Environmental Design Strategies to Improve Thermal Performance of Religious Buildings: A Simulation in Iraq

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Abstract

Religious buildings are part of the context of cities and their urban environments. They are affected by the environmental conditions surrounding them. This research deals with the types of religious buildings, their architectural elements, and their role in enhancing their environmental performance and achieving thermal comfort for their users, as this type of building is characterized by its high energy consumption, as the system is operated even during the period of minimum occupancy. The current research aims to employ natural ventilation strategies for Iraqi traditional religious buildings to achieve comfortable conditions during low occupancy during daily prayer times without resorting to mechanical intervention. A newly built religious building in Iraq was examined and environmental strategies applied to it through virtual simulation using the IES-VE software. The results showed that increasing the thickness of the walls and adding insulating materials to the building envelope reduces the internal heat gain to 49%. The results of applying the combined environmental strategies also showed a decrease in the value of cooling loads by 20%. These show that relying on natural ventilation can reduce energy consumption by 58% of the total energy consumed.

Keywords: Environmental Design, Religious Architecture, Thermal Performance, Thermal Comfort, Environmental Strategies.

1. Introduction

1.1. Background

Environmental design is part of Islamic architecture, especially the religious buildings, because people wanted to coexist with their environment and adapt to it. Applying the principles of preserving the environment in accordance with the Islamic perspective is based on two foundations for evaluating a Man's relationship with his environment. These are: exploitation[1] and

1 Exploitation means that God Almighty has subjugated the environment and its components to help man carry out his mission to populate the earth (Edwards, Brian & Plessis, 2001).

moderation[2] (Edwards, Brian & Chrisna du Plessis (2001). Exploiting passive energy is an alternative to known energy sources of various types to provide comfortable thermal environments in buildings, (Mubaraki, 2013). The issue of energy consumption has recently become a fundamental issue, and since the largest portion of this consumption goes into the construction sector due to the total reliance on mechanical air conditioning systems to achieve a thermally comfortable environment, mosques are considered among the prominent public places in society. However, they are classified as buildings with high energy consumption. In Malaysia, the cost of operating mosques relies heavily on public funds and, statistically speaking, is particularly high in relation to electricity use. This is due to the use of air conditioners to cool huge prayer halls, as they are not designed environmentally and energy-efficiently and therefore do not achieve the required thermal comfort without artificial means (Ibrahim, 2023). The research aims to test the effectiveness of applying environmental design strategies in improving environmental performance and achieving thermal comfort while reducing energy consumption in religious buildings. It also aims to find methodological solutions through which environmental architectural strategies can be implemented that employ the architectural elements to achieve internal thermal comfort.

1.2. Environmental design

Environmental design in areas with a hot, dry climate aims to achieve a comfortable thermal environment by cooling the interior spaces through two types of technologies: passive cooling technology, and active cooling technology. Passive cooling refers to technologies that have been developed to cool buildings in a natural way and at the lowest cost, as it provides cooling for a building without or using a minimum of energy. Energy consumption of this technology is in small proportions compared to the consumption of active methods. Passive cooling is used to improve energy efficiency, and it works in cooperation with cooling active (mechanical) cooling to reduce energy expenditure when high consumptions occur.

Passive cooling techniques depend on renewable natural energy sources, as it requires effective designs with regard to air flow patterns around a building in addition to the influence of other neighboring buildings (Ivan & Poul, 2018). To implement this, a set of environmental strategies must be implemented, such as adopting proper shapes and dimensions of the building, the shape of the ceilings and openings, the extent of shading on its facades, the thickness of the walls, the materials used in construction, and the external colors, in a way that is compatible with the climate. The area it is located as well as the direction of the sun, wind movement, terrain, etc. play a significant role. Moreover, it should take into account the function of the building and the nature of the activities that will be housed in the spaces of the building, (Mohaibesh, 2021).

Architecture of religious buildings has architectural types that are common to each other in terms of architectural compositions and the principles used in their construction. However, the style of mosque buildings is unique from the type of buildings of holy shrines and kindergartens to the specific location, as they were built over the graves of the righteous people. Thus, some environmental strategies are determined in them, such as the location of the building block, which is either within an urban fabric or alone in its location. It may also be within a hill or in a valley. In this context, this paper examines the role of environmental design strategies in the traditional Iraqi architecture of religious shrine buildings in achieving internal thermal comfort.

1.3. Thermal Comfort

Thermal comfort is one of the most important environmental design requirements that must be provided to the occupants of buildings of all types and styles, and religious buildings represented by mosques in particular, since they spend most of their time in the internal environment of the building. Most social activities and events, in addition to holding prayers, take place in mosques and religious buildings in general. It was the treasury and the place where matters

2 Moderation is an approach that governs the way people benefit from the environment and its components in a moderate manner in managing their livelihoods. It is linked to harnessing. Moderation stems from Man's position in

of succession were discussed, people's problems were solved, and people were directed in the right direction.

