share Of Overall Electric Energy Consumption (%)
Mercury Vapor 125W	3100	431	1193499	22.2%
Mercury Vapor 250W	1900	551	1525796	28.4%
HPS 70W	100	8	22153	0.4%
HPS 150W	750	128	354450	6.6%
HPS 250W	2840	824	2281771	42.4%
Total		**1942**	**5377670**	**100.0%**

Table 32 shows the recommendations to replace each type of the existing lighting types in the public lighting grid including the annual expected energy saving, annual cost saving, the required investment cost, the expected life time for the system and the simple payback period for these recommendations. Figure 46 shows the share of each lighting type of the total electric load.

Table 32: Public grid lighting retrofit

ECMS	No. Of Lamps To Be Replaced	Total Connected Load (Kw)	Annual Electric Energy Saving (kWh)	Annual Cost Saving (Td)	Investment (Td)	Expected Lifetime (Yr.)	Simple Payback Period (Yr.)
Replace MV 125W with LED 75W	3100	232.5	549674	126425	1395000	25	11.0
Replace MV 250W with LED 100 W	1900	190	999660	229922	950000	25	4.1
Replace HPS 70W with LED 40W	100	4	11077	2548	25000	25	9.8
Replace HPS 150W with LED 75W	750	56.25	198686	45698	337500	25	7.4
Replace HPS 250W with LED 100W	2840	284	1495336	343927	1420000	25	4.1
TOTAL		**766.75**	**3,254,432**	**748,519**	**4,127,500**		**5.5**

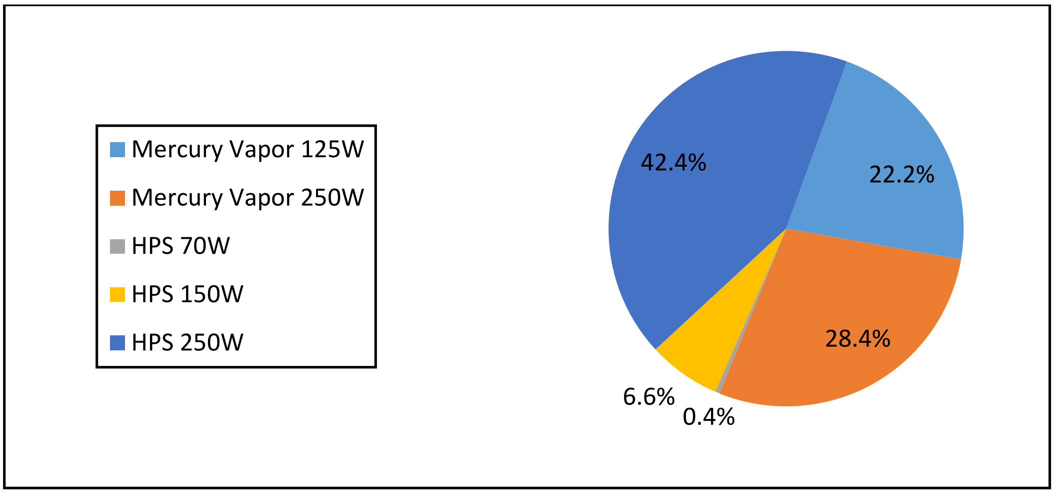

Figure 46: Public grid lighting load breakdown according to lighting units' types

Figure 47 shows the share of the electric energy consumption of each of the lighting type to the total annual energy consumed by the public lighting grid. Figure 48 shows the annual energy consumption before and after applying these recommendations.

