A SYSTEMATIC APPROACH FOR ENERGY AUDIT IN MOSQUES

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ABSTRACT

In harsh climatic areas, mosques need to be air-conditioned in order to provide an acceptable level of comfort quality for worshippers. Mosques are characterized by their unique intermittent operating schedule determined by the prayer time, which varies continuously according to the local solar time. Achieving the required comfort quality necessitates the use of an air-conditioning system which consumes substantial amounts of energy, the exact quantity being determined to a great extent, by the thermal envelope design, as well as the operation time and strategy of the air-conditioning system. This paper presents a systematic approach for energy audit in mosques. The audit process requires the collection of base information, field data, sample mosque selection criteria, and equipment and simulation software considerations. The audit process constitutes part of a comprehensive study aimed at assessing not only the impact of the envelope thermal design but also the operation of the air-conditioning system on thermal comfort and energy consumption in mosques in the hot- humid climate zone of the eastern region of Saudi Arabia.

Keywords: Energy Audit, Mosques, Thermal Comfort, Saudi Arabia

INTRODUCTION

In Muslim communities, mosques represent a place of great importance and function. The mosque constitutes the central location where people gather for their daily as well as weekly prayers (i.e. "*Friday*" prayers). Worshippers in mosques need to feel comfortable and relaxed in order to attain a feeling of tranquility and peace. However, mosques are characterized by having a unique operation schedule as compared to other types of buildings. They are usually occupied five times intermittently throughout the day all year round with each occupancy averaging a fraction of an hour to an hour. A limited number of studies have dealt with thermal comfort requirements in mosques. One such study on thermal comfort requirements for "*Friday*" prayer conducted in *Riyadh* during the hot season reported that worshippers indicated that most of them were comfortable, and only a few would have preferred cooler conditions [1].

The subject of thermal comfort in buildings is closely related to the issue of energy conservation. However, the desired thermal comfort may not be achieved due to the improper operation or control of the air-conditioning systems, resulting in under or overcooling of the space and possibly with a higher level of energy consumption than necessary. Many studies have been carried out on various building types to investigate this relationship and explore a means to conserve energy without compromising comfort [2,3]. These have included investigations into the impact of various energy conservation measures, air-conditioning (A/C) systems and component characteristics on the thermal performance of building and thermal comfort of occupants. Results indicated that adaptation of a higher set point temperature in summer could lead to a significant reduction in the consumption of cooling energy without a corresponding loss of thermal comfort [2].

In Saudi Arabia, all buildings including mosques account for a major share of energy consumption. This grew to more than 70% of the total electric energy consumption in the kingdom for the year 1998 [4]. The demand for energy in mosques can be critical as they are all operated at almost the same time of the day in each region, especially at the times of *Duhr* and *Asr* prayers, which fall within the most critical demand periods in summer. Though research on energy consumption and conservation in mosques is lacking, many studies have been conducted on energy conservation in other types of buildings, particularly residential ones. Said and Abdelrahman [5] conducted a parametric energy analysis on a detached single-family house in *Dhahran* using "DOE" simulation software. The study showed that there was great potential for reducing energy consumption in residential buildings if they were properly designed and operated. As much as a 38% reduction in the total annual energy consumption was reported possible by considering the combined effect of the analyzed parameters.

Studies on envelope optimum thermal design of residential and office buildings in the hot and hot-humid climate zones of Saudi Arabia were also conducted [6,7]. Annual energy savings of as much as 37% and 28% respectively were achieved in the optimization of a small two-story residential building in each of the two climate zones in *Riyadh* and *Jeddah* cities. Various annual energy savings were achieved through envelope thermal design optimization of large, medium, and small office buildings in the two climate zones with as much as 15%, 19%, and 40% savings respectively for the three office sizes in *Riyadh,* compared to about 8%, 12%, and 24% for the same offices in *Jeddah* [6,7].

Compared to the research work on other types of buildings, envelope thermal performance and air-conditioning operation strategies in mosques have been largely neglected. This fact further supports the need to develop a comprehensive knowledge base about the performance of thermal and energy systems in mosques in Saudi Arabia, where large numbers are already being operated and where many more mosques are expected to be built in the future. A detailed energy audit, through which the performance and consumption of energy systems are identified, represents a first step towards achieving this objective. This paper summarizes the process of energy audit in mosques as a step towards a comprehensive study of their overall thermal performance.