1.4. Islamic shrines

The region of Iraq is almost devoid of a shrine or a memorial or sacred shrine, on whose land the prophets, saints, and scholars have lived and died. Their histories have recorded their passage through this land and their residence in them. Traveling in Iraq from its North to South often encounters the presence of maqams, holy graves and shrines of righteous saints, as they were the cause of growth and urban expansion in those areas. Cities often grew and expanded in them and became sprawling due to the presence of a holy grave or a shrine that people undertook to visit (Alkilidar, 2015).

2. Review of Literature

A number of studies dealt with the thermal comfort of religious buildings. Fathima, Sabarinah and Nurul (2018) points out that a domed roof provides better thermal performance compared to a flat roof, because the opening at the top of the dome increases the wind speed inside. On the other hand, Jamal (2007) concludes through a thermal simulation program for studying the thermal performance of buildings (Ecotect) that the vaulting system works to reduce temperature by 2-6 degrees Celsius and helps to obtain thermal stability in the summer. According to him, in winter, the heat loss of the vaulted ceiling is higher than the flat ceiling. Thus, its effect will be negative, which requires certain treatments. Given that the cold period in Iraq is four months, and the other eight months are between hot and moderate, he considers the vaulting system an appropriate treatment for the region.

Budaiw (2010) concluded that adding (2.5cm) of polystyrene insulation to the interior walls of the building achieves a 9% reduction in cooling energy and about 12% in cooling loads. As for the ceilings, when thermal insulation is added to them With the same thickness of wall insulation, the cooling energy decreases by about 10%, and this reduction is similar to what was obtained when insulating the wall with (2.5 cm) of polystyrene, and this is an indication that the ceiling has a more important impact on energy performance, and by doubling the level of insulation approximately three times by An additional 2% reduction in cooling energy is obtained, and in contrast to wall insulation, the cooling load decreases steadily as the ceiling increases.

Mubaraki (2013) show that the internal thermal gain by worshipers in mosque buildings and the lack of air movement are among the most important causes of high thermal stress inside a prayer hall, The proposed solution is to combine the air ventilation system equipped with an evaporative cooling system at the level of the minarets and the system. Vertical ventilation at the level of the domes reduce the indoor air temperature by 9 degrees Celsius, while the relative humidity range between 60-65% after it was 37-40%. They recommend adopting the technology applied in this research to enhance natural ventilation as it provides thermal comfort and elimination, from the thermal stress of mosque buildings.

Atef et al. (2021) use a rectangular shape instead of a square. They have proven effective, as the length-to-width ratio is 1.5-1. The optimal length is 12.5 m, and the optimal width within it is 8 m. As for the height, the best thermal solution is to be within 6 meters using the roof dome, as the best diameter of the dome for the best thermal performance inside was 3 m. The strategy of covering the roof to shade it was more effective, with a distance of 50 cm between the original roof and the canopy, as in the Figure 3. As for the openings, the results showed that the best percentage of openings was at 27% for the western facade, with a minimum height of 1 m for the beginning of the openings and 25 % for the southern and northern facades with a height of not less than 1 meter to the beginning of the window. The optimal ratio was 23%, with a height of at least 2 meters for the beginning of the East facade window. As for the exterior colors, the study proved that a reflection factor of 0.84 should be adopted, which was also the most realistic degree of reflection.

Nabeeha Amatullah Azmi, Azhaili Baharun, Muslum Arıcı, Siti Halipah Ibrahim (2023) have concluded that a reduction of up to 4-6 degrees Celsius in the internal wall surface temperature can be achieved through appropriate design of the qibla wall, which reduces the average radiant temperature, for the worshipers by 2-4 degrees Celsius. Combined with the ventilation strategies, thermal comfort can be significantly improved by at least 40% for the prayer during the hottest times of the day, and by up to 80% for the night prayer. The results indicate that appropriate comfort conditions can be achieved without the need for air conditioning to perform at least two or three of the five daily prayers.

