

Research Article

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Mosque design strategy for energy and water saving

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Abstract: The built environment plays an essential role as a climate change agent. Natural resource exploitation, energy consumptions, and waste management need to be built for more environment-friendly. The Mosque is a religious building built in every space on earth since a quarter of the world population is Muslim. This situation brought an urgency for making Mosques more sustainable and friendly to the natural environment. Carrying these facts, this study aimed to suggest a design strategy for making a sustainable mosque. Through a collaboration of passive design strategy, present technologies work of literature, and a study case, this study shortlisted primary design strategies in (1) building layouts, (2) lighting strategy, (3) HVAC strategy, (4) water conservation strategy, and (5) IT strategy. By keeping these major design strategies, Mosques can be made more environmentally sustainable. Several design recommendations are suggested in each major design strategy that may bring help for making sustainable Mosque on every space on this earth.

Keywords: mosque, sustainable building, innovative design, energy saving, water saving, IoT

1 Introduction

Mosque was derived from the Arabic term of “masjid” or “space to perform sujud” that related to meaning as

submission space [1]. Mosque as Muslim worshiping built environment was built as a space not only to do prayer (salah) but also to do many worshiping activities such as reminding Allah name (zikr), reading Al Quran, and religious education as school, etc. [2,3]. The Mosque has always become the central part of Islam culture that demanded to be supported by high-quality building or architecture artifacts [4]. The Mosque that was built by the Prophet Mohammed SAW first on Madina was delivered as a model of environmentally sustainable practices [5]. The Nabawi (prophet building) Mosque design and technology probably did not suit modern and next-generation. However, the principles of specific sustainable strategies can be adopted as a guideline and actuated on the planning and designing of the Mosques. The philosophy of the first Mosque built by the prophet, a guideline regarding space, and form design with the Islamic principles shall be followed [6].

There were several studies performed on sustainability design concentrated on the energy usage model of Mosques. Most of them show that Mosques have been found to consume an excessive huge quantity of energy [7,8]. The discussion of the modern Mosque design problem is the way to get architectural aesthetic and highly delivered to an arrogance over the context [9]. However, there still many Mosques on earth are having potentials for sustainable Mosque design [10]. The sustainable Mosque that gives information on building nowadays was considered in all aspects of built environments. The generic strategies of Mosque design can have both good and lousy sustainability effects [11].

Through studies of Mosque design, building materials, space compositions, operational supports, and micro-macro climate, architectural codes must assist the architect to apply passive designing strategies and collaborate with current developing technologies. After that, through comparing the basic or architectural and essential operational characteristics of Mosques with sustainable building codes such as Green Building Council Indonesia [12], USA’s Leadership in Energy and Environmental Design (LEED) [13], English Building Research Establishment Environmental Assessment Method (BREEAM) [14], Malaysia Green

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Building Index [15], and Green Mark of Singapore [16], the study points out the several factors of environmental sustainability Mosques. The aim of this research is to suggest strategies toward comprehensive studies of Mosque and sustainability strategies. Literature study and Mosque sustainability discussions on an example were performed to investigate energy saving. This study provided major design strategies in (1) building layouts, (2) lighting strategy, (3) HVAC strategy, (4) water conservation strategy, and (5) IT strategy.

2 Materials and methods

2.1 Literature study

This method was the main method that was included in the Introduction section as the background of this scientific writing to set the research basis. Some literature researches of sustainable environment and building codes from Indonesia GBCI, America LEED, England BREEAM, Malaysian GBI, and Singapore Green Mark were quickly resumed on the main space of the mosque and currently developing information technologies. Then, concentrated on two main aspects: energy and water conservation.

2.2 Study case (simulated scenario)

This method to discuss the scenario resumed the literature study of sustainable environment codes and Mosque spaces [17]. The building elements of the Mosque are the formal or basic space characters of the Mosque. This study case will be named as a simulated scenario of building layout, lighting, HVAC, water consumption, and IT composure.

3 The brief discussion of sustainability

Sustainable development is emphasized constantly in every space on earth as its effort in building construction industry to save the planet Earth from pollution, run out of the natural resources, and struggle to develop structures that are feasible in each contextual site [11]. Every human in this industrial world has a part to make small

or large changes that help the environment for the future. All efforts for saving energy, reducing wastes, and helping restore damaged habitats are credited to sustainability [18].

