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Post Energy Audit of Two Mosques as a Case Study of Intermittent Occupancy Buildings: Toward more Sustainable Mosques

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Abstract: Mosques are buildings with a unique occupancy schedule and special energy and water consumption scheme. Generally, this type of buildings lacks the application of energy efficiency solutions and sustainable guidelines during the conception, construction and the operation phase. Interestingly, these iconic edifices can play a key role in raising awareness for sustainability and promoting cleaner energy technologies. The first aim of this work is to present energy audit results, recommended energy savings solutions for two historical mosques in Marrakech (Morocco). A detailed discussion of the adopted solutions is presented and an economic assessment was performed. Then, a two-year energy savings evaluation was conducted for the two mosques. Conclusions about the adequacy of the proposed solutions is presented. The second part is dedicated to outline some guidelines and sustainable criteria to consider for establishing an international sustainable mosques label. The creation of a such sustainable label will encourage spreading sustainable best practices in mosques and other types of buildings. It will also help to compare sustainable performances of different mosques around the world by establishing an adapted sustainable rating system.

Keywords: building energy audit; post energy audit results; sustainable mosques; sustainable label guidelines

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1. Introduction

In response to the increasing energy consumption trend in the building sector, many countries have developed different policies and strategies aiming at limiting and controlling this energy consumption [1]. These policies consist generally of thermal codes, calculation frameworks, labels, buildings rating system according to energy consumption level, economic incentives to install renewable energy solution and obligatory energy audit [2]. As the energy savings challenges differs according to the building's main utility, energy consumption scheme and operation schedules, some countries adapted their frameworks for each category of building. For example, some European countries like Austria divided their nonresidential buildings framework calculation into 11 categories which are: office buildings, nurseries and compulsory schools, secondary schools and colleges, hospitals, care homes, guest houses, hotels, bars and restaurants, meeting places, sports facilities, and sales outlets [2].

This strategy will also help establish adapted performance ratios, benchmark between buildings within the same category and promote best practices.

One of the most iconic building in Arab and Islamic countries are mosques, which are religious worshiping buildings for Muslims that could serve also as multi-functional community space that involve occupancy. Besides the significant role that mosques play on shaping the society mainly through religious activities [3], they have, as a building, a very particular energy consumption scheme and occupancy schedule [4]. According to the Deloitte study, the number of the mosques around the world exceeded 3.6 million in 2015 and it is expected to rise to 3.85 million by the end of 2019 [5].

This subject interested many researchers that studied different aspects of mosques, such as indoor comfort, energy consumption and impact on sustainability.

As for any type of buildings, occupants' comfort is a central aspect that affects its main function. For mosques, feeling comfortable during the prayer help worshipers to attain a feeling of tranquility, peace and serenity. The authors of [6] studied air change rate influence on indoor air quality in Al-Masa'a between Al-Safa and Al-Marwa hills inside Al-Haram mosque using a CFD simulation software. The authors of [7] monitored and assessed, according to the ASHRAE standard 55 (2010), the quality of indoor thermal comfort of an old mosque in Turkey. They also investigated the benefit of using a low-energy heating solution consisting of an electrical underfloor heating system with intermittent operation schedule to reduce thermal discomfort during cold season.

Ref. [8] studied the sustainable lighting schemes in historical mosques using fenestration to ensure an optimal daylight autonomy by achieving visual comfort and reducing energy consumption. The authors of [4] studied the impact of façade passive design strategies of urban mosques on the urban environment, thermal comfort and energy consumption.

The authors of [9] explored in detail the effect of some mosque's stereotype elements, like symmetry and structurally redundant elements, on the three dimensions of sustainability. They provided also a quantification of negative and positive impacts of these elements for a case study mosque.

Ref. [10] is a case study based on software simulation how an effective design strategy for a Big mosque can lower energy consumption in Kingdom of Saudi Arabia.

Mosques are categorized as intermittent occupied buildings [11,12] with a particular operation schedule. They are occupied five times a day for a period of 30 to 60 min each time. These times are: dawn, noon, afternoon, sunset and evening. We should also consider a congregational prayer on Friday mid-day that takes more than 2 h.

In general, a mosque's most important energy consumptions utilities are: lighting, Heating Ventilation and Air Conditioning (HVAC) systems, hot water, fans, sound equipment and sometimes the mosque includes a residential area for the imam (the person responsible for the mosque). The energy consumption size of each utility depends on the climate condition, mosque architecture, activities held in the mosque, country, etc. For example, in the arid climates, HVAC equipment are the greater energy consumers [6,8,13].

These precedent papers focused on presenting mosques' main energy consumption characteristics and proposed some solutions to reduce it. However, no study showcased post audit results to assess the adequation of the solutions proposed and the relevance of energy savings estimations. Another remark is that there was no global view for mosques' sustainability aspects; the major key factor that was redundantly studied is energy consumption besides acoustic and thermal comfort.

This study will initially focus on presenting the work done for two historic mosques in Morocco. It consists of an energy audit to identify main energy uses, energy-intensive equipment and to establish a global energy balance. Then, we propose main solutions to reduce this energy consumption and monitor for one-year energy savings results of these solutions to conclude about their adequacy and pertinence.

The second part is dedicated to proposing some guidelines to include for establishing an international sustainable mosque label.

2. Energy Audit

2.1. Presentation of the Two Mosques

The two studied mosques are the Koutoubia Mosque and the Casbah Mosque. These mosques, beside their historic value, were chosen by the Moroccan Ministry of Islamic affairs to be the pilot mosques for the Green Mosque project and also to showcase this ambitious project during the COP21 that was held in Morocco in 2016.

- Koutoubia Mosque:

There are six interior rooms, one above the other. Wrapping around them is a ramp that can be used by the muezzin to reach the balcony. The prayer hall is in a "T" shape. It is large, to the south, and abuts the courtyard at its northern end. The prayer hall is a hypostyle with more than 100 columns that support horseshoe-shaped arches along the parallel naves. Figure 1 below shows the architecture of Koutoubia Mosque.

Figure 1. Koutoubia mosque architecture. Source: Google Maps.

- The Moulay El Yazid (Kasbah) Mosque:

The mosque's shape in plan is almost a square. The layout is dominated by the size of its courtyard, which is divided into five parts: a very large central courtyard and four smaller auxiliary courtyards. The courtyard is 42 m long and 62 m wide overall, while the prayer hall is only 22 m long and 62 m wide.

As shown the Figure 2, a large roofless space is surrounded by the indoor prayer hall on one side and by another roofed gallery running along the other sides, the main courtyard features two fountains serving for ablutions before prayer. The prayer hall itself is located on the south side of the courtyard and is a hypostyle space with rows of arches three aisles deep. Figure 3 below shows the entrance view of the two mosques.