CLASSIFICATION OF MOSQUE TYPES

Mosques in Saudi Arabia can be classified broadly into two major categories. These are designed and built by the *Ministry of Islamic Affairs, Endowments, Da`wah and Guidance* (*MIAEDG*) and those designed and built by private donors. The first category of mosques is standardized into various sizes ranging from small and medium, to the large type of mosque. They have similar characteristics in terms of layout, shape and construction materials, as well as the type of air-conditioning and other energy systems used. Mosques in this category are designed, built, operated and maintained by the *MIAEDG*. The privately donated mosques do not usually follow a specific standard in their design or construction. Some of them are donated to the ministry after construction, for operation and maintenance, while others continue to be operated and maintained by the donor under the supervision of the ministry. Due to the diversity of mosque types with respect to their size and type of construction, it was found necessary to limit this investigation to those mosques designed by the *MIAEDG*. These mosques were surveyed to assess their actual condition and subsequently criteria were set for selecting representative sample mosques for detailed energy monitoring and/or simulation.

A list of mosques located in the eastern region was obtained from the *MIAEDG* [8]. This list included mosques built by the ministry as well as those built by private donors. Exclusion of the latter group resulted in a total of 156 candidate mosques. Sets of design drawings for some typical mosques were also obtained for preliminary review and assessment of the major common characteristics and systems to be considered in developing an appropriate energy audit form.

DEVELOPMENT OF MOSQUE "ENERGY AUDIT" FORM AND DATABASE

Energy audit is a necessary process to identify and quantify energy and cost savings that can be achieved through investment in energy conservation measures. "The energy audit serves to identify all of the energy streams into a facility and to quantify energy use according to discrete functions" [9, *pp.1-2*]. A systematic approach to energy audit in mosques was developed to provide an accurate and practical account of energy consumption and energy performance in mosques. The approach offers a step-by-step procedure that takes into account the diversity of mosque types, the uniqueness of mosque design and energy system types and operation.

In order to collect relevant information from mosques during field surveys, a special energy audit form was developed. This form included the main information concerning mosque location, construction type and year of construction, size, A/C system type and number of units, lighting system, envelope configuration and general characteristics in addition to other relevant aspects of the mosque and its surroundings. The information collected for each mosque was classified in the following major categories: general information; surroundings; mosque physical data; zoning; construction information; window system; lighting system; A/C system; air circulation system; hot water system; power supply; and an area for additional comments.

A preliminary audit form was developed and used in a pilot survey in a sample mosque in *Dhahran*. The objective was to test the appropriateness of the form contents, the ease of its use and how it is interpreted by each member in the survey team as well as testing the adequacy of information to be collected. The form was then revised by clarifying certain items, deleting redundant items and adding additional information required. The final revised audit form shown in *Figure 1* was then used to conduct the complete field survey. Out of the 156 mosques, a total of 132 mosques were located and surveyed employing the audit form developed. The remaining 24 mosques were either not located or found to be not typical or useful for the purpose of this investigation. Subsequently a database was developed, using Microsoft Access 2000 software for the purpose of transferring all collected information and storing it electronically. The collected information was then input into the developed database for further use in processing and retrieving the data in the desired form. This was also meant to help select representative sample mosques for detailed monitoring and/or simulation.

DEVELOPMENT OF SELECTION CRITERIA FOR SAMPLE MOSQUES

Considering the number of surveyed mosques and the time and equipment required, it would have been impractical to carry out detailed energy investigations for all surveyed mosques. Instead, representative sample mosques had to be selected based on specific criteria that took into account in a practical way the diversity of the surveyed mosques without impacting the credibility of the research findings. The selected sample mosques had to be typical and reflect the most common types built in terms of capacity, construction, shape, and type of the air-conditioning system with minimum deviations from the original design. The comprehensive mosque information compiled and stored in the database was utilized to categorize mosques according to their capacity, aspect ratio and type of air-conditioning system. In order to select a representative sample of mosques, a two-phase procedure was utilized. In the first phase, mosques were grouped according to capacity into six main groups as summarized in *Figure 2*.

The objective was to select a number of mosques from each group proportional to the total number in each category. In the second phase, a two-step elimination process was utilized to further reduce the list of candidate mosques for detailed energy monitoring and analysis based on the following criteria:

1. Location (i.e. mosques located close to the *Dhahran* area were preferred for easy access and close monitoring by the project team members); and
2. Amount and cost of required energy monitoring equipment.

In the first step of the elimination process, the convenience of monitoring and collecting data and the cost of the energy audit/monitoring process were considered in reducing the number of mosques in the target sample. Based on the above criteria the number of mosques in each of the six groups of the list was further reduced as shown in *Table 1* by excluding mosques located far from the Dhahran area. In the second step of the elimination process the number of mosques was further reduced considering the following criteria:

1. Uniformity of the air-conditioning (A/C) system;
2. Degree of deviation from original design; and
3. Accessibility and degree of surrounding obstructions.