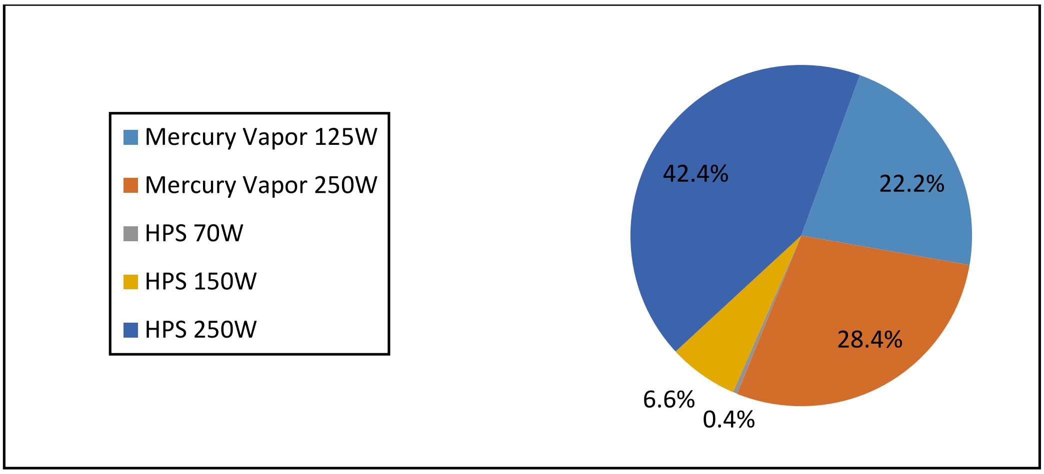

Figure 47: Public Grid Lighting energy consumption breakdown according to lighting unit type

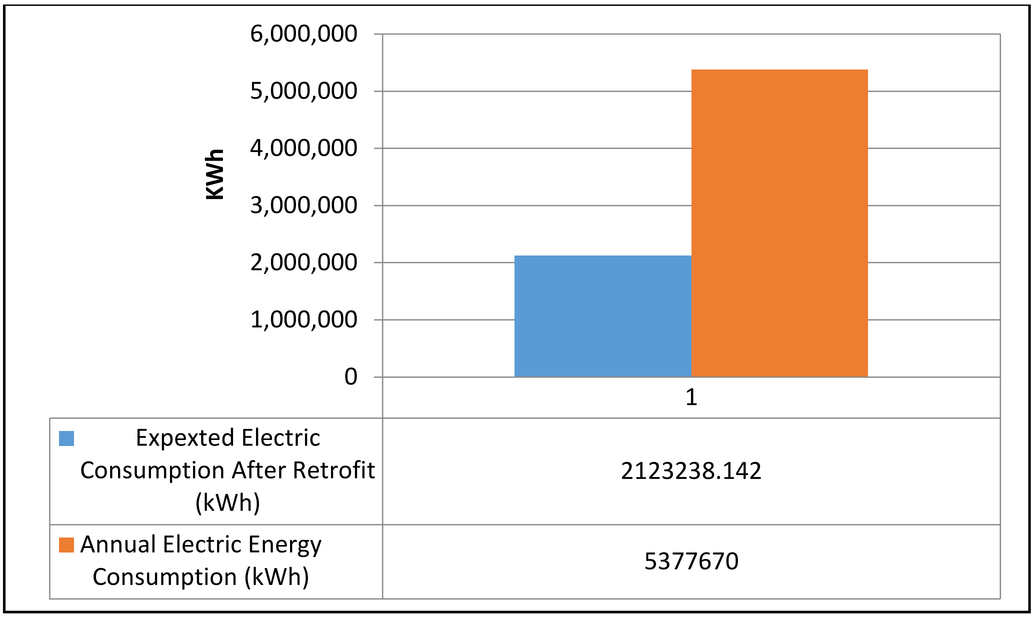

Figure 48: Public lighting grid consumption before and after retrofit

Improvement of public lighting grid

Improvement of the public lighting grid is very important in order to cover all the required areas within the Monastir municipality and be able to cover any possible expansions in the future. This can be performed by:

1. Applying regular preventive and corrective maintenance plan for the grid.
2. Installing the necessary protection schemes for the grid.
3. Installing high efficiency lighting units and grid components such as transformers, etc.

4. Applying energy-efficient control schemes for the lighting grid in order to reduce the consumed energy.

5.7 Water pumping station

Based on our assessment, the following are the recommendation for the water pumping station:

1. Replacing three pumps with new efficient larger pumps with a VFD controller.
2. Secure relative sources of electricity for the pumping stations.

1. Replacing three pumps with new efficient larger pumps with a VFD controller

Since the parallel pumps consumes more energy than single pumps to deliver a specified flow, thus using single pump with capacity larger than the existing pumps will reduce the needed input power and will make the control easier than the parallel pumps. Therefore, it is recommended to replace three existing pumps with two larger pumps (one standby) while keeping one existing pump as a back-up, to insure that the new single pump can deliver flow rates between 0 and 600 m^3/hr with a pressure range of 2 – 3 bar, and an output power of around 45 kW with efficiency range of 75% - 81%.

Moreover, pressure-dependent control is particularly suitable for this kind of open systems with variable volumetric flow. This is brought about by various withdrawal rates (throttling) at the consumption points. Thus, the variable frequency drives are highly recommended for the pumps to supply sufficient pressure (flow pressure) to the consumption points at different flow rates. Due to the varying volumetric flows, variable pressure losses occur in the transport pipes. If the measuring point lies at the pump, the controlled operation curve has a constant (horizontal) path. Figure 49 shows a schematic diagram and control curve for the pressure-dependent control (Source KSB).