Figure 2. Kasbah mosque architecture. Source: Google Maps.

(**a**) (**b**)

Figure 3. Views of the two mosques: (**a**) Entrance view of Moulay El Yazid (The Kasbah) Mosque, Marrakech; (**b**) View of Al Koutoubia Mosque, Marrakech.

Table 1 below summarizes important information about the two mosques (surface area, type, capacity, etc.).

Table 1. Summary of important data about the two mosques.

	Al Koutoubia Mosque	**The Kasbah Mosque**
Construction date	1199	1190
City	Marrakech, Morocco	
Total surface	5300 m^2	8000 m^2
Activities	Everyday prayer, Friday prayer, Literacy and Quran Course	
Accommodation capacity	2500 persons (approx.)	2000 persons (approx.)
Opening time	Half an hour before and after each prayer	Half an hour before and after each prayer
Presence of commerce	No	No
Presence of habitat	Yes	No
Site coordinates	31°36′55.2″ N, 7°59′26.6″ W	31°36′55.2″ N, 7°59′26.6″ W

2.2. Energy Audit Methodology

Auditing mosques follows the same steps and procedures as auditing any commercial building. Ref. [14] developed a systematic approach to energy audit in mosques. The main objectives of the energy audit were to collect and analyze data about energy use in the two mosques. These data include: zoning of the mosque, A/C systems, lighting systems, power supply, hot water systems, etc.

The first step was to conduct an opening meeting with the main stakeholders of the energy management of the two mosques (operational and administrative) to understand the main challenges and characteristics of mosque's energy consumption. It was also important to specify and limit the energy audit scope. Then, a data collection work was done to identify and list the main energy consuming equipment, their technical characteristics and energy usage scenarios.

A measurement plan was conducted to complete needed data and a get daily energy consumption scheme for both mosques. With the help of electrical network analyzer, a thermal camera and luxmeter, an energy balance of the most important energy uses of the mosques was established. Then, the gathered data was analyzed to identify the most relevant energy efficiency solutions.

As there was no energy sub-meter for each energy use (lighting, vacuum cleaner, etc.), the energy balance was established based on the installed power of each equipment and its running time. Table 2 below details the power of each equipment.

Table 2. Equipment power for each mosque.

	The Kasbah Mosque		**The Koutoubia Mosque**	
Facilities	**Quantity**	**Total Power (W)**	**Quantity**	**Total Power (W)**
Vacuum	1	3000	1	3000
Lamps	680	27,200	850	34,000
Lamps	6	150	12	300
Fluorescent tube	4	112	4	112
sound system	1	600	1	400
Water dispenser	1	550		
Fan	1	45		
Fridge *			1	300
Television *			1	100
Water heater *			1	2000
Freezer *			1	250
Washing machine *			1	1500

(*) Equipment that was used in the imam's house, which is attached to the Koutoubia mosque.

This power balance was complemented by an energy balance that takes into consideration the duration and usage scenario for each equipment to estimate the daily and monthly energy consumption profile. Figures 4 and 5 present respectively the calculated theorical energy consumption distribution of Koutoubia and Kasbah Mosque:

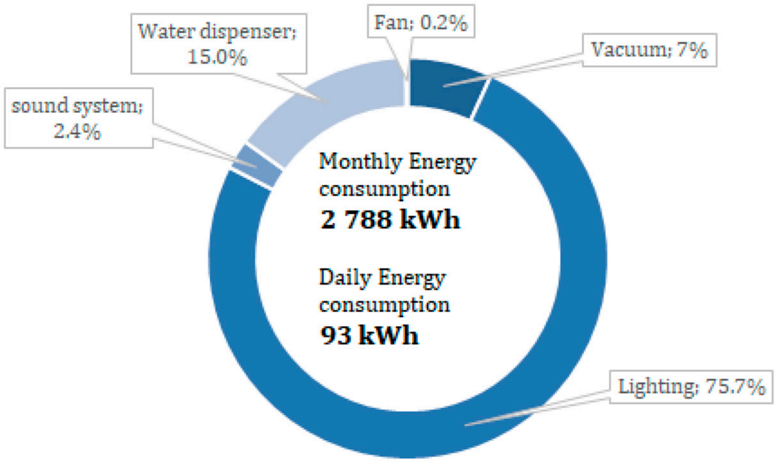


Figure 4. Theorical electrical consumption balance for the Koutoubia mosque.

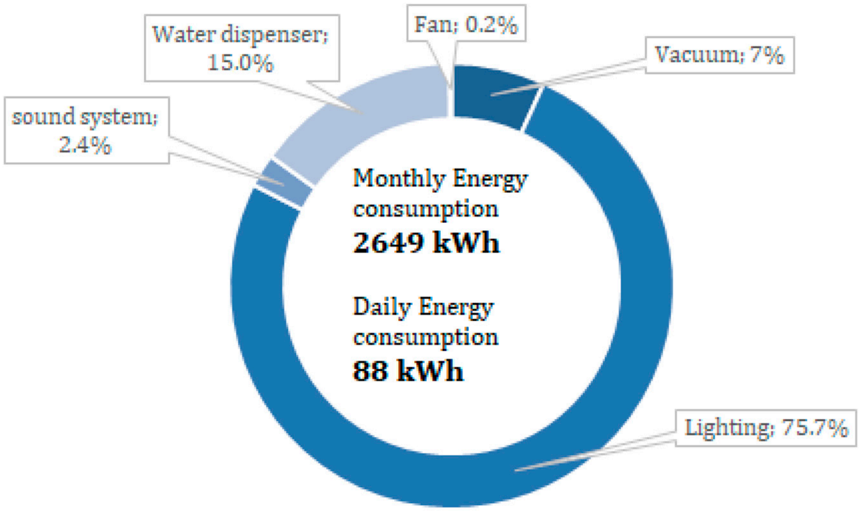


Figure 5. Theorical electrical consumption balance for the Kasbah mosque.

This theorical energy balance was compared to electricity bills of the two mosques for three years (2014 to 2016) to validate the results. For example, the bill indicates that energy consumption for Kasbah Mosque varies from 1700 kWh to 3500 kWh per month, with an average value of 2400 kWh that confirms the results of the theorical energy balance. For Koutoubia mosque, average monthly energy consumption is 2500 kWh, which is similar to the calculated energy balance.

As in most historical mosques, no HVAC system is used in the two mosques [7]; they are naturally ventilated through the courtyard. Moreover, the two mosques have “wide” walls composed of rocks ensuring a good thermal inertia that helps flatten out heat thermal fluctuations keeping a thermal comfort [15].

