Predicting Energy Use for Mosques During Ramadan

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Abstract:

Energy usage patterns in mosques are significantly affected during the holy month of Ramadan. During Ramadan, mosques face an increase in energy demand due to the extended operation hours, higher occupancy, and other communal activities. Due to this, it is important to predict energy use for effective energy planning and cost management. This study highlights the importance of predicting the energy useage of mosques during Ramadan. Methods included in this study analyzing historical data trends, conducting surveys with worshippers and mosques staff, and modeling and simulation mosques to forecast energy consumption. This study audits a mosque in a typical residential neighborhood in Kuwait where an energy model is built and calibrated using hourly observations. Based on a calibrated energy simulation model, it was predicted that energy consumption during Ramadan will increase by 2.7%. Additionally, the model evaluated Ramadan's energy consumption impact by comparing Ramadan with no-Ramadan scenarios; the results show that Ramadan contributes almost 8% to energy consumption increases. This initial analysis predicts the energy demand during this holy month so mosques can adequately meet this demand while minimizing costs, reducing environmental impact, and promoting sustainable practices.

Keywords: Mosque, Energy, Intermittent occupancy, Prediction, Energy modeling

1. Introduction

Islam is followed by nearly a quarter of the world's population, with approximately 1.6 billion followers across 50 regions (Elshennawy & Abdallah, 2017). Mosques hold significant religious importance for Muslims worldwide as places of worship and gatherings. In recent times, there has been a notable increase in the number of mosques in response to the growing urban populations. According to an estimation by Deloitte (2015), there are about 3.6 million mosques globally, and this number continues to rise.

According to Ministry of Awqaf and Islamic Affairs mobile application, the number of mosques in Kuwait in last report update in 2023 are 1,776 mosques (Ministry of Awqaf and Islamic Affairs, 2023) and this number in continues increase. The Ministry of Awqaf and Islamic Affairs is in authority for the maintenance and the functioning of all registered mosques in Kuwait. Besides this, it also handles energy bills, and pay for electricity and water. According to Ezzahi, (2018) the energy bill paid by the Ministry of Awqaf and Islamic Affairs increased from two million dinars annually to around seven million in the according to the 2017-2018 fiscalyear. This is due to the increase in consumption tariffs for government agencies in the last regulation, from 2 fils per kilowatt to 25 fils, and from 800 fils per 1,000 gallons of water to 4 dinars. Kuwait's mosques use 6% of the country's energy, which is considered to be a significant amount (Emadi, 2018).

Unlike other types of buildings, mosques have intermittent operations during the day. These unique operating hours correspond to the five daily prayer times in Islam: Dawn (Fajr), Midday (Dhuhr), Afternoon (Asr), Sunset (Maghrib), and Evening (Isha). The timings of these prayers in mosques are directly linked to the position of the sun, resulting in daily variations. However, due to the consistent and predictable position of the sun on specific dates every year, it becomes possible to precisely identify the prayer times for those particular dates, which would be helpful in predicting energy usage patterns. The duration of these prayers varies from a fraction of an hour to an hour, including pre-prayer and post-prayer (Abdou, Al-Homoud, & Budaiwi, 2005; Azmi & Kandar, 2019). Daily prayers typically last around 30 minutes, while Friday prayers take approximately 120 minutes. The occupancy patterns in mosques range from 10-30% during daily prayers to almost 100% during Friday prayers. Notably, during the month of Ramadan, the occupancy pattern is higher compared to normal days, especially during the last 10 nights (Abdou, Al-Homoud, & Budaiwi, 2005; El-Shennawy &Abdallah, 2017), making it a significant month for study. Ramadan, the ninth month in the Islamic calendar, is considered a special time of devotion, characterized by fasting, charity, and spiritual reflection. During this month, mosques face increased energy usage due to extended operational timings, higher occupancy, and a wide range of communal activities.