3. Research Methodology

3.1 Data collection

The style of buildings of religious shrines and shrines is generally characterized by simple geometric configurations, but they differ in size. For the purpose of choosing a model for a modern, typical religious building or a newly constructed one that meets the purposes of the hypothetical study, the researcher reviewed all the modern designs of religious buildings and shrines prepared by the Engineering Department for Iraqi Shrines, which shows Figure (1) Three typical models adopted in the design of shrine buildings. It has been observed that Model No. (1) is repeated in the construction of modern shrines, as it was applied in a number of Iraqi governorates, and thus it will be chosen as a model for the virtual study. The thermal and operational characteristics are considered similar for all types of religious buildings, and therefore the thermal behavior and energy behavior are not expected to differ for all types. When treated as individual areas. The model will be simulated with the same environmental conditions as in the (base case) Table No. 1, from the location of the building block, orientation, area, building characteristics, and internal thermal conditions of occupancy and occupancy schedule, and this information will be relied upon in the inputs of the thermal simulation program as a base case (before applying the strategies). This study adopts "simulation study" as the main research method, and energy simulation software—namely IES (Integrated Environmental Solution)—was used to evaluate the thermal performance of the building. Solar shading performance was also evaluated using SunCast analysis, as part of the IES program. The simulation was conducted on June 21, which is the day of the summer solstice, as the solar radiation on this day reaches the highest elevation angle above the building (80 degrees), as in the results of the solar analysis of the IES program in its Sun cast unit, Fig.1. The next stage was to apply environmental design strategies in order to evaluate the collective impact of applying all these strategies on achieving indoor thermal comfort, shading, thermal performance and energy levels for the entire case study model. While natural ventilation removes unwanted heat from the building, the remaining strategies aim to slow down the transfer of heat into the building, either by thermal conduction or heat transfer. Action or ill radiation that comes primarily from the sun. The strategies that were taken into consideration in this study include thermal insulation, a natural ventilation system with the lower and upper openings in the neck of the dome and the air envelopes, as well as glazing and the glass type.

3.2 A Case Study

3.2.1 Current status overview

The city of Baghdad was founded in the eighth century and became the capital of the Abbasid Caliphate. It is located along the Tigris River and soon after its founding, it became an important commercial, cultural, and intellectual center in the Islamic world (Ibrahim, 2023).

3.2.2 Climate characteristics of Iraq

The study area is located in the city of Baghdad in Iraq, at latitude 33-30 degrees North and longitude 44-40 degrees East. It is 34.1 m above the sea level and is classified as warm areas and contains two main seasons, a hot summer and a cold winter. Climate is characterized as a desert or semi-desert climate, with strong solar radiation resulting from drought and a high rate of evaporation. Temperatures vary between the summer and the winter and between day and night. Air temperature reaches around 50°C in late July. Relative humidity (RH) ranges between 22% in June and 71% in December, and most winds may bring with them local dust and sand. The length of the moderate period is eight months, while the cold period is four months, which requires showing importance in achieving thermal comfort in the summer months due to their long period (Sudany, 2015).

3.2.3 The selected case study

The style of religious shrine buildings is generally characterized by simple, stereotypical geometric formations that differ in size. Figure 2 shows three typical models approved in the design of shrine buildings by the Engineering Department at the headquarters of the General Secretariat of Iraqi Shrines. It has been observed that the first model is repeated in the construction of modern shrines, and thus it is chosen as a model for the virtual study. The thermal and operational characteristics are considered similar for all the types of religious buildings, and therefore the thermal and energy behavior of all types is not expected to differ when dealing with them as individual areas.

The model is simulated with the same environmental conditions of the base case, from the location of the building block, orientation, area, building characteristics, and internal thermal conditions of occupancy and occupancy schedule. This information is relied upon in the inputs of the thermal simulation program as a base case (before applying the strategies).