The main factor that influences the energy consumption and which is hard to predict, is the lighting consumption. In addition to being by far the major energy use for the two mosques, the lamps usually used are an incandescent low-quality type that are damaged frequently and easily, sometimes more than 20 lamps are changed each week. Replacing damaged lamps is not systematic, and this results in frequent and for some long periods a reduced installed power for lighting and, consequently, poor-quality lighting. This explains the difference in energy consumption throughout the year, as generally the activity and the occupancy schedule is the same. We took this into consideration when establishing our theorical energy balance; we considered only 40% of installed power of lighting is operational.

Another factor to consider also for lighting energy consumption is the courtyard that plays a relevant role in promoting natural lighting and spreading it all over the mosque through the internal fenestration and glass doors. This passive technique and others similar to it are used generally in most historical mosques, which lowers lighting energy consumption, as discussed by El-Darwish et al. [8].

As these historic mosques have a high heritage and value, the proposed energy-saving solutions should be carefully examined to preserve their historic value of the edifice [7].

Some energy efficiency solutions were considered but could not be implemented in the two mosques due to budget restrictions and tight deadline. Below is a list of these solutions:

- Programmed timer for lighting: this solution will help turn off lights in the mosque and toilets, automatically in predefined hours.
- Lighting zoning: improving the lighting control so that not all the spotlights will be used at once; zoning by area and limited number in each chandelier. This also includes possibility to have two or three status lighting for the mosque according to the natural lighting degrees.
- Recycling pumps: it is one of the very efficient options that could help increase the energy efficiency of a Solar Water Heater (SWH). These recycling pumps will help keep the water hot whenever the tap is opened, so it avoids thermal losses of hot water in the duct systems by permanently recycling the water between the ducts and the storage tank.
- Installing energy meters for the imam's house to monitor the energy consumption of the house.
- Grid injection: injecting surplus electricity produced by photovoltaic (PV) panels in the grid is not allowed yet in Morocco.
- Green Roof: it is one of the sustainable solutions for roof insulation that ensures a good thermal comfort in buildings and energy savings. In the case of historical mosques, it is difficult to install this kind of solution on the roof as it can damage or the terrace of the mosque [16].

The adopted solutions are the following: LED Lighting, Solar Water Heater and PV panels. The details of the sizing of these solutions is described in the paragraphs below.

2.3. *Efficient Lighting*

Light in mosques has a symbolic and spiritual meaning, as it is used to enhance the decorative and aesthetic aspects of the interior spaces [17]. As three prayers out of five take place during evening or night, lighting energy consumption is the second highest energy use in mosques just after the HVAC systems and first when no conditioning is used [18]. Besides this key role, lighting is also an important energy use that should be optimized. As pointed out by [8], the daylight autonomy is key factor to evaluate natural lighting performance in mosques and the artificial lighting system should be designed to complement this passive lighting.

For the two studied mosques, the need for visual comfort has two main objectives: (i) help perform the prayer, which is an activity that does not need a higher illuminance; (ii) read the holy Quran, which occurs generally in the front lines (near the mihrab). The architecture of the two mosques makes no need of artificial lighting during most of the day as the courtyard ensures a good natural lighting.

We measured with a luxmeter the illuminance values two hours before sunset, and the results are presented in Figure 6 below:

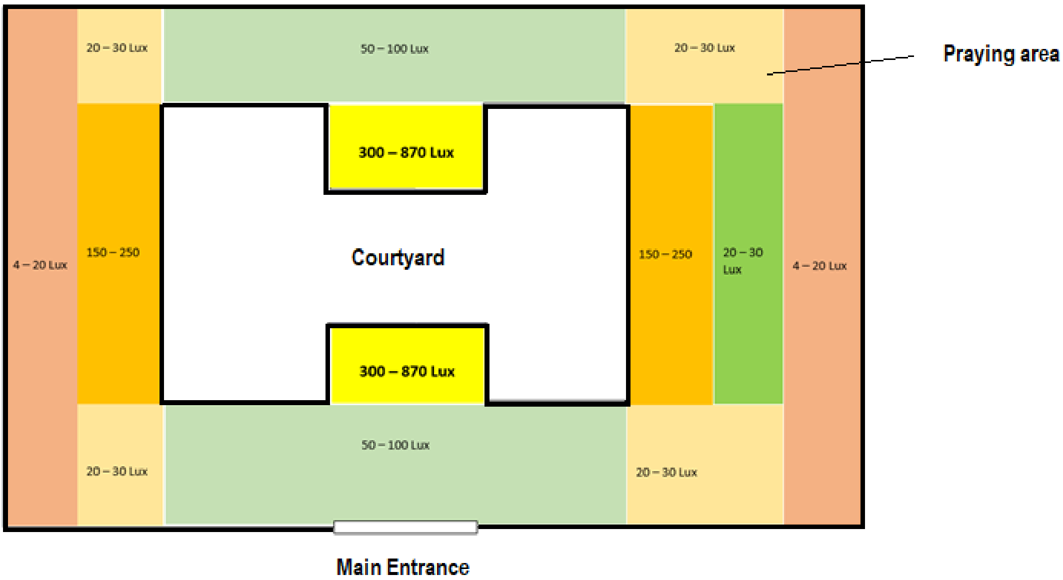
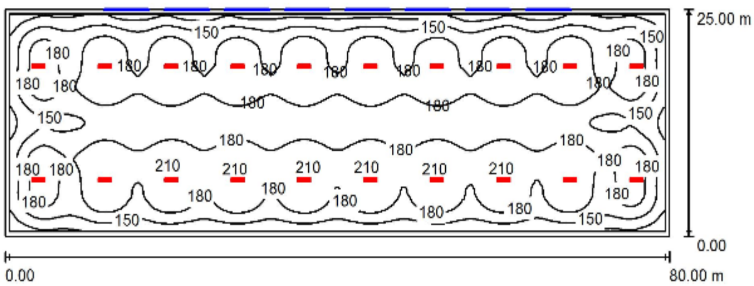


Figure 6. Illuminance measurements results two hours before sunset in the Moulay El Yazid Mosque.

As presented the outline, even 2 h before sunset, the main areas of the mosque lack sufficient lighting. As there is no local standard for lighting requirements in buildings, we based our study on the European norm [19]. We targeted in the study an illuminance value of 300 lux at 20 cm off the ground (position for holding the Quran) for the front lines and 100 lux for other areas. A simulation of artificial lighting illuminance was performed using Dialux®software to define the adequate characteristics of artificial lighting that will be used. Simulation results are illustrated in Figure 7.



Height of Room: 12.000 m, Mounting Height: 7.000 m, Maintenance factor: 0.80 Values in Lux, Scale 1:572

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	173	91	214	0.529
Floor	30	168	83	209	0.494
Ceiling	30	59	43	70	0.731
Walls (4)	50	90	42	147	/

Workplane:
Height: 0.200 m

Figure 7. Artificial lighting's illuminance simulation results using Dialux Software.