This paper will explore the significance of predicting energy use in mosques during Ramadan, as it is one of the most sacred worship seasons for Muslims. The study emphasizes the importance of accurately forecasting energy consumption during this period to ensure effective energy management.

Until recently, there has been a lack of studies on mosques' energy consumption, leading to a lack of research in this area compared to other building types. However, this study shed the light on the possibility of predicting the energy use of mosques during Ramadan.
The review paper on mosques' energy consumption categorizes studies aimed at reducing energy consumption for mosques into three main topics. The first focuses on improving the building envelope and implementing passive techniques, including the utilization of renewable systems such as PV systems, roof options, glazing, and optimized building forms (Mushtaha & Helmy, 2017; Al-Homoud et al., 2005; Sezer & Kaymaz, 2016; ElShennawy & Abdallah, 2017; Azmi & Kandar, 2019; Abdou et al., 2005; Al-Tamimi & Qahtan, 2018; Bakri et al., 2018; Mokhtar, 2015).

The second area of research involves studying different thermal performance using simulation software (Al-Shalaan et al., 2017; Budaiwi et al., 2013). Meanwhile, the third area employs prediction and simulation models to evaluate and reduce energy consumption, focusing on enhancing the thermal performance and indoor occupant comfort levels within the mosque (Alajmi, 2010; Alashaab & Alamery 2018; Samiuddin & Budaiwi, 2018).

2. Methodology:

The study aimed to predict energy usage during Ramadan by analyzing an existing mosque using both quantitative and qualitative research techniques. The approach involved examining historical load profile data, conducting surveys with prayers attendees and mosque staff, and utilizing simulation and modeling method. The prediction for energy use during Ramadan was performed in two scenarios. In the first scenario, a calibrated model is used to predict the energy consumption for the upcoming Ramadan. The second scenario evaluated the impact of Ramadan on energy usage by comparing the predicted energy consumption for the mosque during Ramadan with a no-Ramadan scenario.

Mosques Description:

The study considered a mosque located in one of Kuwait's neighborhood, Al-Qadisiya. The mosque's total built-up area is 506.5 m^2 (5,452 ft^2), out of which 308.4 m^2 (3,320 ft^2) is conditioned space. Constructed in 1985, the mosque comprises a large prayer hall for men (Haram), an open courtyard (Sahen), men's restrooms and ablution areas, women's prayer area, women's restrooms and ablution areas, and an accommodation room for the guard and Mua'athin (prayer caller). Despite the fact that the first energy code has been in operation since 1983, there is little indication that they are effective on the buildings which were built in this period (Jaffar, 2020). It's assumed that the mosque's construction materials are same with those used during that period due to the absence of envelope data sources.

The mosque primarily serves the local neighborhood residents who mainly come for prayers. Its operating hours is associated with the five daily prayer times. Mosques in Kuwait usually employ packaged air conditioners (AC). Additionaly, split units are used in the rooms of the Imam and mosque guard. During winter, HVAC systems are often switched off.

Figure 1 demonstrat the schematic floor plans of the case stuied mosque. Table 1 describes the mosque's main characteristics, including the year of construction, glazing type and the physical properties of the envelope (area, height, and thermal properties).

Table 1

Sheerifa Mosque Main Characteristics

Parameter	**Sharifa Al Saqer Mosque**
Construction Year	1985
Climate	KWT KISR Coastal Station-TMY
Orientation	SW
Area of ground Floor (ft^2)	3,320
Height flr-flr (ft)	14.7
Height flr-ceil (ft)	11.4

Number of prayers	
Men	201
Women	62
Envelope construction	
U value walls (Btu/h.ft^2.F°)	0.04
U value roof (Btu/h.ft^2.F°)	0.122
Windows type	Single glazing

