كتاب الابحـــاث
PROCEEDINGS

المُؤتمَر العَالمِي الأوَّل لعمَارة المَسَاجدْ

THE FIRST INTERNATIONAL CONFERENCE ON MOSQUE ARCHITECTURE

5-7 DECEMBER 2016 ٦-٨ ربيع الأول ١٤٣٨ هـ

جامعة الدمام
UNIVERSITY OF DAMMAM

جائزة عبد اللطيف الفوزان لعمارة المساجد
Abdullatif AlFozan Award for Mosque Architecture

﴿إِنَّمَا يَعْمُرُ مَسَاجِدَ اللَّهِ مَنْ آمَنَ بِاللَّهِ وَالْيَوْمِ الآخِرِ وَأَقَامَ الصَّلاةَ
وَآتَى الزَّكَاةَ وَلَمْ يَخْشَ إِلَّا اللَّهَ فَعَسَى أُولَئِكَ أَنْ يَكُونُوا مِنَ الْمُهْتَدِينَ﴾

(القرآن الكريم - سورة التوبة - الآية ١٨)

المُؤتَمر العَالمِي الأوَّل لعمَارة المَسَاجدْ

THE FIRST INTERNATIONAL CONFERENCE ON MOSQUE ARCHITECTURE

"Pioneering Practical Experiences and Applicable Innovative Solutions"

Organized by

ABDULLATIF AL FOZAN AWARD

AL FOZAN HOLDING GROUP, DAMMAM, SAUDI ARABIA

جائزة عبد اللطيف الفوزان
Abdullatif Al Fozan Award
for Mosque Architecture لعمارة المساجد

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INTRODUCTION

As the prestigious event in collaboration between 'The Abdullatif Al-Fozan Award for Mosque Architecture' and the University of Dammam (UOD), the College of Architecture and Planning is pleased and proud to host 'The First International Conference on Mosque Architecture (ICMA 2016)' in Dammam, Saudi Arabia. The interests and wills of both organizers have led to cooperate in organizing this conference. In 2011, ALFozan Group has founded Abdellatif ALFozan Award for Mosque Architecture as a global platform for the development of contemporary mosques in the world.

The function of mosques encompasses a wide range of activities for the spiritual, educational, cultural, political, social and economic welfares of the community. However, the comprehensive functionality of mosques could be realized only through the application of adequate scientific expertise in its design, construction and operation.

On the other hand, many traditional mosques are viewed as symbols for the Islamic architecture, and hence there exists a sentimental concern to preserve their aesthetic identity. Therefore, in both functional and aesthetic perspectives, the design and construction of mosques have unique concerns that call for exclusive interactive platforms wherein academics, architects, researchers and professionals share their views and expertise. This will contribute to realizing energy efficient and sustainable mosque buildings while maintaining their traditional, architectural and aesthetic features.

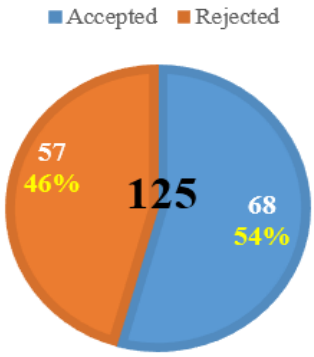
Accordingly, the conference topics have been categorized under three main themes: a) Pioneering contemporary practical experiences, b) Applicable innovative and inspiring technical solutions, and c) Lessons learnt from the past and applied into the present context. The first theme has three sub-themes: Inspiring architectural design experiences, Mosques and the urban context, and Impacts of pioneering practical experiences. Right from the announcement of this conference, there have been overwhelming responses from the global research community, architects and other individuals, which is evident from the large number of papers received (Fig.1).

The submitted abstracts and full papers were scrutinized through double-blind-review by a panel comprising 33 international experts, with respect to the scientific merit, contextual relevance and adequacy of presentation. Out

of the total 125 abstracts received, 68 were accepted and out of the 53 full papers submitted, 41 were accepted; more than 50% of the accepted papers are from the international researchers, 32% are from researchers of UOD and the rest are from other parts of KSA (Fig.1). All accepted papers were further checked for plagiarism, and ensured that the contents of each paper comply with copyright norms. Finally, all the manuscripts were proofread, language-edited and formatted before being delivered for printing. The scientific articles address interesting and significant issues related to the conference themes, which are arranged in a logical sequence in the following pages.