Sustainability and sustainable development are popularly used phrase to describe a vast spectrum of activities that are generally related to ecological but which may not necessarily be sustainable for long periods [19]. In reality, sustainability is about understandably logical conscious choices by not spending more options in wishes of gaining an increased return on investment. Sustainability itself is about working with nature and not fight against it. Furthermore, it is more than buildings that are supposedly environmentally responsible that sacrifice occupant comfort. This does not imply about purchasing green products or recycling assets at the end of their useful lives that are not sustainable. This condition is related, and it is friendly for both environmental aspect and user health [20]. Thus, the main purpose of the three targets model (produce more, distribute more just, and preserve for the future) will be the based on the criteria of sustainability in this study.

In the resume of Green building codes of the tropical area in Indonesia (GBCI), Malaysia (GBI), and Singapore (Greenmark) about sustainability mentioned that six rating tools of sustainability (site development, energy conservation, water conservation, material cycle, indoor air comfort, and building managements), and sub-tropical area of England–Europe (BREEAM), America (LEED) shown additional of acoustic, health, and heat insulation tools [20]. The concept of sustainable design in Mosque shall refer to the previously mentioned rating tools [21,22] (see Table 1). Therefore, the water and energy conservation aspects will be the main concern.

4 Contextual Mosque design

The mosque is a religious building which is based not only on Islam law (sharia) but also on cultural adaptation of the building site as a contextual response in design [23]. The Mosque design commonly considered the worship mode that is performed with worshippers' standing, bowing, and prostrating. At certain periods and circumstances, the worshippers sat on the floor in focus to listen the imam preaching or to communicate message (khutbah) while standing on the mimbar floor and sometimes a prayer time communicator (muadzin) called a prayer time (adzan). The podium or mimbar typically being elevated above floor level but varies for different Mosques [24,25].

The most important element that affects the Mosque design is its Qibla direction so every Mosque on this Earth

Table 1: Green building standard comparative studies

Main criteria	Total (%)	BREEAM (%)	LEED (%)	DGNB (%)	GREENSHIP (%)	GBI (%)	BERDE (%)	GREEN MARK (%)	LOTUS (%)	TREES (%)
Energy	24	14	24	10	25	25	8	61	26	23
Health and well-being	12	14	15	17	7	17	6	3	9	20
Management	10	11	7	22	6	18	13	3	8	5
Water	10	6	10	2	24	10	6	11	13	7
Land use and ecology	9	9	11	8	10	8	17	4	11	6
Material	9	13	10	8	12	6	5	7	11	10
Waste	6	7	2	16	3	3	10	4	9	5
Transport	6	8	7	3	4	3	16	2	3	5
Pollution	6	9	6	1	6	4	6	2	6	9
Innovation	4	9	5	0	0	6	9	4	0	6
Others	4	0	4	14	3	0	2	0	5	5
	100	100	100	100	100	100	100	100	100	100
Description	Average RSI (%)	BREEAM (%)	LEED (%)	DGNB (%)	GREENSHIP (%)	GBI (%)	BERDE (%)	GREEN MARK (%)	LOTUS (%)	TREES (%)
Environment	90	88	92	73	93	98	80	98	92	93
Economic	79	80	79	91	72	83	78	86	70	73
Social	43	50	47	43	37	36	59	17	41	54

Source: Luangcharoenrat and Intrachotoo (2019).

always considers Kabah in Masjidil Haram, Mecca, as the orientation of many different Mosques in different neighborhoods (Figure 1). The result of the Kabah orientation brought a non-contextual shape of the Mosque or at least the prayer room shape. This condition has shown that collaboration of both Kabah the main orientation to do prayer and contextual site design strategies of Mosque was needed. Some adaptations are shown in Figure 2 of Huntington Islamic Centre Mosque that have two axes of Mosque orientation [26]. One axis for the prayer room is heading to the Kabah in Mecca, Saudi Arabia, and the other is leading to the street and entrance of the Islamic centers.