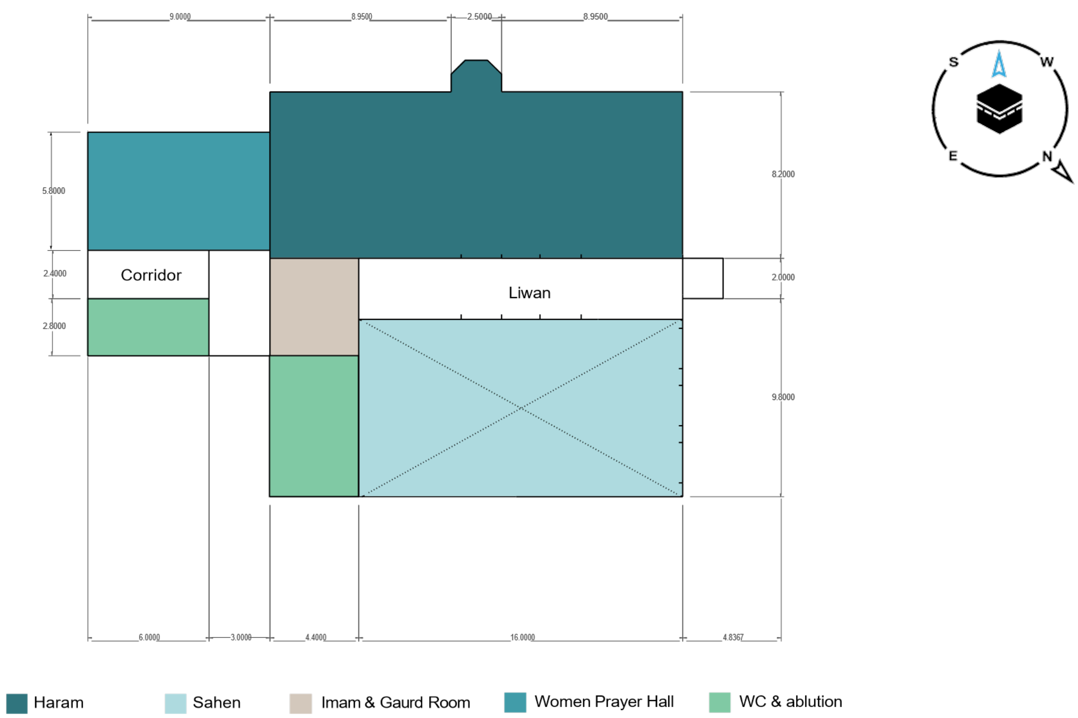

Figure 1 schematic floor

Metered Energy Data Analysis:

KISR provided hourly energy readings for Shareefa Mosque from 2016 to mid-2019, Figure2 shows energy consumption during prayer times for Sheerifa mosque in 2018. It compares the energy consumption of a typical summer day with a day in the last 10 days of Ramadan.