The keynote speakers of this conference are renowned experts in their fields, who are: Dr. Prince Khalid Abdullah Mohammad Moqrin Al-Meshari, KSA, Architect Abdel-Wahed El-Wakil, Egypt, Prof. Dr. Ashraf Salama, UK, Prof. Dr. Tarek Hassan, UK, Prof. Dr. Rabee M. Reffat, Australia, Dr. Zuhair Fayez, KSA and Architect Emre Arolat, Turkey. They will be providing valuable inputs to the audience, with respect to the various conference themes.

The panel discussion on 'Future Vision of Mosque Architecture' will be chaired by Prof. Ahmed Farid Mustafa, who is one of the founders of the College of Architecture and Planning of UOD. The outcomes of keynote lectures, regular sessions and panel discussion will indeed help in formulating the expected future trends in the mosque architecture, which will be considered in the future events organized under the UOD-ALFozan collaboration.



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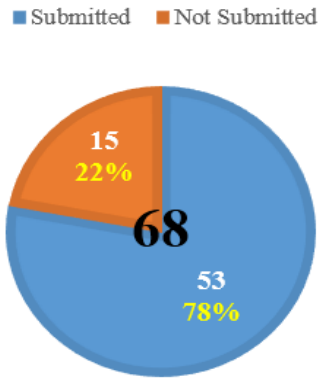

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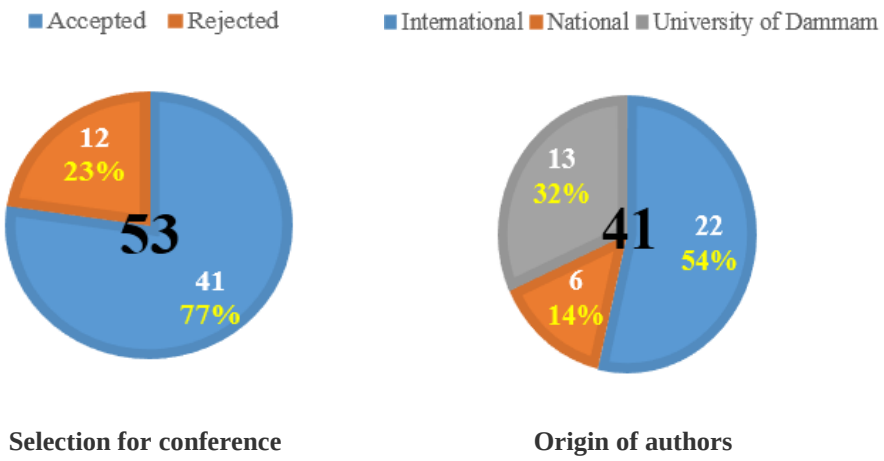

Fig. 1: Data of submission and acceptance of papers, with origin of authors.

The ICMA 2016 team expresses their deep gratitude and appreciation for the support and guidance from **His Royal Highness Prince Saud bin Nayef bin Abdulaziz Al Saud** - the Governor of Eastern Province.

Moreover, the organizers are highly indebted to **His Royal Highness Prince Sultan bin Salman bin Abdulaziz Al Saud**, president of Saudi Commission for Tourism & National Heritage, and the Board of Trustees Chairman of the Abdullatif ALFozan Award for Mosque Architecture, for his great supports.

They also gratefully acknowledge the leadership roles of the rector of UOD His Excellency Dr. Abdullah M. Al Rubaish, the Managing Director of ALFozan Group Mr. Abdullah ALFozan, the Vice rector of UOD Prof. Abdullah bin Hussein Alkadi (Organizing Committee Chair), Dr. Abdul Mujeebu (editor) the General Secretary of ALFozan Award Dr. Ibrahim Mubarak Alnaimi, the Dean of College of Architecture and Planning Prof. Abdulsalam Ali Alsudairi (Executive Committee Chair).