This situation becomes the basic design strategy of this research which is closely related to the passive design of buildings in responding the certain regulation and situations [27]. The contextual Mosque passive design is 17% of the valuation score in sustainable strategy [12] that brings further impact to the five other strategies. This study leads to contextual passive design toward site entrances, potential natural lighting, potential shading (HVAC), and water conservations.

The multiple orientations of the Mosque have been the main discussion in this study. As mentioned earlier, the street entrance and qibla orientation have put axis on the Mosque. These conditions may not result in an axis, and then if we put another design consideration, there will be other axes to be added. From these criteria, the instant solution may be the circular form of Mosque (zero-angle) or rotatable buildings (dynamic architecture).

The zero-angle Mosque is a Mosque with a circular form of prayer room especially as the response of many axes of orientation. The examples of this kind of mosque are Sumur Gumuling Mosque in Indonesia [28] and Yesil Vadi Mosque in Turkey [29]. By the many orientation reasons of it, both Mosques are using circular prayer space (Figure 4). The concept of no angle brings the flexibility of

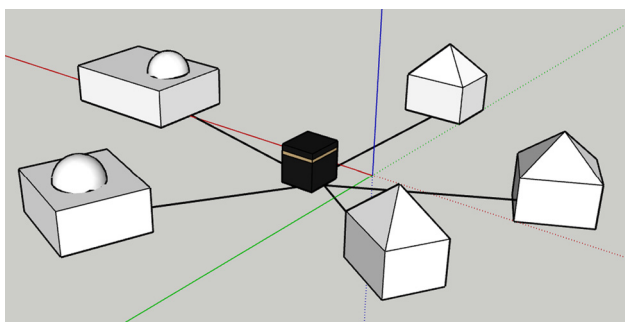


Figure 1: Main orientation of all Mosque (Kabah).

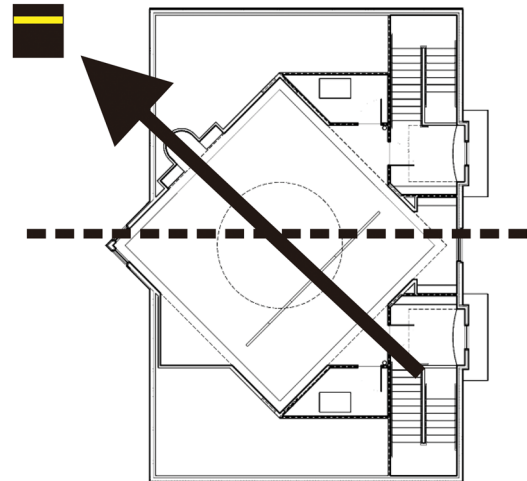


Figure 2: Dual orientation of Mosque in Huttington. Source: Kahera (2009).

orientation not just for qibla response nor street façade, but it may facilitate other requirements in directions.

The rotatable building was another scenario of making the building more responsive to the contextual change already developed in Dubai for residential and commercial towers. However, for the Mosque design, this innovation might be not suitable in small scale space, related to the function of the prayer room. The activities of praying might be disturbed by the building motion so this scenario for this era can be considered not possible.

From this study, we can conclude the two big contextual passive shapes of (1) dual or more Mosque building orientation and (2) the circular shape of Mosque. A scenario may be adopted for each Mosque considering the contextual condition of the surroundings (physical and non-physical) as being mentioned that principle of prophet Mosque is the representation of islam environment sustainable images.

5 The lighting strategy

The building lighting system consists of natural daylighting and artificial lighting. Both lighting systems originally were designed to meet the 200 lux of the light intensity standards [30–32]. The Mosque is a venue for not only performing prayer but also reciting al Quran, religious school, and other activities, which brought Mosque shall have a minimum intensity of conference light standard.

Natural lighting can be obtained during the day from direct sunshine or sun reflection through other materials.