As can be observed from *Table 1,* some mosques have three or more different A/C systems. According to the second set of criteria, mosques with minimum diversity in terms of A/C system types were selected and considered more appropriate for further energy simulation as they represented a more normal trend in A/C design and offered a better opportunity for more reliable correlation between energy consumption and A/C system type and operation strategy. Accordingly, it was then decided to select at least one mosque from each group for detailed study. A number of mosques were selected for site visits in order to confirm their suitability to the study according to the above set criteria. As a result, some mosques were observed to have been subjected to major construction changes compared to the original design and were excluded since they lacked the characteristic of being typical and would present a major challenge when performing energy simulation due to difficulty in obtaining relevant information. Also, mosques in which energy systems were highly diversified or control systems were not well placed or randomly connected to the power supply lines were also excluded. Based on the full consideration of the second set of criteria, six mosques were selected for in-depth energy monitoring and analysis. The subsequent activities involved acquiring energy consumption histories (i.e. utility bills) and details of the physical characteristics of these mosques for the purpose of detailed investigations. *Figure 3* summarizes the major steps and components of the systematic approach that was followed for energy audit in mosques.

MONITORING OF MOSQUE ENERGY CONSUMPTION: *A PILOT STUDY*

The selection of the proper monitoring equipment is an important issue in monitoring of energy usage. A large-size mosque (referenced *TH-13*) was selected for installing, operating and testing the energy consumption monitoring equipment. *Figure 4* illustrates the *TH-13* mosque information along with its geometric configuration showing its major characteristics. Considering the intermitted occupancy of the mosque, energy consumption was monitored using "*Elitepro*" energy data logger [10] using a 1-minute interval data acquisition for two successive days. *Figure 5(a)* illustrates the pattern of base-load energy use in the daily cycle with peak load of lighting usage at the five daily prayer times during Thursday and Friday. No air-conditioning units were operating during the monitoring period. As can be seen from part (a) of *Figure 5* the fine resolution of the acquisition made it difficult to observe the energy usage pattern represented by the envelope of the fluctuations.

The data acquisition interval was then modified from one minute to five minutes. *Figure 5(b)* shows the monitored base-load consumption for a weekday. The energy consumption pattern can be better observed and interpreted with a 5-minute interval acquisition with less data to be managed. In order to test the operation of the meter/data logger for an extended period of time, the daily pattern of electricity use was monitored for six successive weekdays. *Figure 5(c)* illustrates the consumption patterns superimposed. The consistency of daily peak base-load occurrence time, duration and magnitude verifies the consistent operation and data acquisition of the monitoring equipment.

Since it is planned to monitor several mosques in different locations, one problem with having multiple sites is the need to regularly download all data from those sites. Therefore it is beneficial to utilize monitoring equipment that supports multiple remote data collection. The "*Elitepro*" logger can be equipped with modem and be configured to automatically initiate scheduled telephone data retrieval sessions as well as receive calls with instructions from the connected PC. This feature can help manage the collection and download of monitoring data at almost the same time for all mosques under investigation.

CONCLUSIONS

This paper presented a systematic approach for energy auditing in mosques and collecting the necessary base information and field data towards a comprehensive study on the impact of envelope thermal design and air-conditioning systems operation on thermal comfort and energy consumption in mosques in hot-humid climate. Mosques built by the *MIAEDG* were surveyed, representative sample mosques were identified for detailed energy monitoring and/or simulation, and a sample set of potential energy monitoring equipment was acquired and tested. Work is in progress to conduct long-term energy consumption monitoring in the selected mosques as well as conducting calibration of an energy simulation program for identifying the proper envelope thermal design of the mosques in the hot-humid climate of the Eastern Province of Saudi Arabia.

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Mosque "Energy Audit" Form

Date: -------------------------, Audit Team Members: 1. ------------------------------ 2. ----------------------------

- **GENERAL INFORMATION**

❑ Mosque Reference Number : ------------------ [Indicate Mosque Reference No. on map(s)]
❑ City : ---------------------------------
❑ Neighborhood : ---------------------------------
❑ Address : --

- **SURROUNDINGS** [Show necessary information on plan sketch]

❑ North : ------------------ South : ------------------ East : ------------------ West : ------------------

- **CONSTRUCTION INFORMATION**

❑ Year of Construction: --------------------
❑ The mosque was renovated recently : No ☐ Yes ☐, Year of renovation : ------------------
❑ The mosque configuration was modified : No ☐ Yes ☐ [Indicate Major Modifications on Sketch]