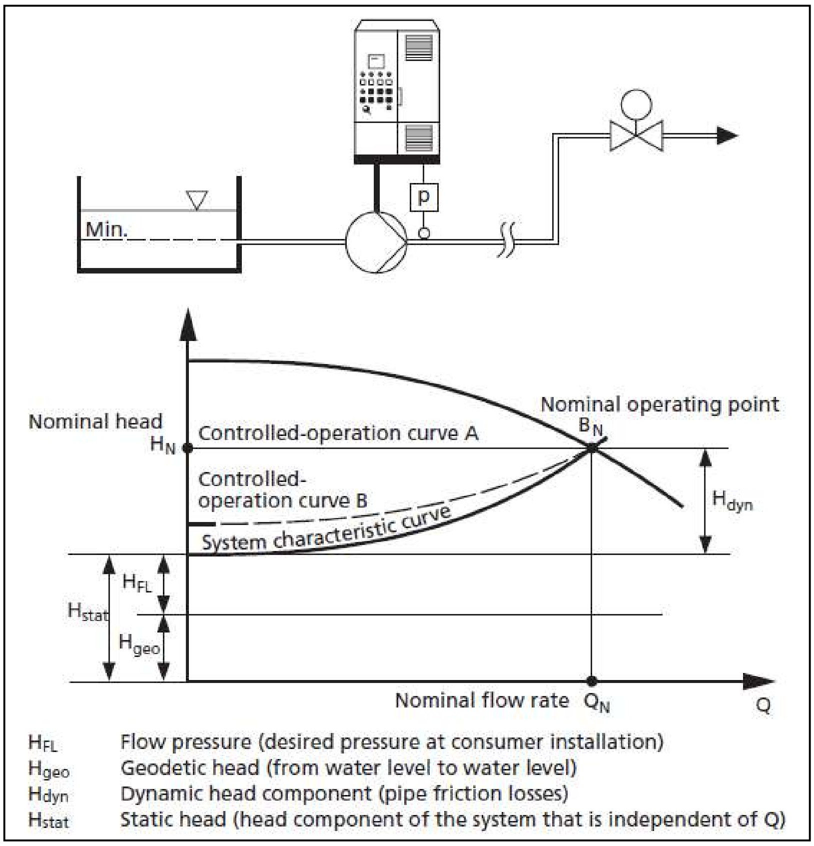

Figure 49: Schematic diagram and control curve for the pressure dependent control

Energy saving can result from using a larger single pump with a variable speed controller instead of the existing pumps. The energy saving was calculated based upon some figures and diagrams sourced from a large pumping company, as per the H/Q diagram (Figure 50), the power diagram (Figure 51) for the input power at the pump shaft, the diagram relating to the saving electric power (Figure 52) and the load profile (Figure 53). Electricity costs are taken to be TND 0.22/ kWh.

The annual load duration curve is converted into rectangular blocks for convenience to express the ordered annual duration curve when using the VFD controller as shown in Figure 54.