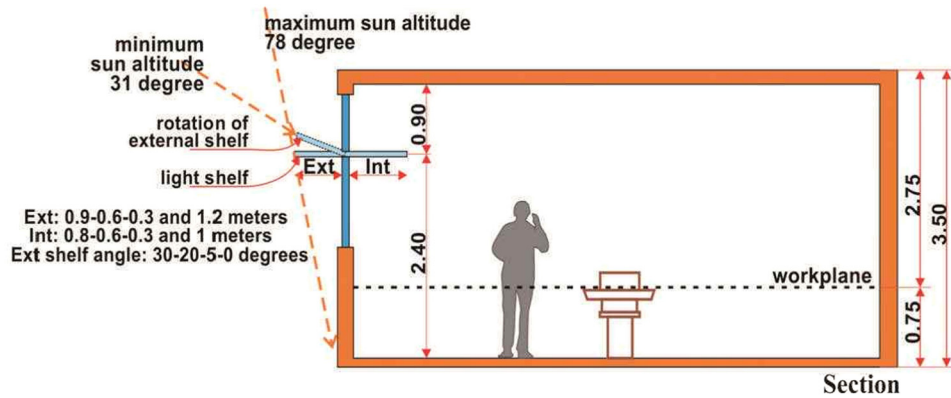


Figure 3: Daylighting device suggestions. Indarto (2018).

These criteria bring mandatory building openings on the specific functional room or can be substituted by light selves installment to enlighten the spaces. The direct sunshine during day afternoon may the biggest source of natural lighting, but the flares and other light renders may demand certain treatments. The most potential natural light scenario is the skylight reflection via other materials and light shelves installed (Figure 3) [33]. The optimal natural lighting strategy by bringing the daylight via windows with overhang for filter and light self is highly related to the building orientations (Figure 4). Misleading design by putting the opening directly on the west-east side (sun path) not only brings light but also flares and sun heat that shall be avoided in basic passive design strategies. Furthermore, the standard of Indonesia building openings for natural lighting is 1/6 of the floor area [27].

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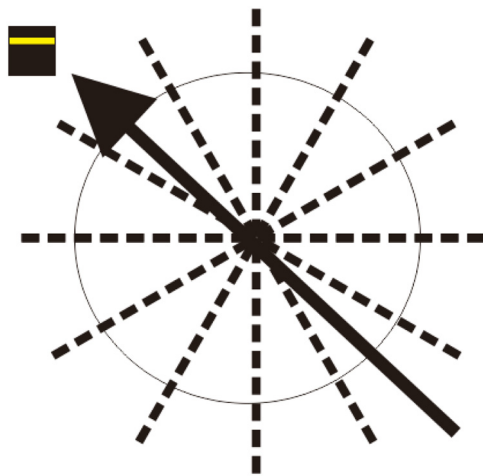


Figure 4: Multiple orientations of circular shape Mosque.

originally were designed to meet the 200 lux of the light intensity standards [30–32]. The Mosque is a venue for not only perform prayer but also reciting al Quran, religious school and other activities brought Mosque shall having a minimum intensity of conference light standard.

The level of lamp illumination also affects the psychology of the human who lives in the room as described by Yu and Akita [34] that cooler light in high intensity and the warmer light in low intensity can create a more comfortable environment. There were standard lamps in artificial lighting applications related to light productions, such as bulbs, compact fluorescent lamp (CFL), and light-emitting diode (LED). Bulb produced the light by burning the filament inside the glass, CFL used the halogen gasses inside the pressured glass, and LED using an arranged diode to emit the light as the name [35]. From the three lamps, the most sustainable option is LED with various cool-warm ambiances.

The position of artificial lighting shall be managed by the distance to the wall opening [12]. This condition has been suggested by sustainable design because the principle of artificial lightings is supporting the room in the absence of natural lighting. In this automatization era, the presence of a photosensor and motion detection device also supports the energy efficiencies of the Mosque. The installation of motion and passive infrared sensors for lighting proof the reduction of monthly electric energy consumption is between 30 and 40% lower when compared to the one without sensors installation [38].

These conditions of artificial and natural lighting may resume by strategies of (1) optimization of wall openings on the north–south side of the building for natural lighting, (2) the passive overhang and light selves' device above the windows or wall openings, (3) installation of multi-sensor lamps, (4) arrangement of lamp line (windows-based orientation) and (5) LED usage lamps.