- **MOSQUE PHYSICAL DATA**

❑ Mosque Dimensions (W x L x H), m (as measured) : W : --------, L : ---------, H: ---------
❑ Dimension of Structural Module, m (as measured) : W : --------, L : ---------
❑ Number of Structural Modules : ------------
❑ Exterior Wall Color : Light ☐ Medium ☐ Dark ☐

- **ZONING** [Show different zones on plan sketch]

❑ Jumah, "*Friday*" Mosque : No ☐ Yes ☐
❑ Women Prayer Hall : No ☐ Yes ☐ , Air-conditioned: No ☐ Yes ☐ Area , m^2 ---------
❑ Separate "*Daily*" Prayer Hall : No ☐ Yes ☐ , Air-conditioned: No ☐ Yes ☐ Area , m^2 ---------
❑ Closed/Open Court : No ☐ Yes ☐ , Air-conditioned: No ☐ Yes ☐ Area , m^2 ---------

- **WINDOW SYSTEM**

❑ Number of Windows : -------------------- , Typical Size(W x L) : --------- , ----------
❑ Type : Single Glazed ☐ Double Glazed ☐ Reflective ☐ Other -------
❑ Operation : Operable ☐ Fixed ☐
❑ Interior Shading : None ☐ Venetian Blinds ☐ Curtains ☐ Others, ----------
❑ Number of Entrances to Air-conditioned Areas : -------------

- **LIGHTING SYSTEM**

❑ Type of Lighting : Fluorescent ☐ Incandescent ☐ Other --------
❑ Number of Interior Units/Lamps : ----------------- , ------------------, ---------------
❑ Number of Exterior Units/Lamps : ----------------- , ------------------, ----------------
❑ Lighting Voltage : 220 ☐ 110 ☐

- **HVAC SYSTEM**

❑ AC Type : Central ☐ Split units ☐ Fan-Coil Units ☐ Window units ☐ Other : -------
❑ Number of units : , --------------, --------------------, ------------------, ----------------
❑ A/C Voltage : 220 ☐ 110 ☐ , Location: [Indicate Locations of A/C Units on Plan Sketch]

- **AIR CIRCULATION SYSTEM**

❑ Type : Ceiling Fans ☐ Fixed on the Wall ☐ Stand-alone floor Fans ☐
❑ Number : ------------------, ----------------------, -----------------------------

- **HOT WATER SYSTEM**

❑ No ☐ Yes ☐ , Type of Hot Water Heating System : Electric ☐ Gas ☐ Other, -------------
❑ Number of Hot Water Heaters : -------------, ---------, ----------------------

- **POWER SUPPLY**

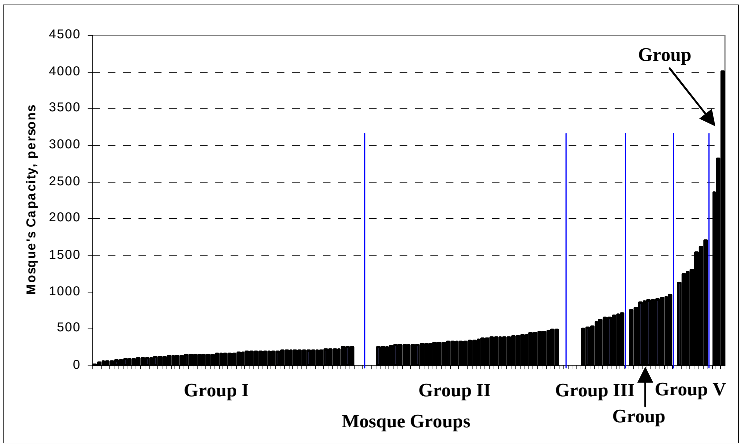
❑ Power Distribution Panels : No ☐ Yes ☐, Number : --------, Location: [Indicate on Plan Sketch]
❑ Electricity Consumption Meter(s) : No ☐ Yes ☐, Number : ---------

ADDITIONAL COMMENTS: ---

Figure 1 Major and sub-components of the developed "Energy Audit" form

Group	Capacity	No. of Mosques
I	≤ 250	60
II	251-500	42
III	501-750	10
IV	751-1000	10
V	1001-1750	7
VI	> 1750	3
	TOTAL	132

(a)



(b)

Figure 2 Summary of the surveyed mosque groups classified by capacity, (a) Tabular and (b) Graphical representation.