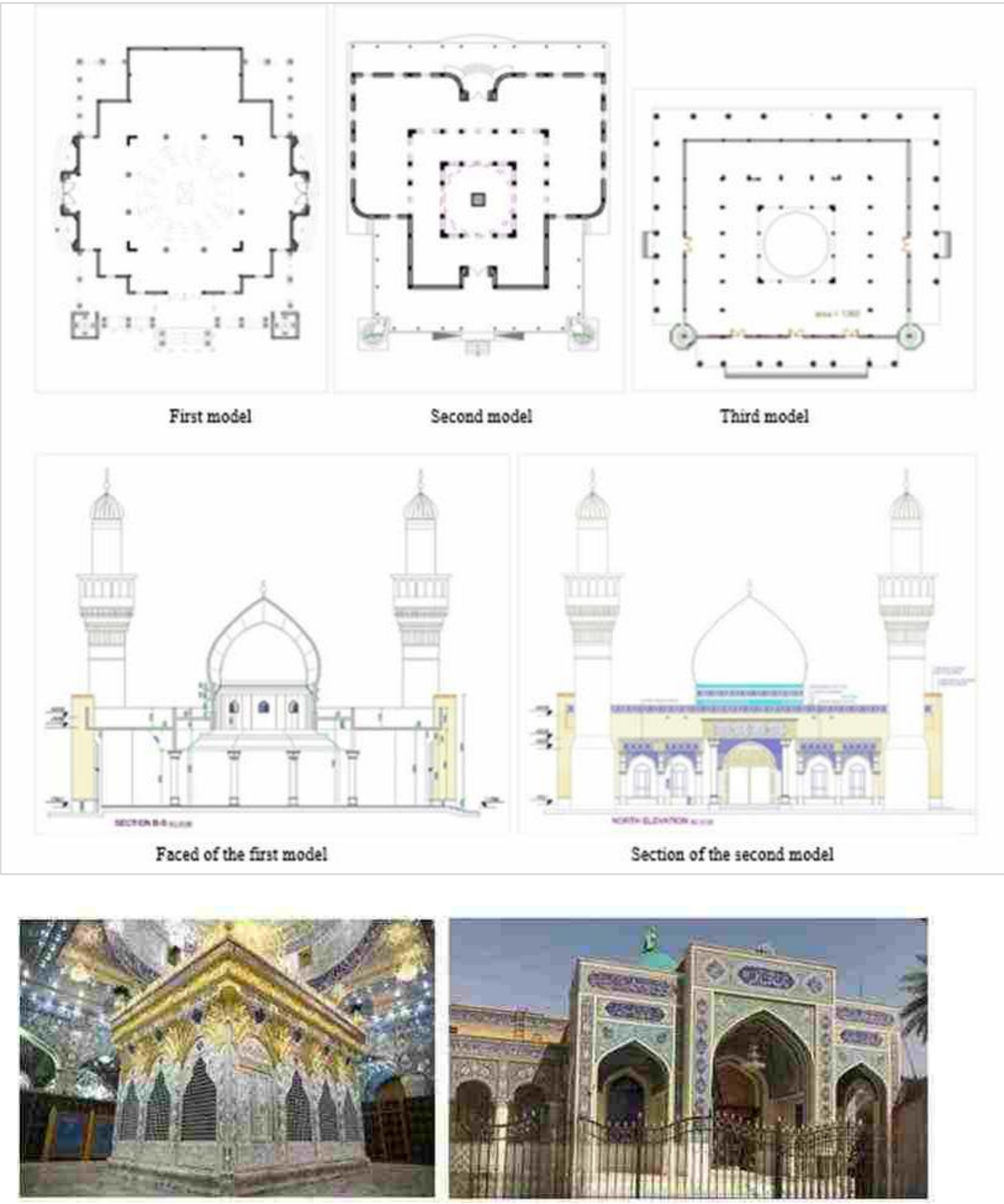

Fig. 1: The three typical models approved in the design of Iraqi Shrines
Source: The headquarters of the General Secretariat of Iraqi Shrines

3.3 Model development

Appropriate selection of an energy simulation tool and obtaining reliable and detailed input data about building systems and operational characteristics are crucial for accurate and correct prediction of energy performance. Based on specific criteria, the most appropriate tool was chosen, after evaluating various building energy simulation tools. Data on the physical, thermal and operational characteristics of religious buildings are obtained through reality surveys. The model chosen for the simulation was simplified for the virtual testing process, as shown in the Figure 3.

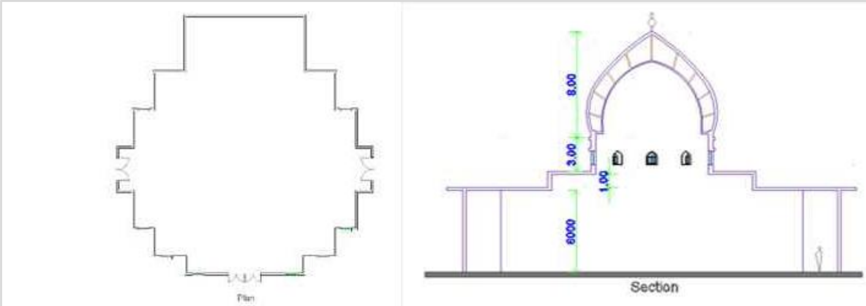

Fig. 2: Type of mosque chosen for simulation

3.3.1 Process-based Simulation

Three basic steps in the process were necessary to achieve this aim: the first step was the creation of the hypothetical basic model, and the underlining of all the fixed and variable parameters to be tested. The second step was the digital simulation process to achieve the results, and the last step was the interpretation and analysis of the results to create the final form and to highlight the general recommendations.

Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan								8.84	18.75	26.99	32.80	35.38	34.29	29.72	22.39	13.08	2.46							
Feb							1.34	13.02	23.79	33.04	39.89	43.25	42.36	37.43	29.46	19.50	8.30							
Mar							8.28	20.47	31.99	42.22	50.03	53.79	52.22	45.91	36.54	25.47	13.51	1.11						
Apr						4.47	16.96	29.46	41.65	52.95	62.04	66.13	62.80	54.09	42.94	30.82	18.34	5.83						
May						10.31	22.57	35.07	47.57	59.70	70.37	75.52	70.16	59.43	47.28	34.78	22.29	10.04						
Jun					0.44	11.89	23.90	36.26	48.78	61.22	72.91	80.02	74.07	62.57	50.16	37.63	25.25	13.19	1.67					
Jul						9.89	21.96	34.36	46.89	59.27	70.80	78.10	73.67	62.76	50.50	37.98	25.52	13.34	1.63					
Aug						6.05	18.44	30.97	43.37	55.18	65.25	70.45	67.11	57.81	46.27	33.95	21.43	8.98						
Sep						1.76	14.28	26.57	38.22	48.55	56.17	58.95	55.67	47.73	37.25	25.51	13.20	0.67						
Oct							9.38	20.93	31.40	40.01	45.63	47.04	43.85	36.88	27.42	16.45	4.61							
Nov							3.62	14.44	23.97	31.56	36.33	37.51	34.87	28.89	20.45	10.35								
Dec								9.72	19.11	26.67	31.67	33.40	31.58	26.51	18.89	9.46								