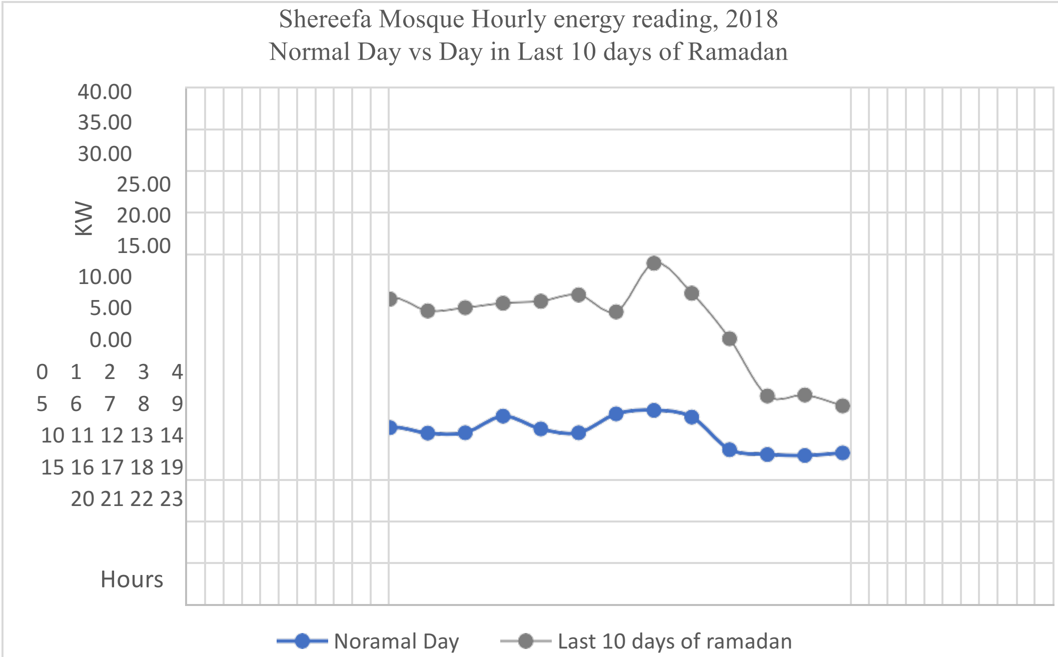

Figure 2 Actual energy use for typical summer day and day in last 10 days of Ramadan

From the graph one can notice:

1. The intermittent energy use as a result of intermittent occupancy patterns.
2. A significant difference (on the order of 70%) is found when comparing energy consumption of a typical summer-day with a day in the last 10 days of Ramadan.

The above indicate the challenge presented with mosque building typologies given such unique occupancy behaviors.

Simulation and Modeling:

The important of building simulation is that it allows for the evaluation of a building's system performance, and it is cost-effective, time-efficient, and enhances the understanding of results (Yang & Becerik-Gerber, 2015). In this study eQUEST software was used for modeling and simulation. eQUEST is considered an easy-to-use simulation software that simulates building energy and provides a qualitative analysis with visuals. (Arshad, 2021). Figure 3 shows the main factor required to run the simulation.

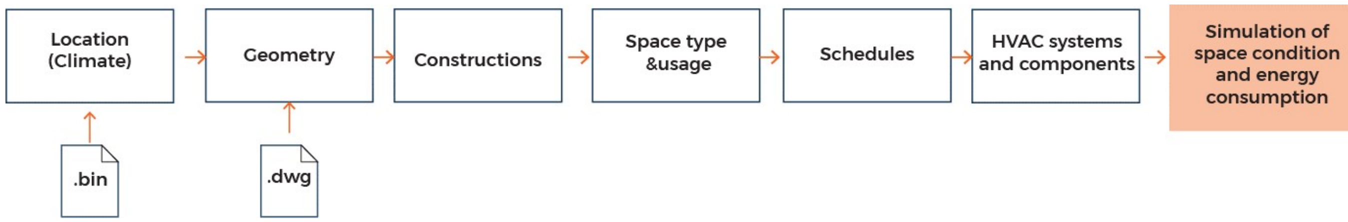

Figure 3: eQUEST Outline Schematic Design Wizard (Wood, 2011)