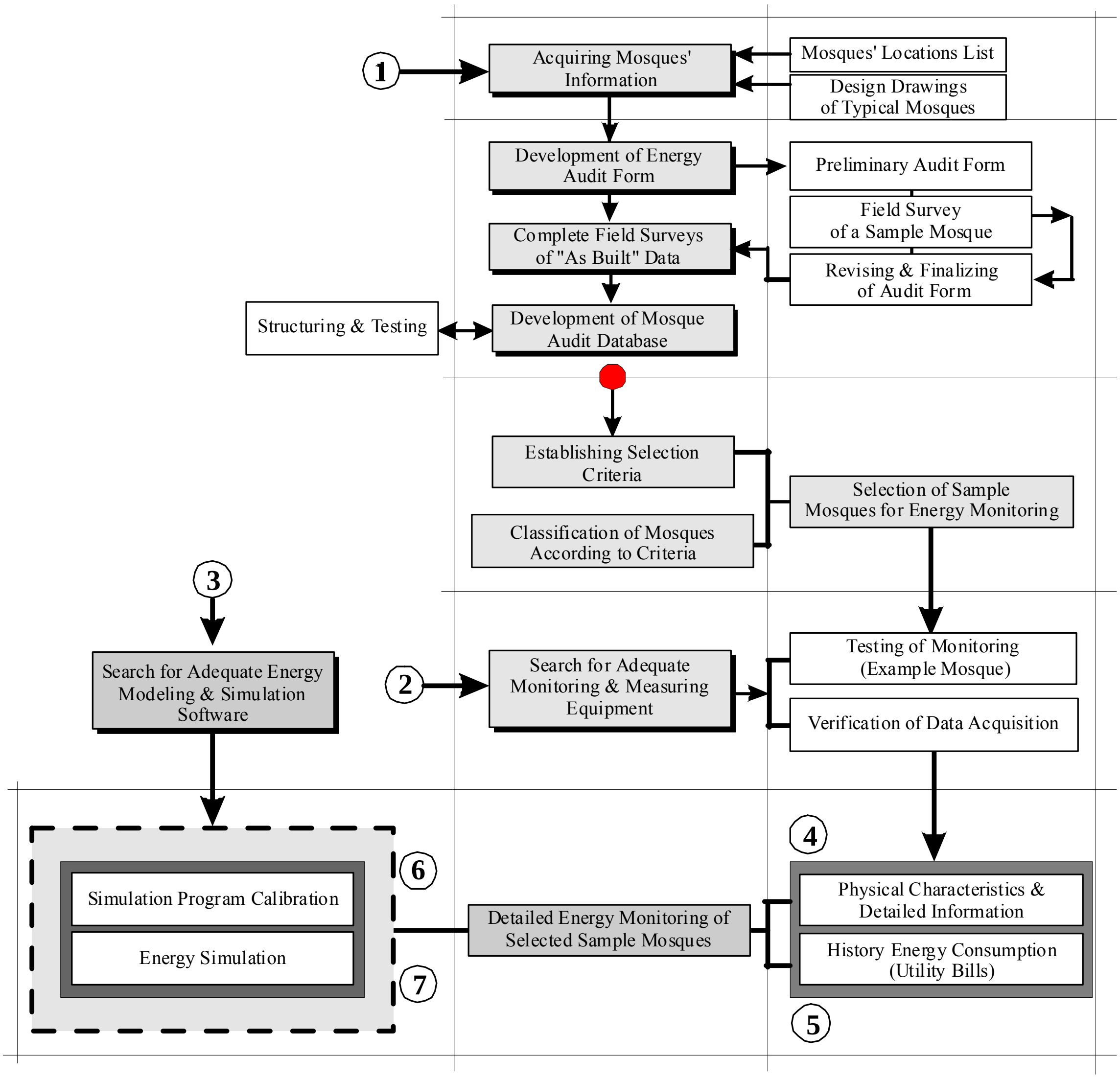


Figure 3 The major steps and components of the systematic approach that was developed for energy audit in mosques

Table 1. List of mosques (sorted and classified by capacity) after eliminating distant ones