Another challenge that limits the efficiency of artificial lighting is that it is an indirect lighting system: chandeliers that contains light bulbs directed to the roof as shown in Figure 8. To maximize the illuminance and minimize the installed lighting power, higher illuminance bulbs with 360° lighting angle were installed in the exterior circumference of the chandeliers. Lower illuminance and reduced lighting angle were installed in the interior circumference of the chandeliers. This helped to maximize the illuminance and lower the installed power as the bulbs on the chandelier's outer circumference had the most impact on lighting. Table 3. below presents a summary of the LED bulb characteristics that were recommended in this project.

Figure 8. Photo of the chandeliers containing incandescent lamps before revamping with LED lamps.

Table 3. Summary of characteristics of LED bulbs used.

Number of LED bulbs	860 for Al Koutoubia 700 for The Kasbah Mosque
Power	8 W
Type of LED chip	E27
Min. Luminous flux	720 lm
Angle	360° for the outer circumference of chandeliers 180° for others
Color rendering index min.	80
Color of the bulb	White hot
Power supply	AC 85–265 V
Frequency	50–60 Hz
Minimal protection	IP 20

2.4. PV Panels

Installing PV panels is one of the most popular energy saving solutions, especially in a country with a high solar irradiation potential. It has the advantage of a guaranteed energy savings (based on irradiation potential of a site), making the economic profitability and the ROI (Return on Investment) calculation simpler and the decision of investment easier. Furthermore, when installed, it is a recognizable solution that is a good way for the promotion of renewable solutions. [20,21].

Calculating an optimal installed PV power for each project was handled. There are many scenarios that were discussed: (i) Covering all the electrical consumption with PV, in this case a storage system based on electrical batteries should be included to cover night energy demand. Consequently, the investment for the PV and storage system is the highest in this scenario. (ii) Covering just the electrical demand during the day. It is the lowest power and investment scenario, but as the day's energy demand varies during the year, it is difficult to design PV installation that matches this exact need. (iii) The third scenario, which was chosen, is to choose an installed power greater than total energy demand during the day by 20% to allow grid injection when it will become possible in Morocco.

To avoid any damage for to the historic terrace of the mosque, the fixing of the PV panels consisted of small mobile concrete pad. Another aspect that was taken into consideration is to choose a place that is not shaded during the day by the high minaret of the mosque. The design of the PV system was done using PVSYST software. Table 4 below summarizes main PV panels characteristics that were recommended in this project.

Table 4. Summary of main PV panels characteristics.

	Al Koutoubia	The Kasbah Mosque
Daily need	21.15 kWh/day	8.4 kWh/day
Panel technology	Crystalline poly	
Unit peak power	250 Wc/panel	
Total peak power	7 kWc	5 kWc
Types of inverters	Three-phase	
Billboard	Displays the instant power generated and the energy accumulation since the first day of operation	

2.5. Solar Water Heater

As it is mandatory in Islam to do the ablution (washings) before praying, each mosque has toilets and a hot water system that is heated with gas. For Moulay Yazid Mosque, in addition to toilets, the fountains in the courtyard are also used for ablution.

This makes the energy consumption of hot water significant as the number of persons doing their ablutions daily varies from 200 to 500 persons. The daily thermal energy can be estimated at 35 kWh at maximum, as each person uses in average 1 to 2 L of water heated to approximately 30 °C. Accordingly, the storage tank of the SWH should cover this daily need.

In Table 5 below is presented the proposed solar water heater characteristics for the two mosques. For both mosques, the proposed SHW is the same as the frequency of using the hot water is similar.

Table 5. The Solar Water Heater proposed for both mosques.

	Al Koutoubia	The Kasbah
Sensor type	Vacuum tubes	
Surface of the sensors	7 m^2	
Storage tank	– Storage volume: 1000 L – Installed on ground	
Traffic type	Forced circulation	
Location	60 m away	10 m away

An executive summary of economics and payback periods of the adopted saving solutions for the two mosques is presented in Table 6.

Table 6. Main economics values of energy saving solutions.

	Al Koutoubia			The Kasbah		
Suggested Solutions	**Savings kWh/yr**	**Cost MAD**	**ROI Year**	**Savings kWh/yr**	**Cost MAD**	**Payback Period**
Relamping LED	84,900	10,000$	<1	32,250	8300$	<2
Solar water heater	12,500	5700$	4	12,500	7000$	4
Photovoltaic panels	13,740	14,500$	7	9950	13,500$	7

3. Post Audit Results

3.1. Main Energy Savings Results

Assessment and monitoring of actual savings is a key step in any energy efficiency project. It will help evaluate the adequation of the proposed solutions and relevance of the initial assumptions. To do so, there are many methods that can be used to analyze energy consumption in a building [22–25]. Ocampo Batlle et al. discussed different calculation methods and designed a methodology to estimate energy baseline and consequently assess energy savings, which was based on the guidelines of ISO 50001 and ISO 50016 standards [26].

The first step is to establish a correlation between the total energy consumption of the mosque and the variables and factors of influence based on an analysis of historical data (electricity bills after installation of adopted energy efficiency solutions). These variables can be divided into two categories, controllable and non-controllable. Controllable variables are those that can be managed, for example: occupancy schedule, areas of operation and equipment that are manually controlled. Non-controllable variables are mainly climatic factors [26].

For our case, as previously noted, no HVAC systems are used so no non-controllable variables can be considered to establish an energy consumptions baseline. For the controllable variables, which are operation schedule and areas of operation inside the mosque, remains almost the same during the year. The slight change can be noted for lighting schedule that can be a little longer during winter season compared to the summer season.

Consequently, and to simplify calculation, we chose to compare past energy consumption (for each month) with the energy consumption during the first two post audit years (for the same month) so we can include the difference in lighting schedule between months.

During the energy audit, we proposed three energy efficiency solutions and summarized the estimated energy savings in Table 6. Figures 9 and 10 show LED lighting and PV panels that were installed in Koutoubia mosque. Two-year post audit measurements were conducted to compare and evaluate the actual energy savings for the two mosques which is illustrated in Figures 11 and 12. The main sources for data were the electricity bills for the two years and the energy meter for the PV installation.

Figure 9. The installed PV panels in Koutoubia Mosque.

Figure 10. Photo of Koutoubia mosque after installing LED lighting.