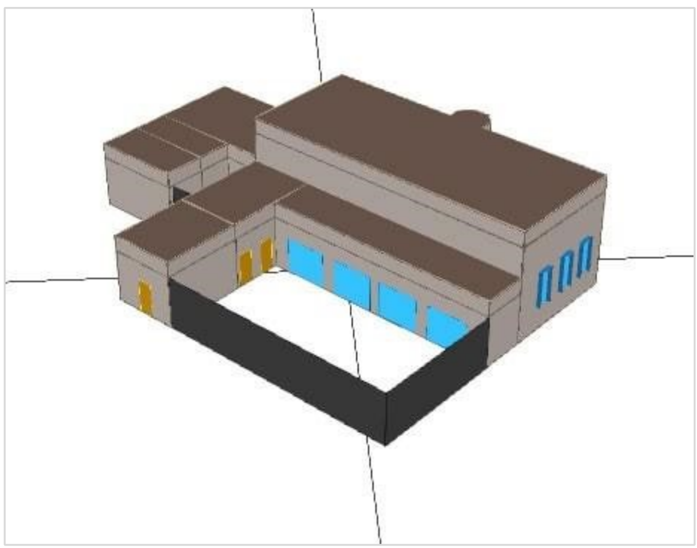

Figure 4 Mosque simulated model

Figure 4 illustrates the baseline simulated energy model for the the mosque which was created using the data outlined in Table 2. Incuding, building geometry and material which was obtained from the Ministry of Awqaf and Islamic Affairs, Engineering department, weather data, internal loads, HVAC system, and schedules of occupancy and operation.

Table 2

Main Parameters Used in The Model

Parameter	Description	Source
Location	Kuwait	
Weather file	KWT KISR Coastal Station- TMY	
Orientation	SW Qibla Angle for Kuwait City (Kuwait) is 224.65° degree (according to the true north)	(Qibla direction finder for Kuwait City: Kaaba direction - qibla locator)
Modeling simulation program	eQuest 3.65	
Occupancy pattern	• Calculate the number of occupants • Occupancy schedule prayer time 45 minutes / prayer including (arrival period+ prayer period + departure period)	Based on survey data
Occupancy density	0.8 m^2/ person (9ft^2/person)	(Al-Homoud et al., 2009)
Infiltration rate	1 ACH occupied 0.5 ACH unoccupied	(Budaiwi, 2011)
Cooling setpoint temperature	22 °C	
Cooling COP	2.4	(Cerezo et al., 2017)
Lighting power density		
Prayer Hall	1.5 W/ft2 (25.8 W/m2)	(Al-Homoud, 2009)
Rest rooms & ablution	0.69 W/ft2 (7.4 W/m2)	(Al Touma & Ouahrani, 2017)

HVAC

The spaces are cooled with DX units. The HVAC specifications were not known, so the data inputted into the models were obtained from literature and energy conservation codes. The default data in the simulation model was also kept.

Schedules:

A site survey with the Imam was done to study the occupancy pattern and how do they operate the systems. The survey included questions that give knowledge to amount of people who comes to pray at each prayer time. The questions were to give an estimate occupied number of rows for each prayer time. The most benchmark times are weekdays, Friday prayer time, first twenty days in Ramadan, Friday for twenty first days in Ramadan, Last 10 days in Ramadan, and Friday last 10 days in Ramadan. Also included in the survey questions about the operation of the systems: lighting and indoor temperature thermostat.

Table 3 shows Sheerifa Mosque occupancy schedule. The survey was given for the men praying area. The total numbers of rows in the men praying area equals 5 rows,34 prayer per row. The maximum number of people the hall can fit is 194 prayer.

Table 3

Sheerifa Mosque Occupancy Schedule

	Fajer		Dhur		Asr		Maghrib		Esha		Qiam	
	Rows	Fraction	Rows	Fraction	Rows	Fraction	Rows	Fraction	Rows	Fraction	Rows	Fraction
Normal day 30/4/2019	1.5	0.3	1.75	0.35	2	0.4	3.5	0.7	3.5	0.7		
Normal Friday 3/5/2019	1.5	0.3	0	0	2	0.4	4.50	0.9	4.50	0.9		
First 20 days of Ramadan	5	1	2	0.4	2.5	0.5	5	1	5	1		
First 20 days of Ramadan Friday	5	1	0	0	2.5	0.5	5	1	5	1		
Last 10 days of Ramadan	5	1	2	0.4	3	0.6	5	1	5	1	2.5	0.5
Last 10 days of Ramadan Friday	5	1	0	0	3	0.6	5	1	4.5	0.9	2.5	0.5