#	ID	Use	NL	NW	L	W	AR	Area	Capacity	C	Wm	Fm	FC	W	O	Group
										HVAC Type						
			#	#	m	m	ratio	m^2	Persons	#	#	#	#	#	#	
4	DM052	D	3	1	9.4	5.9	1.6	55	58	-	-	-	-	17	-	Group I: Capacity <= 250 (Number of mosques = 21)
18	TH53	D	3	3	11.6	10.8	1.1	126	131	-	-	-	-	9	-	
20	TH32	D	3	2	13.6	9.7	1.4	131	136	-	-	-	-	6	-	
21	TH16	D	3	3	11.6	11.6	1.0	133	139	-	-	-	-	8	-	
23	KH77	D	3	2	14.5	9.6	1.5	139	144	-	-	-	-	6	-	
25	TH39	D	3	3	12.0	12.0	1.0	144	150	-	2	-	-	8	-	
28	DM070	D	3	2	14.6	10.0	1.5	146	152	-	2	-	-	6	-	
29	DM242	FD	3	2	15.0	10.0	1.5	150	156	-	3	-	-	6	-	
30	DM243	FD	3	2	16.3	9.3	1.8	151	158	-	-	-	-	6	-	
32	TH22	D	4	3	13.8	11.3	1.2	156	162	-	-	-	-	12	-	
33	TH27	D	3	3	13.5	12.0	1.1	162	169	-	-	-	-	8	-	
34	TH12	FD	3	3	13.1	13.1	1.0	170	177	-	-	-	-	8	-	
35	TH08	D	3	3	15.0	11.7	1.3	175	182	-	-	-	-	10	-	
36	KH26	D	4	2	19.2	9.3	2.1	179	186	-	4	2	-	6	-	
41	DM095	D	4	2	19.7	9.7	2.0	191	199	-	4	-	-	6	-	
42	DM173	D	4	2	19.7	9.7	2.0	191	199	-	6	2	-	8	-	
43	KH15	FD	5	4	15.6	12.3	1.3	192	200	-	-	9	-	5	-	
44	TH30	D	3	3	13.9	13.9	1.0	193	201	-	8	-	-	-	-	
50	TH54	D	3	3	15.3	12.9	1.2	197	206	-	2	-	-	8	-	
53	DM154	D	3	2	19.9	10.2	2.0	203	211	-	5	-	-	7	-	
58	DM064	D	5	2	24.6	9.6	2.6	236	246	-	5	3	-	8	-	
62	DM063	D	7	3	24.3	10.0	2.4	243	253	-	10	1	-	4	-	Group II: Capacity >= 251, <= 500 (#25)
63	KH45	D	5	2	24.9	9.8	2.5	244	254	-	7	2	-	1	-	
66	DM260	D	3	3	18.0	15.0	1.2	270	281	-	-	-	-	9	-	
67	DM282	D	3	3	18.0	15.0	1.2	270	281	-	-	-	-	10	-	
68	DM277	FD	3	3	18.0	15.0	1.2	270	281	-	-	-	-	10	-	
69	DM050	D	5	2	23.8	11.5	2.1	274	285	-	11	-	-	2	-	
70	DH007	D	4	4	29.0	9.5	3.1	276	287	-	10	-	-	8	-	
72	DM016	FD	3	3	19.5	14.7	1.3	287	299	-	2	-	-	11	-	
75	DM148	D	4	2	20.0	15.0	1.3	300	313	-	-	-	-	8	-	
76	KH28	D	5	3	20.7	14.6	1.4	301	314	2	-	-	-	12	-	
78	KH17	FD	5	4	19.7	15.8	1.3	311	324	-	10	5	-	-	-	
80	KH09	FD	6	4	23.4	13.6	1.7	317	330	-	-	4	-	12	-	
83	KH03	FD	7	4	24.3	13.7	1.8	332	346	-	-	7	-	-	-	