Fig. 3: solar analysis of the IES program in its Sun cast unit

3.3.2 Selection of energy simulation tool

The IES program is a huge dynamic software tool for virtual simulation, to evaluate the performance of built environments to become more efficient in using natural resources and preserving the health of their occupants at the lowest possible cost. This program simulates and analyzes the building's data virtually to find out its thermal performance to improve the performance of these environments, including thermal and energy analysis, natural and industrial lighting performance, other environmental indicators, energy consumption and renewable energies. Data is linked to a common user interface and one integrated data model. This means that data input for one module can be used for the other modules within the tool. Each of these modules performs a specific calculation, such as "Apachesim" for thermal simulation, "Radiance" for lighting simulation and "SunCast" for solar shading analysis. The output data will be processed and prepared for extraction in "VistaPro" (iesve.com).

4. Base model physical and thermal characteristics

In order to implement the virtual simulation of the building, the study model data was determined within the program, by designing a set of personal files and settings provided by the program to enable one to read the nature of the building's use throughout the simulation period of the summer solstice day on June 21st. This was to achieve an accurate virtual environmental simulation, and the program is used. IES was employed in this research to measure the internal thermal comfort and thermal performance of the external envelope of the model chosen as a research sample, by dealing with information technology, Vistapro, SunCast, Appache, Macroflo and microflo (model) units. This is done through the process of preparing the geometric shape of a simplified model of the study building, which also includes introducing it. Internally, by identifying the internal and external packaging materials of the building model, as well as identifying the internal sources of internal heat gain (number of building occupants, appliances used, lighting units, and everything that generates heat within the space), the weekly profile is determined, as shown in the Figure 2.

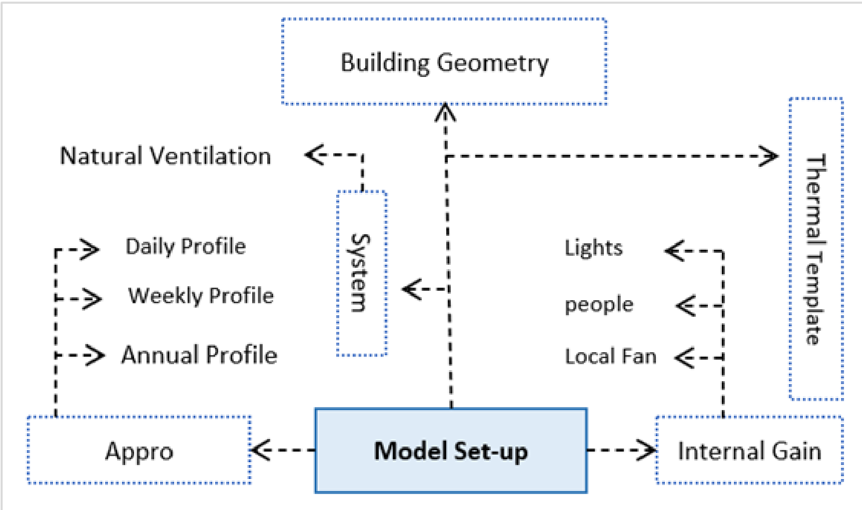

Fig. 4: Program tools and measurement processes
Source: author- Based on (Ibraheem, 2019)

Table 1: Main Thermal and Operational Characteristics of the Base Case Model Mosque.
Source: Author

Components of the constructed model	Description (base case of simulation)
Conditioned floor area (m2)	865
The direction of the building is	North at an angle of 30 degrees west
Window type (thickness)	Clear single glazing (6)
Window area (m2)	3.25
Floor to floor height (m)	6
Wall construction (thickness)	Cement mortar, concrete pour, plaster (0.25)
Wall U-value (W/m28C)	1.4347
Wall and roof solar absorptance	0.5 and 0.7
Roof construction (thickness)	Concrete slabs, clean sand, dirt, felt, concrete, plaster (0.20)
Roof U-value (W/m28C)	1.4347
Window shading	Movable interior (curtains)
Lighting power density (W)	6.5 (scheduled with occupancy)
Equipment power density	(W) 5.5 (scheduled with occupancy)
Maximum occupancy (person)	865 (one m2 per person)
Heat gain of persons (W)	86.5
Occupancy schedule	20 hours/day
HVAC system type	Packaged A/C Units
HVAC operation	Continuous during summer
Total cooling capacity (kW)	1395 (program sized)
Cooling set temperatures (^{O}C)	23