6 Heating ventilation and air conditioning strategy

The system of HVAC's main purpose is to meet the thermal comfort in certain criteria. The required thermal comfort is not necessarily gained to improper operation of HVAC systems where under or overcooling occur in many Mosques and this reflected on the comfort status of worshippers. Air-conditioning system size and operation strategies for buildings with intermittent occupancy are expected to have a major influence on Mosque thermal and energy performance. Furthermore, operational thermal zoning that is normally dictated by the variable occupancy of Mosques can significantly influence their energy performance [36]. The design strategies in HVAC being suggested by Budaiwi and Abdou to split into three zone activities of daily prayers, night prayers, and Friday prayers (Figure 5). The zoning also related not only to the occupation but also to the usual form of zone 1 that is located next to the entrance and zone 3 that is the head of the prayer lines.

Similar to the lighting strategy, the HVAC installation is considering the sun path that brings sun heats. COP and HVAC power will increase due to the heat they must reduce, which has brought consideration toward the functional areas. This section suggested the installation of HVAC priorities to zone 3 as the common line of prayer and far from the wall openings so the air conditioning effort is low and optimum then followed by zone 2 and 1. The sensor technology of HVAC activation also can give big support for Mosque sustainability, so if there were no prayer, the system can automatically turn off or idle mode. The other passive strategy is using the insulation materials between the zone. Budaiwi and Abdou mentioned that the insulation used on the Mosque can reduce the AC operational to reach the thermal comfort of the

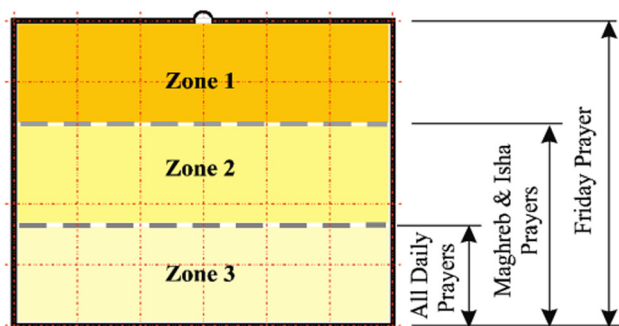


Figure 5: HVAC strategy related to Mosque schedules. Budaiwi and Abdou (2013).

Mosque users, especially for big Mosque with continuous AC operation (see Figure 6). The insulated Mosque has reduced the AC efforts to 13–46% depending on the situation.

These conditions of HVAC being resumed by strategies of (1) zoning of HVAC, (2) instalment of multi-sensor for activation, and (3) room insulation. The three combinations of strategies can be designed based on small scale or big size Mosque for more sustainable Mosque in the future.

7 Water cycle strategy

Water is one of the four elements of prayer, ablution (wudlu) is mandatory for Muslims that is repeated several times a day (mandatory prayer is five times daily). Ablution is performed by the washing of hand palms, face, inner mouth, nose blow, arms until the elbow, part of the forehead, outer ears, and feet. The amount of water that was used by Muhammad SAW for the performance of ablution is one full palm of every act [37]. So, saving water and developing water resources become a part of the sustainable efforts in Islam. Activities that demand water in the Mosque include ablution, irrigation, showers, kitchen and toilet services, and cleaning [38].

Greywater recycling is a good treatment of potable water-wasting problems; however, prevention is more priority. Recently automatic ablution devices are available, but they are expensive and high-cost maintenance. Better to manufacture water-saving taps at a lower price and water filter. The tap design affects water consumption, so, tap design can help the user to save more water. It is also able to propose activation with legs (feet or

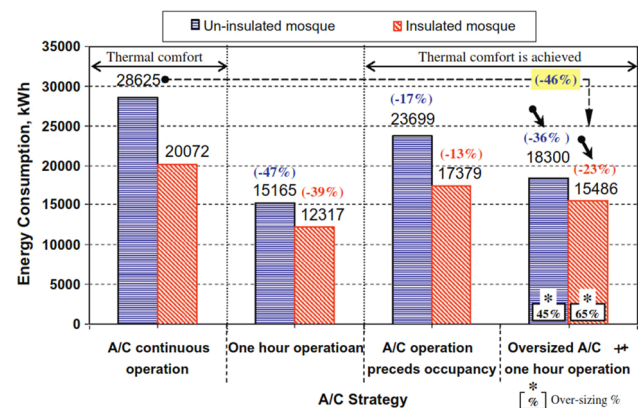


Figure 6: HVAC strategy on insulated Mosque. Budaiwi and Abdou (2013).

knees) instead of hands in opening taps to help to decrease water waste (Table 2).