86	TH48	D	5	3	24.7	14.7	1.7	361	376	-	10	2	-	-	-	
87	TH28	D	7	3	29.0	12.6	2.3	365	380	-	-	3	-	15	-	
88	KH41	FD	5	3	24.9	14.8	1.7	367	382	-	-	-	-	-	7	
89	KH59	FD	5	3	24.8	14.9	1.7	368	384	-	16	-	-	17	-	
90	DM125	D	5	3	25.0	15.0	1.7	375	391	-	-	4	-	10	-	
91	DM126	D	5	3	25.0	15.0	1.7	375	391	-	-	-	-	15	-	
93	DM088	D	5	3	25.9	15.1	1.7	392	408	-	11	-	-	4	-	
94	DM048	FD	7	3	30.5	13.0	2.3	396	412	-	-	7	-	1	-	
97	DM004	FD	7	5	24.6	17.3	1.4	425	443	-	-	6	-	8	-	
98	TH42	D	3	3	24.2	18.4	1.3	444	463	-	-	8	-	-	-	
100	DH014	FD	5	3	29.6	15.3	1.9	453	472	-	8	-	-	10	-	
101	KH12	D	9	3	35.1	13.2	2.7	465	484	-	-	4	-	10	-	
105	DM006	FD	7	3	32.1	15.8	2.0	507	528	-	-	4	-	-	-	Group III: >= 501, <=750 (#7)
106	DM021	FD	7	3	36.4	15.6	2.3	568	592	-	-	4	-	-	7	
107	TH06	FD	7	3	37.5	15.9	2.4	595	619	-	6	6	-	3	-	
108	DM008	FD	5	5	25.0	25.0	1.0	625	651	-	-	4	-	12	-	
110	TH43	FD	7	4	33.8	19.4	1.7	656	684	-	20	-	-	-	-	
111	DM009	FD	5	4	29.0	23.0	1.3	667	695	1	-	-	-	10	-	
112	KH31	FD	4	3	34.3	19.9	1.7	681	710	-	2	-	-	3	-	
114	DM002	FD	7	4	27.6	27.6	1.0	762	794	4	-	12	-	2	-	Group IV: >=751, <=1000 (#6)
115	KH05	FD	9	4	44.3	18.6	2.4	824	858	6	-	-	-	5	-	
116	DH003	FD	9	4	43.4	19.4	2.2	844	879	-	-	16	-	15	-	
119	DM031	FD	9	4	42.0	20.8	2.0	872	908	-	-	6	-	17	-	
121	DM210	FD	9	4	45.0	20.0	2.3	900	938	-	8	-	-	-	-	
122	DM036	FD	7	5	35.8	26.0	1.4	931	970	-	8	-	-	-	-	
123	TH11	FD	3	3	33.0	33.0	1.0	1086	1132	-	-	8	-	-	-	Group V: >=1001, <=1750 (#4)
126	TH13	FD	7	6	42.3	29.7	1.4	1254	1306	-	-	21	-	-	-	
127	DM181	D	7	5	45.5	32.5	1.4	1479	1540	8	-	-	-	-	-	
128	TH01	FD	9	7	44.9	34.7	1.3	1556	1621	1	2	-	-	1	13	
130	RH01	FD	9	5	63.0	36.0	1.8	2268	2363	-	-	14	-	25	-	Group VI: > 1750 (#3)
131	**DM43**	**F**	9	9	52.0	52.0	1.0	2704	2817	4	-	10	-	-	-	
132	DM001	D	9	9	62.0	62.0	1.0	3844	4004	13	-	-	-	-	-	
			#	#	m	m	ratio	m^2	Persons	#	#	#	#	#	#	
#	ID	Use	NL	NW	L	W	AR	Area	Capacity	C	Wm	Fm	FC	W	O	
										HVAC Type						