5. Building performance and analysis

5.1 Solar shading performance using suncast analysis

Mechanical systems are frequently used in hot regions to cool the indoor environment and make it more comfortable for the building occupants. The effect of this is to increase the power load and thus increase the need for electricity. Passive design strategies can reduce the load of active systems if applied correctly. Through the use of IES simulation software, the impact of passive strategies on shading, thermal performance and energy levels was analyzed. Thermal simulation of the model was conducted using the passive cooling strategies to achieve thermal comfort for the religious building: the thermal insulation strategy for the outer envelope, the natural ventilation strategy, and the passive cooling strategies for the air Malqaf. Thehe simulation was conducted for one day, 6/21, which is the day of the summer solstice, as the sun's rays on this day reached the highest elevation angle above the building (80 degrees). In the results of the solar analysis of the IES program in its Sun cast unit, this is shown in the Figure 3.

5.2 The thermal performance of the outer shell elements

The solar analysis of the building model, Figure 5 shows that, of the elements of the outer shell most exposed to solar radiation is the roof, at the rate of (5.44 kwh/m2, and thus the highest heat gain inside the building is 6.10 kw at 7:30 a.m. This reduces the load for internal thermal gain. However, 50mm of the Styropor insulating material commonly used in the construction of these buildings was added to the ceilings and walls, along with 120mm of bricks added to the walls, where the U value decreases to 0.3875 w/m^{2}c. The percentage of internal heat gain decreased to 49%, as shown in the figure 6.

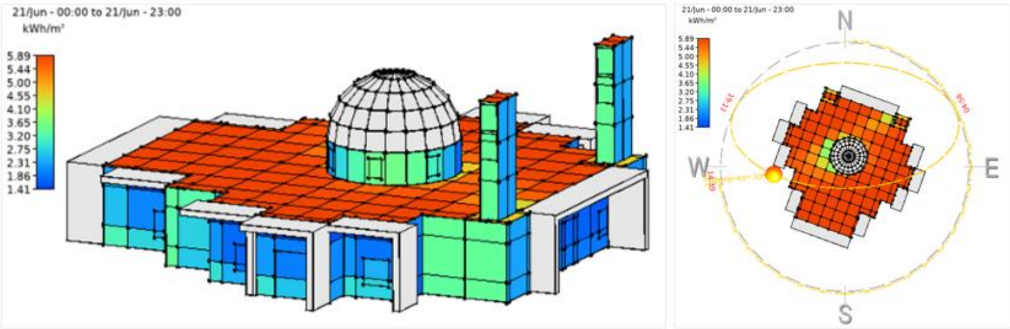

Fig. 5: shows the thermal analysis of the building model (Sun cast)
Source: author

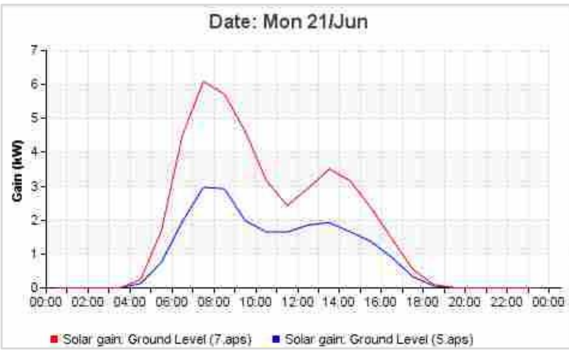

Fig. 6: Solar Gain shows the difference in thermal gain when adding thermal insulation
Source: author

5.3 Thermal analysis

After applying passive cooling environmental strategies to evaluate the thermal performance of the building when relying on natural ventilation and neutralizing mechanical devices, the indoor temperature decreased by 2.66 °C, and after conducting a thermal analysis process for hours on the same day of the simulation. It was found that the greatest impact was on the minimum temperature, as they decreased by 9.85 degrees Celsius from the minimum temperature outside the building, as shown in the figure.7. This shows how the building's internal environment interacts with its surrounding external environment, when connected to the ventilation system. Natural passive cooling is carried out as part of it, through the activation of air envelopes and upper dome windows. The graph shows how the temperature measured for passive cooling inside the building decreases during sunset and then begins to rise at sunrise until it reaches its peak in the period between (12:00 - 15:00) noon. In fact, this is the opposite of what we see in the absence of natural ventilation. How the line measuring temperature change is almost regular because the building is separated from its surrounding environment.