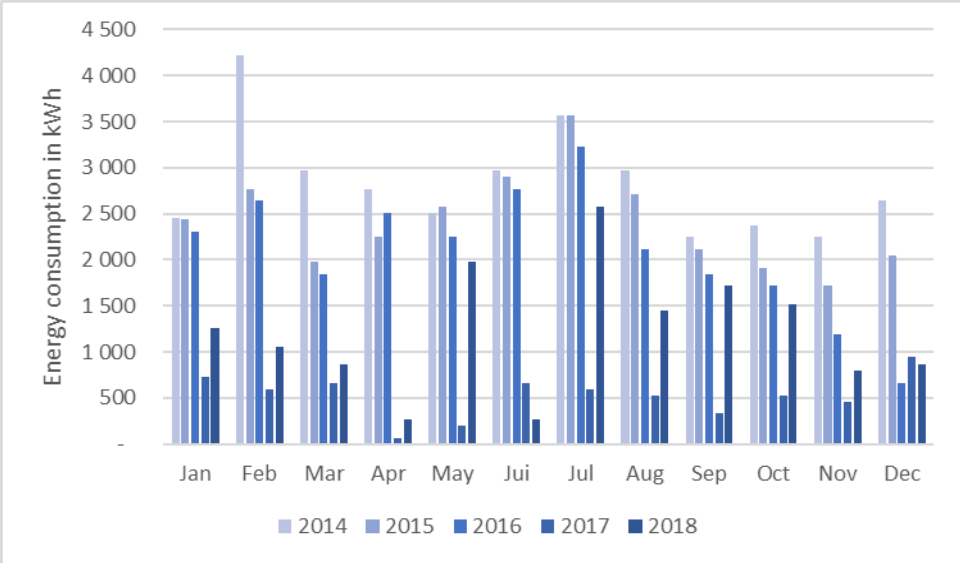


Figure 11. Annual electrical consumption—Koutoubia Mosque.

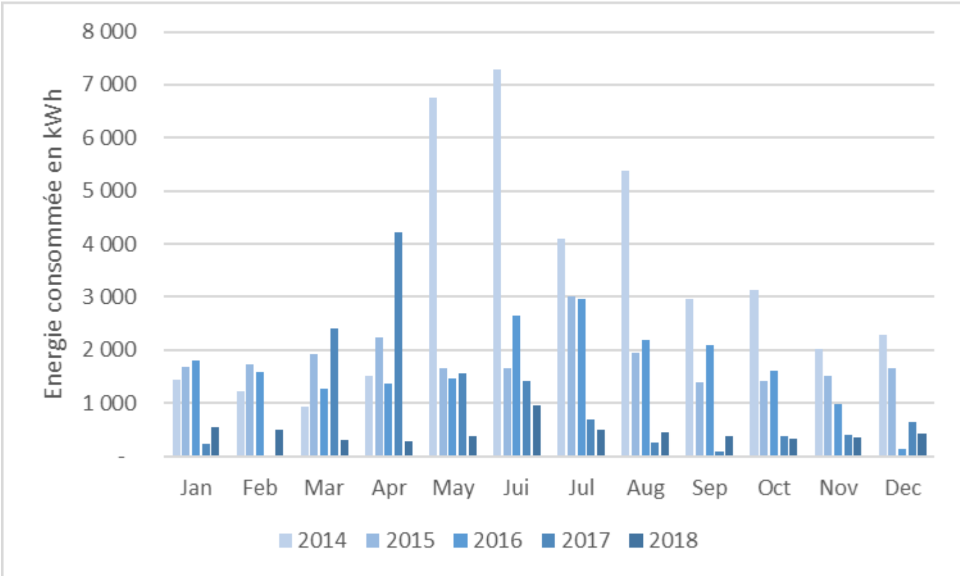


Figure 12. Annual electrical consumption—Kasbah Mosque.

The first graph that should be analyzed is the monthly energy consumption based on the electricity bill for the two mosques. As no energy meter is installed, energy bills are the only data we can use to evaluate the actual energy consumption.

The change in the mosque's energy consumption during the year can be explained by the different activities that are held in the mosques during the year. These activities are punctuated by the lunar calendar, which makes it hard to trace energy performance variation between years as the electricity bills are edited according to the Gregorian calendar.

For example, during the Ramadan month (which follows the lunar calendar) the occupation of the mosque is more important than any other month. This is due to the special nocturn praying and preaching activities that can last up to three hours more per day than the usual occupation schedule. This difference in nocturn activity translates directly to a remarkable increase in energy consumption during Ramadan. This increase in energy consumption can be noticed in Figures 1 and 2 during the two months of June and July. Table 7 details the dates of the first and last night of Ramadan for each year to illustrate the change in the beginning and end of the Ramadan during the years.

Table 7. The start and the end of Ramadan month for each year.

Year	First Night of Ramadan	Last Night of Ramadan
2014	28 June	28 July
2015	17 June	16 July
2016	6 June	5 July
2017	26 May	24 June
2018	16 May	14 June

As illustrated in Figure 13, average yearly consumption dropped from 40 MWh to 5 MWh in Moulay El Yazid. It dropped from 35 to 15 MWh for Koutoubia Mosque. This means that the average annual energy savings for both mosques varies from 60% to 90%.

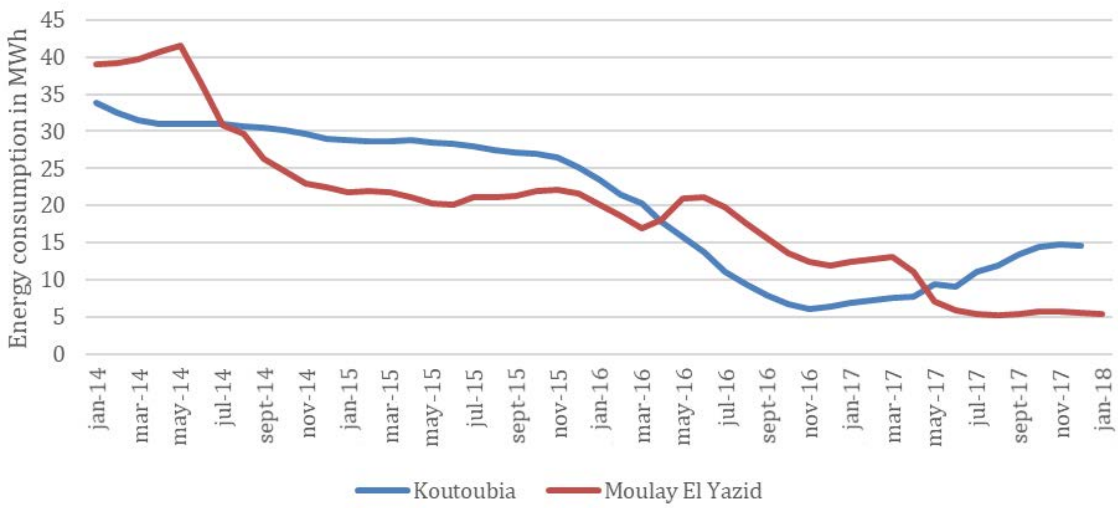


Figure 13. Annualized energy consumption for both mosques in kWh.