Symbol Key

USE	D= Daily prayers, FD=Friday+Daily prayers, F= Friday prayers	C	# of Central Air-conditioning
NL	Number of Structural Modules parallel to "Qibla" wall	Wm	# of Wall-mounted AC units
NW	Number of Structural Modules perpendicular to "Qibla" wall	Fm	# of Floor-mounted AC units
L, m	Length of Mosque, meters	FC	# of Fan-Coil AC units
W, m	Width of Mosque, meters	W	# of Window AC units
AR	Aspect Ratio = L/W	O	Others
Area	Floor Area, m^2		
Capacity	Number of persons (Mosque Capacity)		

Mosque Information

GENERAL INFORMATION
Mosque Reference Number : **TH-13**
Location : **Al-Thuqba**

MOSQUE PHYSICAL DATA
Number of Structural Modules : **7 x 6**
Dimensions (L x W x H), m : L : **42.3** , W: **29.7** , H: **6.10**
Capacity : **1306** persons

ZONING
Mosque Use : **"Friday" + "Daily" Prayers**
Women Prayer Hall : **Separate Area**
Interior Lighting : **Fluorescent**

HVAC SYSTEM / AIR CIRCULATION
Type : **Floor-mounted Split Units**
Fans, # : **Ceiling , 42**

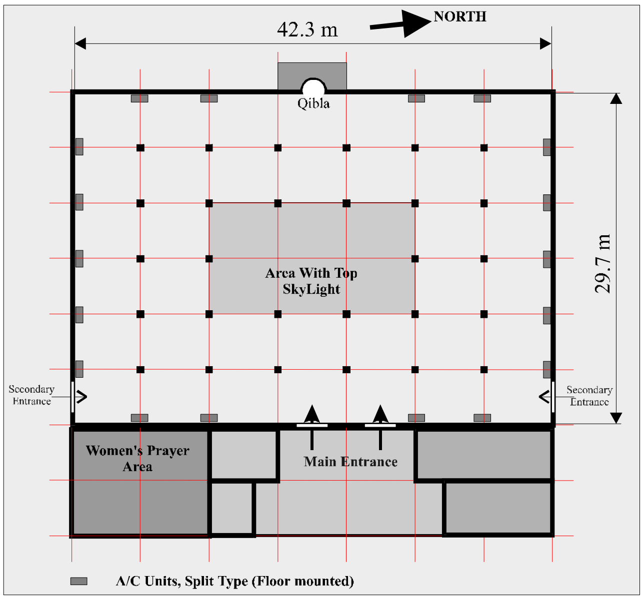


Figure 4 The *TH-13* mosque's geometric configuration and information

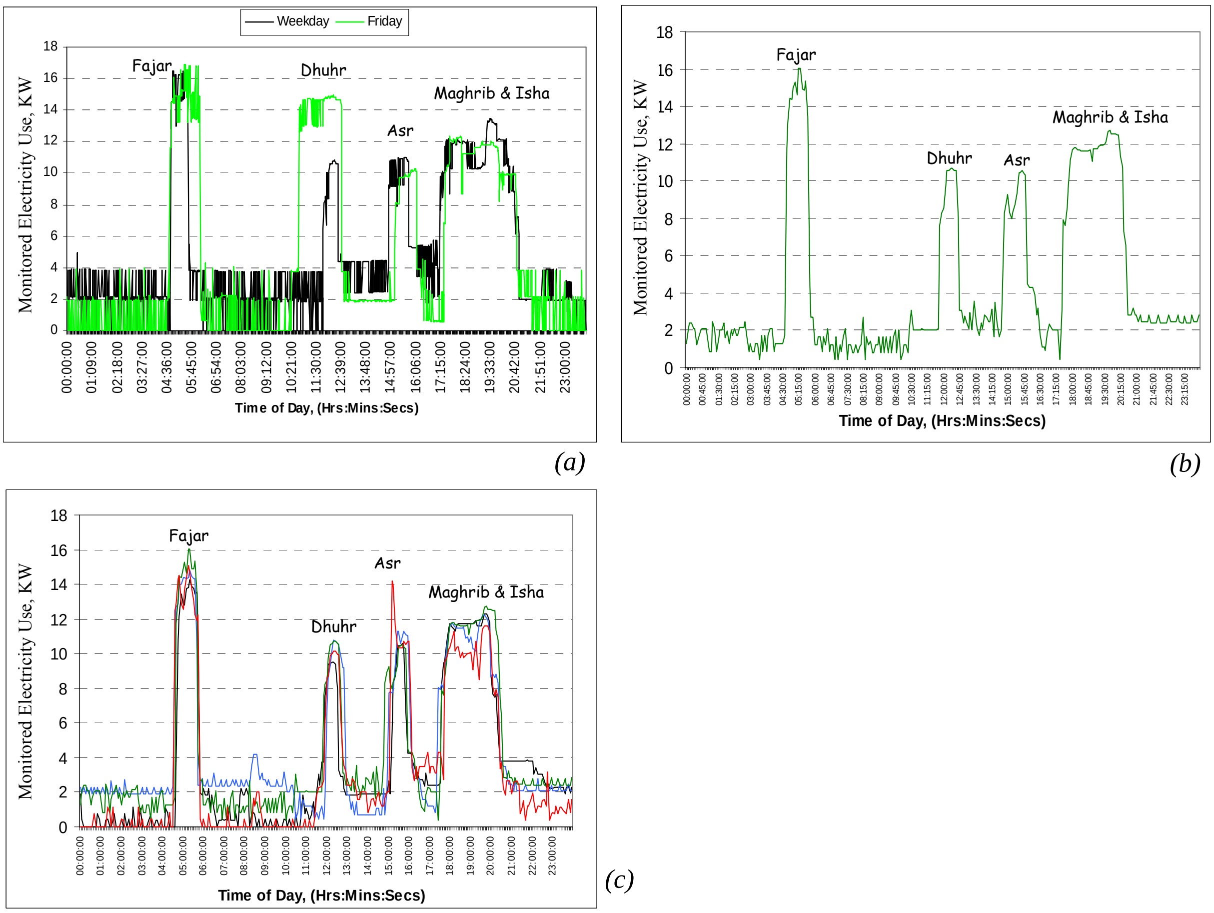


Figure 5 (a) The patterns of monitored electricity use (kW) of the *TH-13* mosque (superimposed) for a weekday and Friday acquired using a 1-minute interval, (b) The pattern of electricity use (kW) acquired using a 5-miunte interval, and (c) The pattern of electricity use (kW) monitored, using a 5-miunte interval, for six successive weekdays.