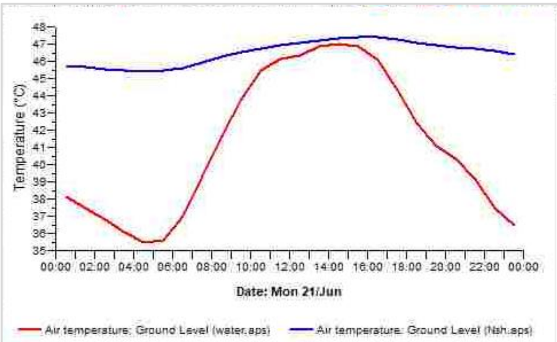

Fig. 7: Represents the effect of applying natural ventilation strategies on indoor temperatures
Source: author

5.4 Cooling sensible loads

The term "sensible cooling load" refers to the amount of thermal energy removed from the building by any cooling method to maintain a temperature that ensures internal thermal comfort. The simulation process was conducted to consider the cooling load of the building. Figure 8 shows that the maximum cooling load, which was evaluated during the day 21/6 amounted to about 2677 kw. The results of applying the strategies showed a decrease in the value of the loads by 519 kw;, that is, by 20%.

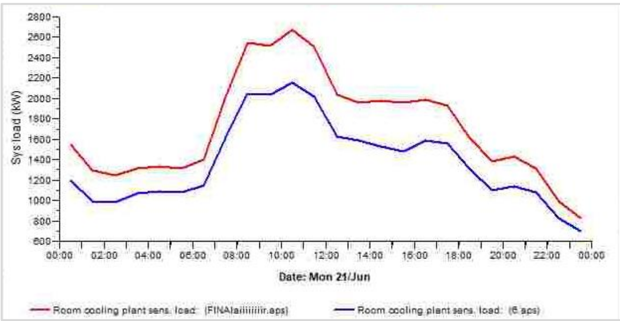

Fig. 8: difference in cooling loads when applying environmental strategies
Source: author

5.5 Total energy consumption

Due to the building's energy consumption, the maximum power reached 1136 kw at peak hour, after it was 1395 kw, as in the Figure 9. This result shows a 19% reduction in energy due to the application of several passive cooling strategies. It gives a representation of the future results if these passive cooling strategies are adopted. Thus, energy consumption can be reduced by only 20% for the month of June, and this in turn helps the administrations based on religious buildings to reduce their energy consumption.

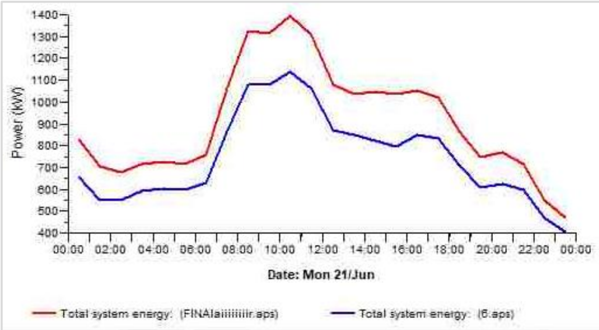

Fig. 9: Explains the impact of strategies on energy consumption
Source: author

5.6 Energy consumption during prayer times for passive cooling

In order to complete the analysis of energy consumption in religious buildings, and since shrine buildings are not at the same level of importance, the number of visitors to them decreases. Since it is a holy place, the demand for it during prayer times is greater than at other times. Assuming this, we suggest that mechanical cooling be operated at certain times: prayer only, i.e. from 11:30 am to approximately 19:30 pm. This condition can be measured through this model, where a detailed thermal analysis is performed in the required hours to confirm the difference in energy consumption through integration with passive cooling and its strategies. Figure (10) shows that the internal temperature reaches its peak during 10 hours of the day. This is the period during which thermal comfort is not achieved, and according to Figure 10, it is between 07:30 - 18:30. From here we choose 9 hours, during which we work to combine the work of the passive cooling system with the mechanical cooling system. Thus, the energy consumption of mechanical cooling devices during the remaining 11 hours of working hours was reduced by 58%. This equates to 12,729 kilowatts. The energy consumed to operate mechanical cooling during an entire day is only 9,188 kilowatts.

		Total system energy (kW)	Air temperature (°C)
			Ground Level
Date	Time	FINAlaiiiiiir.aps	hanin2.aps
Mon, 21/Jun	00:30	830.1014	37.95
	01:30	702.3344	37.30
	02:30	680.6881	36.66
	03:30	713.4020	35.97
	04:30	724.2392	35.39
	05:30	715.4178	35.46
	06:30	758.1536	36.83
	07:30	1063.8038	39.16
	08:30	1327.0996	41.46
	09:30	1316.5973	43.60
	10:30	1395.3453	45.26
	11:30	1308.3309	45.91
	12:30	1077.6648	46.01
	13:30	1036.3353	46.53
	14:30	1044.4474	46.71
	15:30	1036.2227	46.58
	16:30	1051.7479	45.82
	17:30	1021.6162	44.12
	18:30	866.5024	42.20
	19:30	749.6862	40.84
	20:30	769.8950	40.17
	21:30	715.4968	38.98
	22:30	551.5923	37.35
	23:30	471.2533	36.32