Baseline Model Results and Calibration

According to ASHRAE Guideline 14 (2002), simulated models are considered calibrated if their Mean Bias Errors (MBEs) show values within the range of ±10%, and the Coefficient of Variation of Root Mean Square Errors (CV(RMSE)s) range of ±30% when applied to hourly data. In the case of monthly data, an acceptable range for CV(RMSE)s is between 5% and 15%. (Eq. (1)).

$$MBE = \frac{kkkh_{Metered} - kkkh_{sssm}}{kkkh_{Metered}} \times 100\%$$

Simulation results of the annual energy use baseline models were validated by comparing simulated results with actual energy readings. It resulted in an error of 10%. Tabel 4 present actual energy data and the cailbrated steps and results.

According to the baseline simulation, Sheerifa Mosque has an overestimation values in Summer months and under estimated values occurred mainly in March and November. This indicated a need for adjustments in the energy model. The modifications involved lowering the setpoint temperature from 71.5°F to 73°F, the error discrepancy was reduced to 4%. However, it was still noticed that there is an increase in the summer months. In the second calibration, the coefficient of performance (COP) was adjusted from 2.4 to 2.5 by wich the annual energy error discrepancy was reduced to 1%

To evaluate the model's performance the Root Mean Square Error R-squared has been calculated. According to the calculations on the latest calibration, the R-squared value is 0.96, and the Root Mean Square Error (RMSE) is 748.76kWh. The Coefficient of Variation of Root Mean Square Error (CV(RMSE)) is approximately 9.64%, and the Mean Bias Error (MBE) is approximately -1 %.

In this case, the model is performing excellently, with a relatively small prediction error. The model's predictions are very close to the actual data.

Table 4

Actual Energy data and simulated results

Month	**Actual Energy Use (kWh)**	**Baseline model (kWh)**	**% Difference**	**Calibration 1 (kWh)**	**% Difference**	**Calibration 2 (kWh)**	**% Difference**
Jan	1,927	2,110	(10)	2,110	(10)	2,110	(10)
Feb	1,504	1,920	(28)	1,920	(28)	1,920	(28)
Mar	3,653	2,580	29	2,560	30	2,540	30
Apr	4,600	6,540	(42)	6,050	(32)	5,910	(28)
May *	11,350	13,000	(15)	12,110	(7)	11,800	(4)
Jun *	15,486	19,390	(25)	18,300	(18)	17,800	(15)
Jul	16,700	18,030	(8)	17,030	(2)	16,560	1
Aug	16,517	20,340	(23)	19,290	(17)	18,760	(14)
Sep	14,964	14,370	4	13,520	10	13,160	12
Oct	9,925	9,160	8	8,540	14	8,330	16
Nov	2,526	1,710	32	1,710	32	1,690	33
Dec	1,966	2,020	(3)	2,020	(3)	2,020	(3)
Total	**101,119**	111,160	(10)	105,150	(4)	102,600	(1)

* Ramadan 2018 is from 16th May to 17th June.