Solving the problem of excess water consumption can be provided by good tap control design or greywater recycle [39,40]. In order to reduce water usage in ablution practice, we can introduce a new design for ablution tub or other innovations.

8 Automation, control, and monitoring strategy

This part plays a significant amount of contribution in realizing the sustainable Mosque. It enables all the above components to run autonomously by means of appropriate control and monitoring strategy. In order to do so, this part requires to employ communication protocol that allows each component to aggregate performance evaluation of each component through wired and wireless networks.

There are a lot of choices for crafting an appropriate control and monitoring strategy for the sustainable Mosque. To the best of our knowledge, the Internet of things (IoT) technology is the most proper technology to realize our concept of the sustainable Mosque due to its broad applications, e.g., Internet of Vehicles, Internet of Medical Things, and Internet of Underwater Things. [41]. One may wonder whether these mentioned applications in IoT are appropriate for realizing the sustainable Mosque. We can argue that the IoT technology including its vast network protocols can accommodate the need for strategies orchestration by comprehensive solution at its layer as shown in Figure 7.

As for achieving our concept of the sustainable Mosque, there are three layers for orchestrating the previously mentioned strategies. At the bottom layer, each sensor and actuator run independently for avoiding

waste of resources, e.g., water, electricity, and light. This layer can be applied by creating closed loop sensors–controllers–actuators, so that it can moderately regulate the usage of resources against the needs of resources. If there is no need for the resources, the system will automatically cut off the resources.

In the middle layer, the actuators and sensors are connected to each other for controlling and monitoring their performance through a local network. There are various types of wireless and wired network protocols for these purposes including CAN Bus [41], ISA100.11a [42,43], Wi-Fi [44], and so on. This layer not only communicates among devices but also enables the users to directly control and monitor each sensor and actuator on the site. As a result, this layer allows users transparently to observe the internal strategies and to adjust the process if needed.

The most upper layer contributes vital role in diagnosing any unextracted features/information in the lower layer through Big Data analytics [45]. It is expected due to the existence of huge computational resources in cloud computing server. Prior to conducting Big Data analytics, the components in the lower layers should send their computational and resources states to the cloud server through the Internet in some defined periods. Then, the Machine Learning algorithm extracts some information from the uploaded data and recommends some actions for improving the performance of the components in the lower layer. This layer not only enables data analytics but also enables far-away users, i.e., users who are out of local network, to access information of sensors and actuators. In addition, users can also send restricted types of commands for controlling the aforementioned strategies if needed.

One may wonder whether Information Technology (IT) infrastructure and Big Data analytics can contribute significantly for realizing sustainable mosques. We can

Table 2: Ablution tap types

Tap type	Average total ablution time (s)	Percentage of wasted water (%)
Mechanical knobs-tap	59.9	47
Mixing short neck-tap	57.2	42
Mixing high neck-tap	42.8	38
Mechanical push bottom tap	49.8	37
Automatic tap	49.4	30.3

Source: Budaiwi and Abdou (2013).

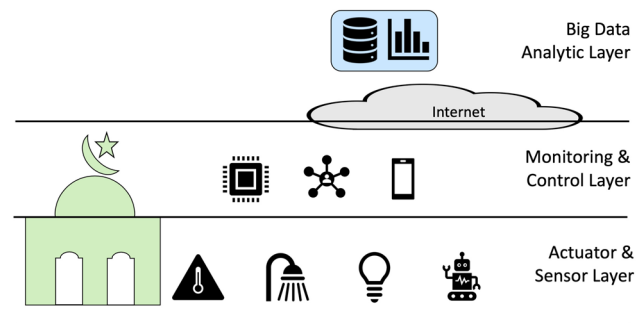


Figure 7: IoT layer for strategies orchestration in the sustainable Mosque.

argue that IT infrastructure and Big Data analytics are needed for at least the two following reasons:

- (1) Automating the controlling and monitoring process of the mosque facilities and energy usages, e.g., electricity, heat, and water, as discussed in these works [46,47]. By applying sensors and actuators across the mosque building, human intervention can be reduced considerably. As a consequence, energy waste due to the human error can be reduced significantly.
- (2) Extracting knowledge or delivering information through statistical analysis and machine learning approach. This action is also considered important due to its ability to conduct prediction of future issues, pattern recognition, data classification, and clustering, and also insightful information presentation based on current collected data as discussed in the previous work [48,49]. As a consequence, the mosque services to the visitors can adapt with any situation and condition. For example, in the current situation of the COVID-19 pandemic, the mosque can also monitor whether the visitors apply health-protocol-based religious activity by recognizing the crowd of visitors around the mosque building as discussed in refs. [50,51].

9 Design guideline synthesis

From the five strategies mentioned earlier, there is a resumed guideline which being adopted on a case study of a Mosque at the simulation level. This Mosque design guideline presumed in coordinates of $-6.979678, 110.406201$ or $6^{\circ}58'46.8''S 110^{\circ}24'22.3''E$. The Mosque is located in Semarang, Indonesia, which have a tropical climate and on the east side of Kabah. The condition of the existing Mosque has followed the direction of Qibla orientation as turning the building from the street. The orientation of this Mosque made it become widen on the east–west (Figure 8). This resulted from a large amount of natural lighting during days and the abundant sun heats at the same time. However, the second option of orientation strategy has been applied by making a new direction of building without neglecting the street or contextual situations.

The strategy on lowering the sun heat and glare of this Mosque is making more roof (extension area) on the street. This adaptation has become a good solution by the Mosque designer to minimize the solar heat and optimize the daylighting from the morning until evening (Figure 9). In the evening or during dark hours, the lighting strategy

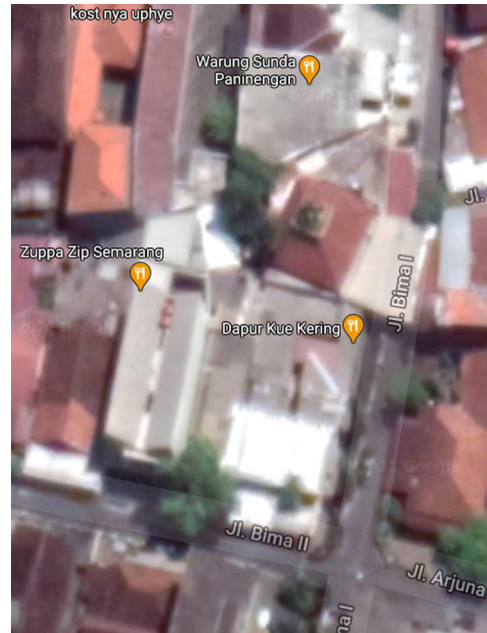


Figure 8: Contextual site of Mosque case. Source: googlemap.com.

can be applied by using LED lamps with motion sensors on the prayer area. The motion sensor has been a priority rather than a light sensor because the usage of the prayer area depends on the activities and not on the light conditions. Furthermore, the sensor not only controls the on/off switch but also provides data for more advanced research of energy usage.

In the section of HVAC, the tropical climate has provided similar temperature and humidity conditions of 25.2°C and an 86% average during a year [52]. These conditions has brought more challenges in HVAC for lowering the temperature during the hot day for several occasions. The strategies of HVAC are by placing three pairs of ceiling fans inside the prayer room with automatic and

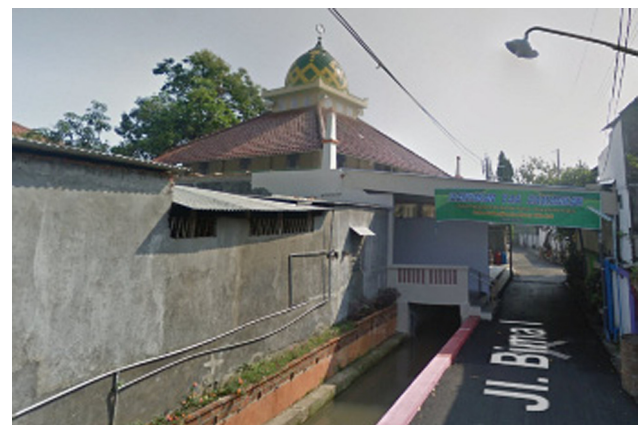


Figure 9: Expansive roof of the Mosque. Source: googlemap.com.