In Figure 14 there is a representation of the annual energy production of PV panels installed on the roof for the two mosques. The average monthly energy production is around 1400 kWh and 450 kWh for Koutoubia and Kasbah mosque, respectively. These values are higher than the daily needs of the two mosques, 93 kWh for Koutoubia and 88 kWh for Kasbah mosque, meaning that just a fraction of the energy produced by PV panels is actually consumed and the rest is lost as the grid injection is not allowed. This can be explained simply by the fact that the produced energy is not used during the day, as lighting, which is a mosque's major energy use, is operational during the end of the day and during the night. The only two ways that we identified to resolve this problem is to store energy using batteries during the day or to inject produced energy into the grid. The first one will need an additional and consequent investment, making it not economically relevant, while the second option is not allowed but could be in the next years.

Another key change is the improvement of the visual comfort after revamping using LED with high illuminance that consumed less than 10% of the incandescent lamps and lasted longer (after more than a year, just three lamps were changed instead of more than 20 lamps each month). This improvement in visual comfort should be considered in calculating energy savings as the actual installed power for lighting before the project did not exceed generally 30% to 40% of its maximal capacity.

For SWH systems that were installed, it was difficult to calculate actual energy savings as the there was no meter for water consumption and no exact data on gas cylinder consumption that was used before. Moreover, the place where the washing is done was not under the control of the mosque staff; it is independently managed. However, when asked about the solution, the person in charge confirmed that they did not need to use any gas cylinder again, meaning all water heating energy was totally covered by the SWH.

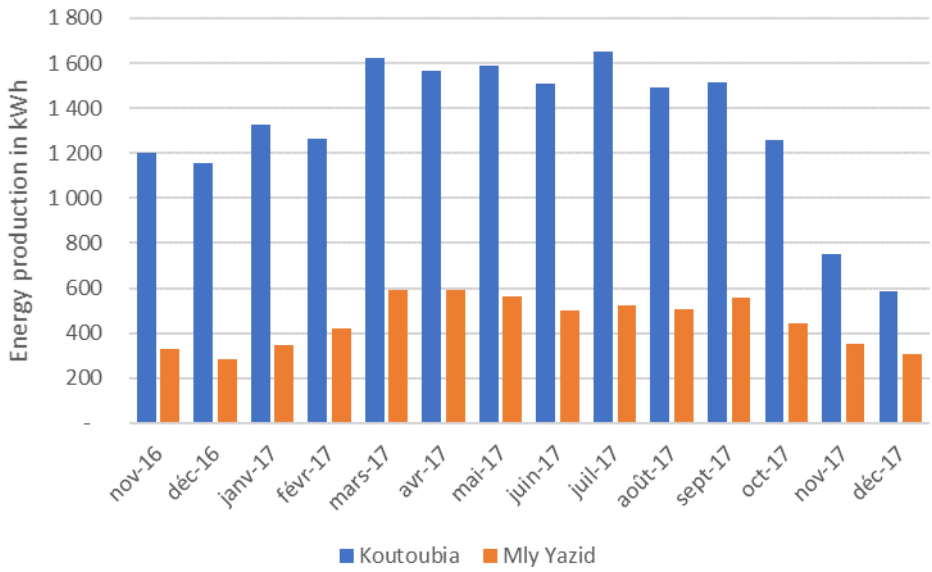


Figure 14. Annual PV production for both mosques in kWh.

3.2. Post Enery Audit Conclusion

Mosques have a special energy consumption scheme and have an interesting energy savings potential. In this study, we implemented the following solutions: LED lighting, PV panels and SWH reduced energy consumptions for both mosques. These standard solutions could be easily replicated in other mosques and could have more energy saving if HVAC systems were used or grid injection was allowed. This would also lower the Return On Investment (ROI) of these solutions, increasing as result the potential of investing in these types of solutions. It will also encourage ESCO private companies to offer services based on similar solutions that can be paid just by savings. This type of project was developed in Morocco and now more than 100 mosques have benefited from it.

The monitoring that followed the implementation of these energy efficiency solutions helped to assess actual energy savings and to detect any changes in energy consumption scheme.

4. Some Guidelines for a Sustainable Mosque Label

The first part of the present work was dedicated to energy consumption and solutions to improve the two mosques' energy performance. These results encouraged us to broaden the area of mosques' assessment by including sustainability criteria and suggesting the creation of an international green label for mosques. As energy is just one aspect of sustainability, other criteria should be studied deeply to give clear sustainable performance assessment that can be applied for mosques. In the following section, some guidelines are given to include in a green and sustainable label for mosques.

There are many international buildings sustainable rating systems that can be applied to different types of buildings (including mosques) and during all its life cycle phases. It consists generally of main objectives, related to sustainable development pillars, that translates to strategies and methods to be respected in order to certify the building project [27–33]. Each rating system has its own certification scheme, criteria and credit system to rate the sustainability of a building project. These criteria are grouped generally into themes or categories that are weighted differently. For example, common shared categories between sustainable rating systems are: Indoor Environment Quality, Energy, and Material [33,34].

To benchmark performance of certified buildings, a rating scale compares the condition of different sustainable objectives for each building and give a global assessment. These rating scales can be represented alphabetically or in the form of a numerical score [35].

Despite the abundance and variety of sustainable rating systems for buildings, to this date there is no label or a rating system dedicated to assess sustainable performance of mosques. The aim of the second section of this work is to propose sustainable themes and categories on which an efficient and adaptive rating system for sustainable mosques can be based. We limit the scope of our work to propose these themes and outline their importance for an international sustainable mosque label. More consistent work is needed for each one of the proposed aspects to identify suitable KPIs (Key Performance Indicators) and precise scale rating system.

4.1. Sustainable Mosques Labels

In Morocco, a label called "Mosquées Vertes" (Green Mosques) has been used by the AMEE (Moroccan Agency for Energy Efficiency) since 2016. It aims at labeling performant Moroccan mosques and encouraging others to adopt greener solutions. This project is driven by four main reasons: (i) Morocco has more than 300,000 mosques with a total yearly energy bill exceeding 200 million dirhams (~21.6 million dollars); (ii) there is no control or monitoring of energy consumption in mosques, especially as in most cases it is contracted and managed by independent associations not the ministry of Islamic affairs; (iii) the symbolic essence of mosques will play an essential role in sensitizing people for energy conservation and green energy; (iv) we wish to be in concordance with the Moroccan National Strategy that targets to reduce the country's energy consumption by 15% by the end of 2030 [36]. Agnė et al. detailed the Moroccan strategy for energy efficiency and renewable energy [37].