Fig. 10: Hourly temperatures during June 21
Source: author

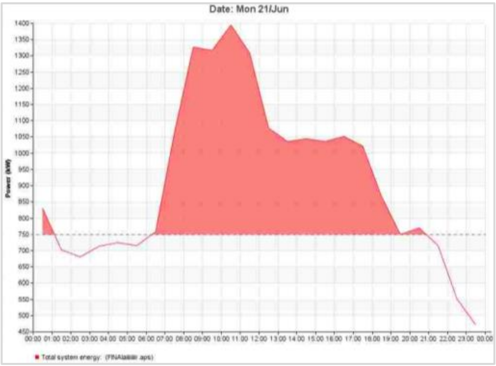

Fig. 11: Energy consumed for mechanical cooling per hour during June 21
Source: author

6. Conclusions

Environmental design strategies for the elements of the religious building either block or reduce the solar gain of the building, as the architecture of traditional Islamic religious buildings achieve thermal comfort for users by relying on passive environmental design through the designer's reliance on environmental design strategies. There, the work of the parts of the religious building is integrated to achieve thermal comfort through its multiple components such as the location, building envelope, and the building components to cool the building in a natural way and at the lowest cost. This is because passive cooling is used to improve energy efficiency, and works in cooperation with active cooling to reduce energy expenditure when high energy consumption occurs. In this research, a case study was selected and several proposed passive cooling strategies were applied. The IES software was the main simulation tool. The simulation results were analyzed and showed that energy reduction and optimal thermal comfort can be achieved if passive cooling strategies are used. In-depth analysis shows that there is a possibility of reducing energy by 19% annually during the summer from the energy consumed in mechanical cooling, when applying the passive cooling strategies proposed within this study. It also demonstrates that the construction of a religious shrine relies on both negative and positive environmental design strategies. It contributes to reducing energy consumption by up to 58% of the total energy consumption in the summer during prayer times, as the building is a sacred place, and the demand for it is greater during prayer times than others. Thus, mechanical cooling is turned on at specific times: prayer only.

References

Budaiwi, I.M. (2011) Envelope thermal design for energy savings in mosques in hot-humid climate. Journal of Building Performance Simulation, 4(1), pp.49-61

Mushtaha, E. and Helmy, O. (2017) Impact of building forms on thermal performance and thermal comfort conditions in religious buildings in hot climates: a case study in Sharjah city. International Journal of Sustainable Energy, 36(10), pp.926-944

Azmi, N.A., Baharun, A., Arıcı, M. and Ibrahim, S.H. (2023) Improving thermal comfort in mosques of hot-humid climates through passive and low-energy design strategies. Frontiers of Architectural Research, 12(2), pp.361-385

Ahriz, A., Mesloub, A., Elkhayat, K., Alghaseb, M.A., Abdelhafez, M.H. and Ghosh, A. (2021) Development of a Mosque Design for a Hot, Dry Climate Based on a Holistic Bioclimatic Vision. Sustainability. 13: 6254

Sudany, J. A. (2011) Energy and environmental performance of a complementary design for the cover of the building. Journal of Techniques, 24(3), pp.12-16.

Alkilidar, M. S. M. (2015) Civilizations and Environmental Particulars of Place in Islamic Holy Thresholds. Journal of Engineering, Vol. 12.1, pp. 27

Edwards, Brian & Chrisna du Plessis (2001) Snakes in Utopia: A Brief History of Sustainability. Green Architecture: Architectural Design (AD), Vol. 71, No. 4, pp.04-11

Helix Building, Kelvin Campus, n.d. Grand Mosque. [Online] Available at: https://www.iesve.com/services/projects/2356/grand-mosque-uae

Ibraheem, Y. (2019) Integrated Façade Systems for Highly to Fully Glazed Office Buildings in Hot and Arid Climates. Thesis submitted to University of Brighton, UK.

Ibrahim, H. K. (2023) Design Strategies Employed to Achieve Thermal Comfort in Traditional Religious Buildings in Iraq. ISVS e-journal, pp. 13.

Ivan, Paul. (2018) Active and passive cooling methods for dwellings: A review. ScienceDirect, pp. 14.

Sudany, J. A. (2015) Employment Minarets Wind-catcher Natural Ventilation and Passive Cooling in the Mosques of Baghdad. International Journal of Current Engineering and Technology, Vol. 2, pp. 7

Younis, M. (2003) Environmental protection in human thought. The United Arab Emirates: Dubai: The Cultural & Scientific Association.

Mubaraki, Ammar. Yasmina (2013) Ventilation and natural cooling techniques in mosque architecture, Thesis submitted to Constantine University, Algeria.

Mohaibesh, D. A. A. A. (2021) Environmental Thermal Performance in Vernacular Architecture in Palestine. Thesis submitted to Al-Najah National University, Iraq.