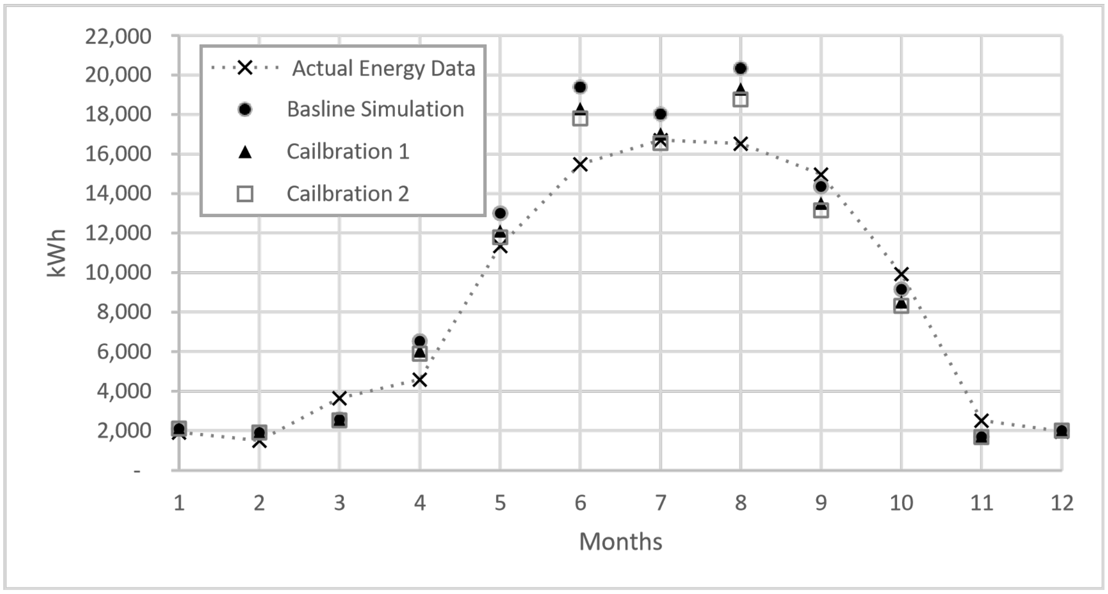

Figure 5 Actual Energy data and simulated results graph

3. DISCUSSION OF RESULTS

Scnario 1-Prediction Upcoming Ramadan-Ramadan 2019

To predict energy consumption for upcoming Ramadan, the calibrated eQUEST mosque model is used as a baseline after validating the simulated results with actual energy consumption data. The model has been adjusted to reflect Ramadan 2019 scenarios by adjusting the operational schedule, lighting schedule and temperature schedule and other relevant parameters.

Ramadan 2018 was from 16th May until 17th June, actual energy consumption was 16,534 kWh, and Simulated result was 17,642 kWh. The predicted model was compared with the calibrated model data as shown in Tabel 5.

Table 5

Prediction Upcoming Ramadan

Month	Calibrated Model-2018 (kWh)	Predicted Model- 2019 (kWh)
Jan	2,110	2,110
Feb	1,920	1,920
Mar	2,540	2,540
Apr	5,910	5,910
May *	11,800	12,780
Jun	17,800	16,650
Jul	16,560	16,560
Aug	18,760	18,760

Sep	13,160	13,160
Oct	8,330	8,330
Nov	1,690	1,690
Dec	2,020	2,020
Total	102,600	102,430

* Ramadan 2019 is from 5th May to 4th June.

Ramadan 2019 was from 5th May until 6th June and Predicted energy consumption is 18,119 kWh. Based on a calibrated energy simulation model, it was predicted that energy consumption during Ramadan will increase by 2.7%

Scnario 2- Ramadan Energy Impact

To evaluate Ramadan's impact on energy consumption, a no Ramadan scenario was created using typical occupancy patterns and energy use and was then compared with the predicted model energy use for the mosque during Ramadan. Results show that during Ramadan energy consumption has increased by almost 8%.
Due to the fact that Ramadan moves back about 11 days each solar year, it is expected that energy consumption during the winter period will be reduced since cooling energy will be reduced.

4. Conclusion

Ramadan is considered one of the peak energy use months, especially for mosques. Energy usage patterns in mosques are significantly affected during the holy month of Ramadan, due to extended operation hours, higher occupancy, and other communal activities.

This study highlights the importance of predicting the energy use of mosques during Ramadan. A simulation analysis was conducted on an actual mosque in Kuwait. In this study, mosque energy is predicted for upcoming Ramadan, and it was validated using historical data. Furthermore, the study also investigates Ramadan's impact on energy use.

According to our findings, Ramadan contributes almost 8% to the increase in energy consumption. Moreover, accurately estimating energy use during Ramadan can ensure effective energy management. It is expected that energy consumption during the winter period will be reduced since Ramadan moves back about 11 days each solar year. Further research will be needed to investigate this.

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