This label is given mainly to mosques that integrate energy efficiency solutions based on PV, SHW and LED. Although it is a good step toward improvement of energy performance for mosques, this label lacks the inclusion of sustainable aspects such as water usage, natural lighting, acoustic comfort, thermal comfort, waste management, mosque architecture, etc.

In Malaysia, the introduction of a green building's rating tool called Green Building Index (GBI) helped to apply sustainable principles in different buildings types (residential and nonresidential) [38,39]. Yendo et al. conducted a study on 45 mosques in Malaysia aiming at establishing a GBI applied for mosques assessing the sustainable potential of these religious buildings. They concluded that main potential sustainable concepts that can be included in the Sustainable Mosque Index are: Energy Efficiency, Indoor Environmental Quality, Water Efficiency, Sustainable Site Planning and Management, Material and Resources, and Innovation and Design [39]. These concepts are clearly similar to the ones considered in a sustainable rating system for buildings.

This section is an attempt to gather main aspects that should be included in an international sustainable mosque. We will limit our focus to present some studies related to different sustainable concepts and criteria that can be considered. When possible, some KPIs are proposed to assess these criteria and benchmark performance between mosques.

4.2. Mosques Function

Before going in depth in discussing standards sustainable aspects, a decisive aspect in mosques' sustainability performance should be stressed, which is the mosque's use or function. To understand its importance, we take into consideration that most mosques are generally used for one purpose: congressional praying that takes place five times a day. Consequently, the total time where the mosque is occupied can be estimated at 3 to 4 h a day. For a building with large surface area and that is intensively consuming energy, this "performance" is very low compared to other types of buildings that are occupied more and consume less energy. So, to improve this factor, we recommend that the mosque's function include other activities such as hosting some adapted community events, lecture of Islamic teaching, literacy classes, and function as a library. It can also be used as shelter during natural disaster, or health center during sanitary pandemic. The function of a mosque should be clearly specified during the design stage, when conception decisions are made, to allow other activities to be held in the mosque.

This function should be taken into consideration when benchmarking between mosques and will help to assess adequately its sustainable performance. The KPIs that we propose to take account of this aspect is to calculate total period in a month, in hours, where the mosque is occupied or in use (it could be expressed in hours per month). This means that other quantifiable sustainable aspects can be weighted according the value of the function KPI. For example, a mosque that is occupied 210 h/month, even if it similar in energy consumption and architecture to another mosque occupied just 105 h/month, is more sustainable than the second one.

4.3. Mosque Conception and Design

The first aspect that has a big impact on energy consumption and mosque's sustainability is its design and architecture. This is even more important when taking into consideration that design decisions are made during the early stage of the construction and are difficult to change after [13]. Therefore, many studies investigated design and conception choices effects on energy consumption, thermal comfort and natural lighting [9,13,24,40–42]. For example, Mustapha et al. concluded that by only using passive design strategies in mosques, the annual energy consumption dropped by 10% and the thermal comfort increased [24]. Azmi et al. studied how specific architectural characteristics of mosques may impact environmental sustainability by assessing current scenario of mosque architecture and looking into existing examples of sustainable mosques [43]. The study also presented some guidelines to follow during each design stage in order to build mosques that are environmentally sustainable.

The major feature of mosques design is the orientation to Qibla, which is a virtual horizontal axis that points from the middle of the floor to Mecca city in Saudi Arabia [9]. This orientation will impact the solar irradiation, thermal comfort and also the building's useful surface.

The second main aspect of mosques design is the stereotype elements that ranges from domes, vaults, arches, fenestration, minaret, etc. Although these stereotypes have an architectural function, they also have impact on thermal comfort, energy consumption, lighting consumption, etc. Consequently, more investigation should be carried out to determine the impact of these stereotype elements.

It is hard to give specific and precise design and architecture choices that could be replicated for all mosques and give relevant results in terms of thermal comfort, energy consumption and sustainability performance. Therefore, we strongly encourage to perform a thermal simulation of the mosque during design stage and compare the performance of all architecture choices that can be proposed.

4.4. Comfort in Mosques

4.4.1. Thermal Comfort

Mosques are buildings with intermittent occupancy schedule; hence, ensuring a thermal comfort during the prayer times is a challenging objective. Moreover, as there are no particular standards for thermal comfort in mosques, which varies from one country to another, it is difficult to assess the performance of a given mosque and to give general guidelines that can be applied in different climate regions. Mosques also have big volumes, huge heights and large domes that make the heating or cooling of the prayer space energy consuming [7].

There are many studies that discuss the thermal comfort aspect in mosques by providing some solutions, evaluating its impact on energy consumption and proposing strategies that should be taken into consideration during design stage [40,42,44–46].

To compare thermal comfort performance between mosques we propose the following KPIs:

- Discomfort duration in hours/month
- Installed HVAC equipment in kW/surface area in m^2
- Energy consumption in kWh/surface area in m^2
- Energy consumption in kWh/sum of (Heating Degree Days HDD + Cooling Degree Days CDD)

4.4.2. Visual Comfort

Generally, the lighting is achieved in mosques by different fenestration types and size; domes, chandeliers and other stereotype elements impact the overall comfort and energy use [8].

Hence, some general design guidelines of these holistic buildings should be established to help architects achieve sustainable lighting. Simulating day light is a powerful tool to assess lighting comfort in a mosque that will help assess the impact of each one these stereotypes [8]. In addition, the courtyard is one of the passive solutions that help in getting more daylight exposure inside of a mosque. To this date, there is no specific norm for lighting in mosques; we estimated that the minimum requirement would be 250 lux at a height of 30 to 40 cm from the ground, which corresponds to illumination needed to read the Quran, which occurs generally at that distance.

Following are some KPIs that could be used to assess visual comfort:

- % of day light autonomy
- Installed electrical lighting kW/surface area of the mosque in m^2
- Illumination in lux/installed electrical light capacity in kW
- Electrical consumption for lighting in kWh

4.4.3. Acoustic Comfort

Acoustic quality in a mosque helps worshipers feel calm and achieve a spiritual fulfillment especially during the Quran recitation and Friday preach. This aspect is not included usually in the design stage that focuses more on the aesthetics or the forms and the space [47].

Setiyowati studied strategies to improve acoustic comfort in Indonesian mosques and focused on the impact of using an absorption material on the wall and the floor and reflection materials on the ceiling. Hence, no reinforcement systems are needed in medium-sized mosques, improving the acoustic comfort and reducing energy consumption [48]. We could not find adequate and adapted KPIs for acoustic comfort.