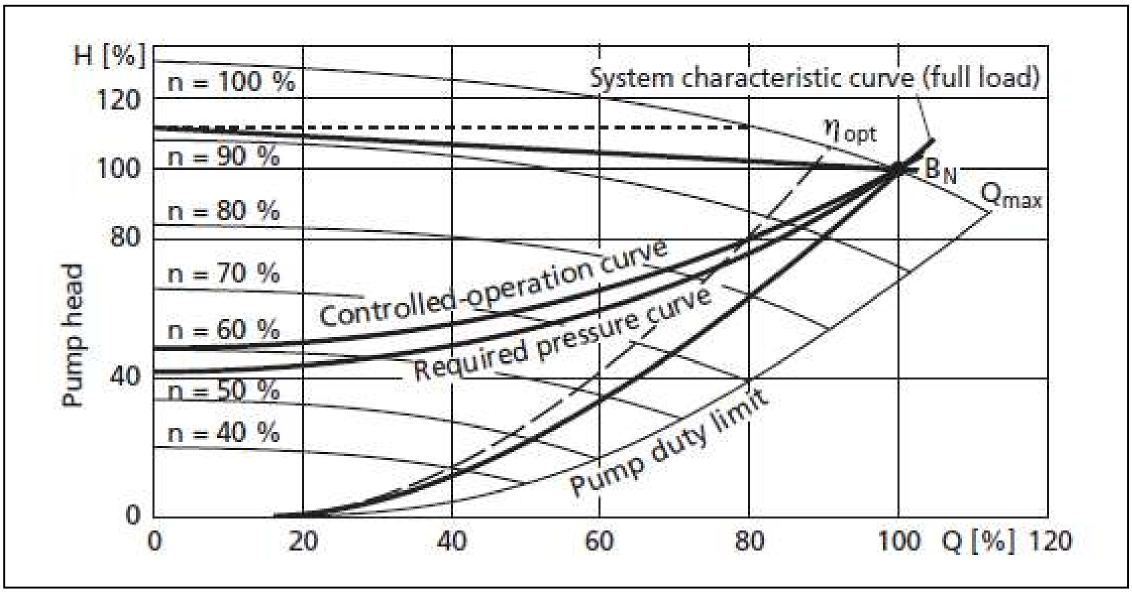

Figure 50: H/Q diagram with VFD control

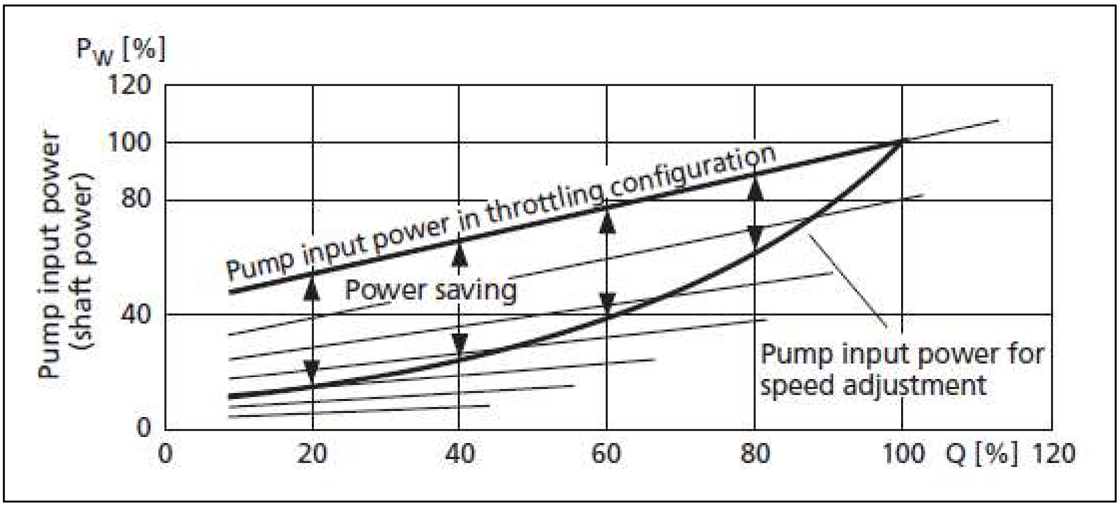

Figure 51: Shaft power diagram with VFD control

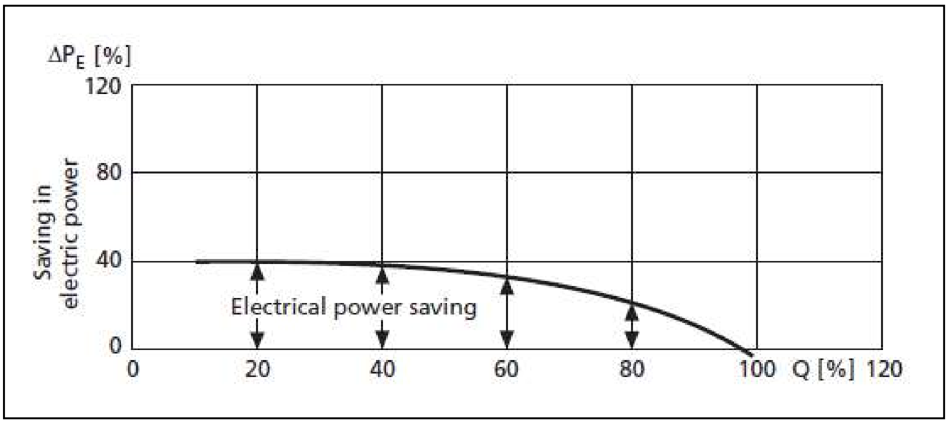

Figure 52: Electric power saving diagram with different flow rates using VFD controller