manual control of human detection. As mentioned by Abdou et al. (2005) that there are three zones related to the prayer time of Friday, maghrib, isya, and daily [37]. The placement of three pair ceiling fans is a response to that universal condition of the Mosque. However, the automatic control can be connected with a lamp sensor during the night and separated during the day. The dual options were related to the importance of air conditioning rather than lighting for performing the prayer [22]. The automatic sensors also send the data through the Internet for further research on energy conservation.

For the water conservation, the ablution area will be suggested to use an automatic tap with also smart sensor to switch on/off and submit the usage data through the Internet. The tap sensor will be designed as a waterproof device and using short infrared (less than 1 m) to be more adaptive on Mosque condition.

Later on, the collected data will be processed on the server to calculate the time, energy, and water use several times. This concept will make the Mosque design more sustainable in facing the energy and water crisis in this era (Figure 10).

The study case of this Mosque can be applied to the other Mosques in the Earth. This sustainable Mosque by simulating the building layouts, lighting, HVAC, water, and connection with IT strategy also gains more information and adaptable transformation based on the environmental issue in the future. Future Mosque shall be less energy, water, and natural resource consumption, so that

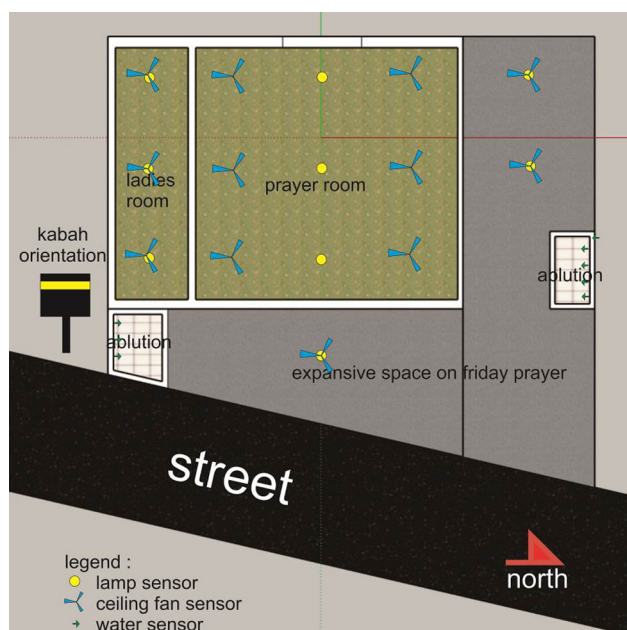


Figure 10: Illustration of design strategies.

Mosque can be a pilot project of many public buildings with certain circumstances on the project factors [53].

10 Conclusion

This research concluded five design strategies of (1) building contextual layouts, (2) lighting strategy, (3) HVAC strategy, and (4) water conservation strategy. The four strategies are closely related to each other, such as the lighting and HVAC installation is depending on the building layouts; or the water recycle in ablution can be functioned as a water cooler for the HVAC shall be linked with number 5 – IT through a monitor and automatic control to emphasize the sustainable Mosque design. Therefore, five of them shall be joined and not being standalone strategies in the application and conceptual design. The concept of a sustainable Mosque is not a future plan or unrealistic dream, since it can be started from today with architectural design, building science, mechanical electrical knowledge, and information technology developments.

The contextual layout of Qibla orientation is discussed with the site condition and position to make a more low-energy Mosque with Islamic law guide. The lighting, HVAC, and water consumption can be controlled and minimized by applying the sensor, actuator, and calculator IT. The sensor could be located separated from the device but in the same area for more optimum results or embedded in the device for more compact and flexible use. The design shall follow the issue of contextual site, local problems, and the improvement in technology to meet our sustainable Mosque's goals. The further development of Information and Design Technology might be the machine learning from the actual data of energy, water, and people occupation in several space and time.

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