4.5. Energy Consumption and Renewable Energy

Energy consumption in buildings is an important aspect that is included in any sustainable rating system. Its importance is due to many reasons: (i) it can be directly correlated to CO_2 emissions depending on the energy mix of the country; (ii) it can be measured precisely, which make monitoring, managing and controlling it simpler than non-quantifiable aspects; (iii) energy consumption depends on objectives of other sustainability criteria (like thermal comfort, visual comfort, acoustic comfort, etc.). For example, visual comfort in Koutoubia and Kasbah mosques improved significantly after the LED relamping operation, which explains the slight increase in energy consumption for lighting.

It is necessary to rightly understand the challenge for establishing an energy efficiency indicator that can be applied to all type of mosques in order to assess their energy performance. For example, the standard ratio kWh/m^2 (energy consumption in kWh per surface of floor area in m^2) is not suitable to compare energy performance between all type of mosques. In the first section of this work, we investigated energy savings opportunities in two historical mosques. This type of mosque is generally conceived according to ancient passive design strategies. Thick walls, big volumes and court yards are main iconic patterns [8,47,49]. Hence, in this type of buildings, HVAC systems are not needed as the mosques ensure a good thermal comfort passively. This simplifies establishing an energy baseline as remaining energy uses know no significant variation during the year (i.e., lighting, acoustic equipment, water dispenser, etc.). Accordingly, monitoring energy performance is reduced to comparing energy consumption between months with no additional variables. Additionally, the KPI energy consumption in kWh/m^2 is suitable to compare performance between mosques with no HVAC equipment. We could also improve this KPI and propose another one based on an energy consumption in kWh per person, if the energy consumption depends directly on the number of worshipers (especially when lighting is used just in the occupied areas of the mosque).

For contemporary mosques, HVAC systems are generally used to maintain adequate comfort temperature, making HVAC consumption the main energy use for the mosque [10,12,50,51]. This means that the KPI should include the variation of the Heating Degree Days (HDD) and Cooling Degree Days (CDD).

Another particularity of mosques is that the change in its occupation schedule is based on religious events that follow the lunar calendar, which means that when comparing performance between mosques for different years, the variation should be taken into consideration.

To keep track of energy performance and benchmark between mosques, the following KPIs can be used:

- Total monthly Energy Consumption kWh/total surface area m^2;
- Total Monthly Energy Consumption kWh/person;
- Monthly Energy Consumption for lighting/total surface area m^2;
- Total monthly Energy Consumption for HVAC systems/(Total Monthly Heating Degree Days and Cooling Degree Days)
- Energy from a renewable energy source in kWh/Total energy consumption.

4.6. Water Usage and Recycling

Water is used in mosques for different activities, mainly ablution (specific washings that have to be performed before praying), cleaning and toilets. It could also be used in the case of some big mosques for irrigation, showers and kitchen [52]. To give an idea about the water consumption in mosques, we will estimate the quantity of water needed for just the ablution operation. Generally, it takes approximatively 0.75 to 1.5 L of water per worshiper. It means that if we suppose that just 50 worshipers are doing the ablution before each of the five daily prayers, the total used water can reach 187 to 375 L per day. The monthly water consumption could be estimated at least at 5600 L and can exceed 11,000 L just for the ablution. All these assumptions are for a relatively small or medium mosque size; for big mosques, it can be more than 8 times that consumption. For example, the estimated total fresh water consumption for The Sultan Ismail Mosque (SIM) located at UTM, Skudai, is 11,550 m^3/y [52].

Manan et al. used a pinch analysis technique to predict potential water savings in SIM. It is a systematic technique for implementing strategies to maximize water reuse and recycling through integration of water-using activities or processes. The main objectives are maximizing water reuse and recycling, which will result in minimizing freshwater consumption and wastewater generation. In the case of SIM, the technique helped reduce fresh water consumption and wastewater production by 85.5% and 67.7%, respectively.

Another aspect, related to mosques design and water use, that was noted by Azmi et al. is the ratio for toilets or sinks to floor area is higher for mosques compared to other types of buildings. This is due to the need to access, at the same time, by a high number of worshipers just before the beginning of the prayers.

In conclusion, the main solutions that can be proposed to increase water efficiency in mosques varies from the optimization of water consumption from the design stage (using techniques like Water Pinch Analysis), using water-saving fixtures, rainwater harvesting systems and greywater recycling.

Following are some KPIs that we can propose to assess water consumption efficiency in mosques:

- m3/number of persons
- m3/number of persons using the ablution area
- m3 of recycled water
- m3 of rainwater harvested

5. Conclusions and Recommendations

As a result of accelerated urbanization and improvement of living standards, the building sector has become a major contributor to global energy consumption and constitutes the largest CO_2 emitter sector. Nevertheless, it presents very promising sustainable development potential, whether for new constructions or existing buildings. In state level, countries should establish an efficient and adapted sustainable strategy for buildings, by developing more concrete and specific codes and regulation to for each building category: hotels, schools, hospitals, public buildings, etc.

Taking advantage of being iconic buildings, mosques can play a very effective role in promoting these solutions and encouraging Muslim communities to adapt them. The objective of this paper was to study in detail the energy consumption scheme, propose energy efficiency solutions and assess energy savings for two historical mosques in Marrakech (Morocco). A detailed analysis of energy consumption scheme of the mosques was carried out and a list of energy saving opportunities was proposed. Due to budget restrictions, not all the solutions could be implemented, and the three adopted solutions were: PV panels, LED lights and Solar Water Heater. A two-year energy monitoring was conducted to calculate actual energy savings for both mosques and the results were discussed. Main observations were that energy produced by panels exceeded the daily energy consumption of mosques, but energy production that happens during the day does not coincide with energy consumption that occurs mainly during the night. This observation could be resolved by using batteries for energy storage or grid injections; unfortunately, neither of these solutions could be implemented for this project. The second observation is the improvement of visual comfort by the installed new LED lights. As the lighting system was based on incandescent lamps that do not cover all mosque areas and that are damaged quickly, to establish a precise and correct assessment of energy savings, the cost of incandescent lamps that were bought for the year and the illuminance generated should be compared to the new lighting based on LED lights and its cost. As the energy savings results were encouraging, this pilot project helped develop many ESCO contracts between private companies and the ministry of Islamic affairs in Morocco where the private company guarantees energy savings with the same solutions in other mosques in Morocco. We recommend to conduct studies similar to this one for mosques, covering more broad aspects such as improving water usage, waste treatment and valorization, visual and acoustic comfort, etc.

The second section of this work was dedicated to discuss and propose some sustainable criteria that can be included in an international sustainable label for mosques, which will help improve sustainable performance in different countries and benchmark KPIs between different mosques. For each criterion, we suggested some aspects to consider and recommend to carry more detailed work aiming at determining some specific and adequate KPIs.

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