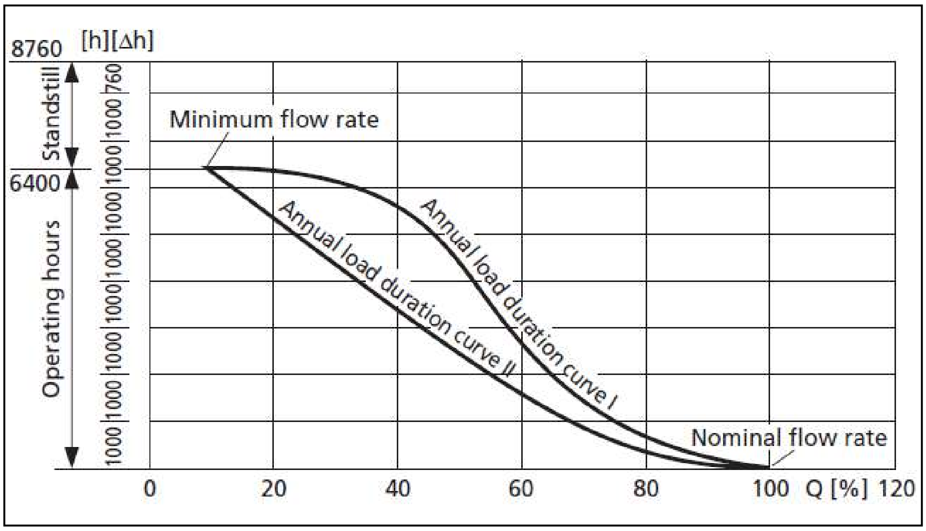

Figure 53: Estimated load profile for pumping operation and flow rates

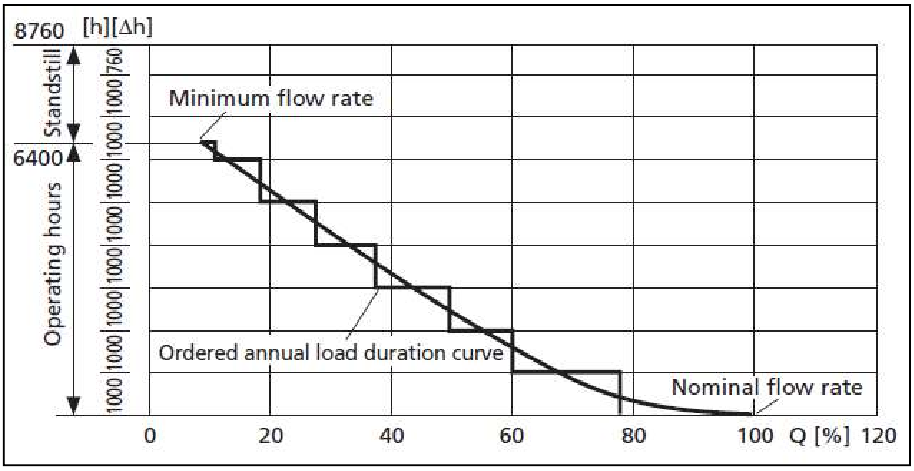

Figure 54: Load profile for pumping operation when using VFD controller

reference to Figure 54, in each case the average flow rate over 1000 operating hours is considered with a percentage of 15.62% of the total operating hours with total hours of 6400 hrs., but in the existing case, projection of this number on the actual total operating hours (7460 hrs.) for the pump was done as shown in Figure 55.

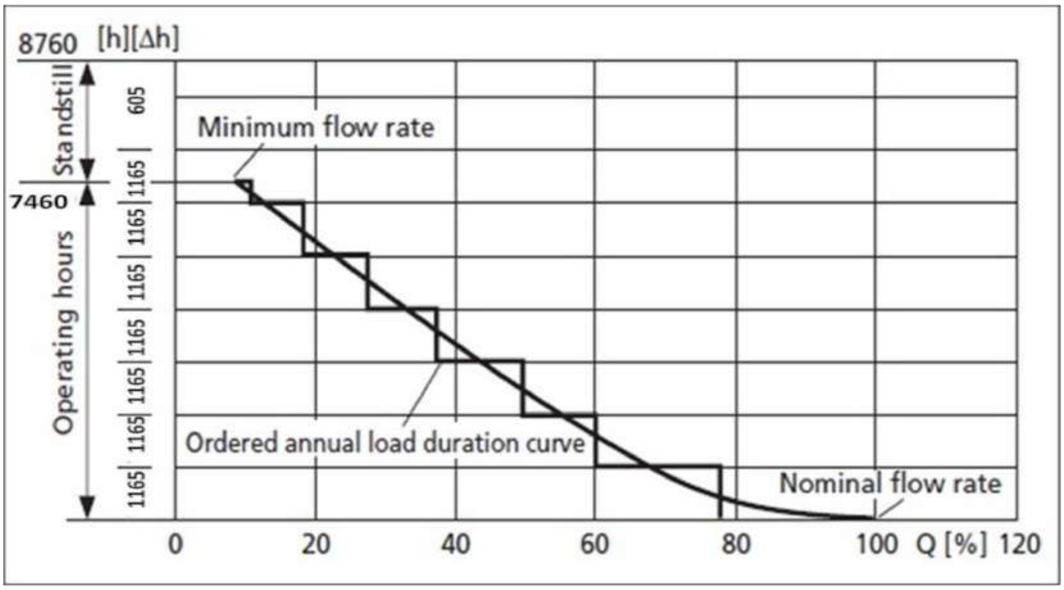

Figure 55: Projected load profile for the actual pumping operation

Each average flow rate can be assigned the saved electric power from the saving diagram. It is estimated that 50% of the flow rate is permanently required within 31% of the total operating hours; the associated electric power saving averages 38 %. Multiplying the saved electric power by the proportional operating hours and the price of electricity yields the saving for the time. Then the proportional savings must be added up.

Table 33 shows the flow rate percentages and the corresponding power and energy saving in addition to the estimated cost saving per year per 1 kW shaft power.

Table 33: Expected energy and cost saving per 1 kW by using VFD controller

Flow rate percentage $Q/Q_{nominal}$ [%]	Saved electric power per 1kw Kw/ (Kw)	Operating hours (hr/yr.)	Annual energy saving per 1 kw (kWh/kw)
69%	0.23	1,165	268
55%	0.35	1,165	408
42%	0.38	1,165	443
34%	0.4	1,165	466
23%	0.4	1,165	466
12%	0.4	1,165	466
9%	0.4	466	186
		7,457	Total = 2,703

From table 33 and based on 45 kW proposed shaft power, the total energy consumption can be reduced by using VFD controller on the new single pump is as follows:

Total Annual Saving (kWh) = 2,703 kWh/kW * 45 kW = 121,635 kWh

Annual energy consumption for the new single pump without using a VFD controller can be assumed as follows:

Total annual consumption without using a VFD controller is:

$$\frac{45\ kW\ (Shaft\ power)}{0.87\ (Motor\ Efficiency)} * 7460\ hrs/yr$$

Total annual consumption without using a VFD controller = 385,862 kWh/yr

Thus, when using the VFD controller the annual energy consumption for the new single pump will reach **264,227 kWh/yr**.

Finally, when comparing the expected energy consumption of the new single pump (264,227 kWh/yr) with the existing pumps' consumption (492,157 kWh/yr), it can be considered that there is an annual energy saving of **227,930 kWh** that can be achieved with expected CO_2 emissions reduction of 144.2 ton CO_2/yr. (considering 0.6328 kg CO_2/kWh[1]).

- **Cost Saving:**

  Cost Saving = 227,930 kWh/yr. * 0.22 TND/kWh = **50,144.6 TND**

- **Cost of Investment:**

  Average cost of the new centrifugal pumps with VSD motors = **49,612.0 TND**

  Average cost of VFD controllers with pressure transducers = **32,247.80 TND**

  Total investment cost = **81,859.80 TND**

- **Simple Payback Calculation:**

  SPBP = **1.63 years**

Relative sources of electricity for the pumping stations

The electricity from the grid network is the only source of energy to run the Monastir pumping station. Therefore, the availability of water and electricity sources at the same time in the pumping station is a critical matter since unavailability of one of them will cease work at the station; this will have an effect on the water security for people and agricultural. Based on this, securing another source of electricity and water will solve this problem.

[1] Reference: ecometrica, Technical Paper /Electricity-specific emission factors for grid electricity, August 2011

One of the best options to secure the electricity through the day is using an on-grid photovoltaic system with a back-up diesel generator for cloudy days and cut-off hours, which can cover the pumping station demand over the course of the year and the energy cost for water supply. A detailed analysis for this part can be found in the renewable energy report.

Other Recommendations for the water pumping station

Due to the numerous routine maintenance requirements, it is recommended that a Computerized Maintenance Management System - CMMS be acquired to keep track of maintenance issues. This will aid in identifying more accurately energy related breakdowns and maintenance events.

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