The great efforts of Prof. Mohammed Essam A. Shaawat (Scientific Committee Chair), Dr. Sayed Mohamed Ahmed (scientific committee member), Dr. Ayman Hashem Alsayed (scientific committee member) the members of various committees, the reviewers and the editors, are also thankfully appreciated. Special thanks are due to the keynote speakers, authors, exhibitors and the participants, without whom the conference would

not be fruitful. Last but not the least, the organizers express heartfelt gratefulness for all who are directly or indirectly involved in making this event a grant success.

With warm regards

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December 2016 - Rabi I 1437

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ENHANCED DESIGN FEATURES FOR ENERGY SAVING OF MOSQUE BUILDINGS IN THE MARITIME DESERT CLIMATE

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Abstract

This study investigates the effects of mosque extensions of side arcades and roof shading on the building energy performance. The study uses standard design for mosque as a reference base case. Energy performance analyses are conducted using an energy simulation model to examine the effects of mosque extensions on the building energy performance, which is measured by the energy use index. Different types of shading configurations are investigated, the Riwaq or arcade around three sides of the mosque and the double roof shade. The impact of these shading configurations are analyzed and together with other conventional thermal insulation and glazing techniques. It was generally found that great savings can be achieved with the use of shading. Arcades around mosque exterior sides can provide reductions in electrical consumption by about 8-10%. The use of roof shading provides similar results, while the combination of arcades and roof shade reduce the electrical energy demand by about 17.5% relative to the base case with no shading elements.

Keywords

Mosque design, Envelope shading, Energy performance, Energy simulation, Electrical consumption

تعزيز تصميم المساجد لتوفير الطاقة في المناطق الحارة الرطبة

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المستخلص

تبحث هذه الدراسة في تأثير ملحقات المسجد كالأروقة الجانبية حول المبنى وتظليل السقف. وتستخدم الدراسة احد التصاميم القياسية لوزارة الشؤون الاسلامية والأوقاف والدعوة والارشاد كمرجع ثابت للدراسات المقارنة. وقد تم اجراء هذه الدراسات باستخدام برنامج محاكاة الطاقة لدراسة تأثير ملحقات المسجد على أداء الطاقة في المباني، والذي يتم قياسة بمؤشر استخدام الطاقة الكهربائية السنوي. وقد تم دراسة تأثير نوعين من تكوينات التظليل، الرواق أو ممر حول ثلاثة جوانب من المسجد وتظليل السقف. وتم تحليل تأثير هذه التكوينات مع الإخذ بالاعتبار عوامل أخرى متصلة مثل العزل الحراري ونوعية الزجاج. وقد خلصت الدراسة الى أن استخدام الرواق حول المسجد يؤدي الى تخفيض الاستهلاك الكهربائي السنوي بما يتراوح بين ٨-١٠%, بينما يساهم تظليل سقف المسجد بتخفيضات مماثلة. واذا ما تم الجمع بين التظليل بالرواق وتظليل السقف يؤدي الى تخفيض الاستهلاك الكهربائي بمقدار ١٧,٥% بالمقارنة مع المبنى الاساس بدون تظليل.

الكلمات الدالة

تصميم المساجد، تظليل المباني، أداء الطاقة، برامج محاكاة الطاقة، استهلاك الكهرباء

1. INTRODUCTION

Mosques pose particular problems because of their specific functions and characteristics. The need for the provision of comfort in a single large volume with intermittent and short duration use is imposing, particularly in the harsh climatic conditions of the Gulf Region. Mechanical equipment or air conditioning systems are commonly used for provision comfort to the worshippers. The electrical energy consumption of mosques is evidently large, representing about 16% of government buildings' consumption. While this may only represent 2% of the total electricity demand in the Kingdom, savings in mosques energy consumption follows recent and ongoing trends and confirms the enshrined Muslim principle of efficiency in usage of resources (EEA, 2011).

Monitoring studies of mosques indicated that the majority of electricity demand by mosques is due to the operation of air conditioning systems. More than 80% of annual electricity is utilized by air conditioning systems (Al-Homoud et al., 2005). Envelope heat gain is the primary source of mosque building cooling load. This emphasizes the importance of envelope design and construction for the control and minimization of mosque cooling load particularly in the hot harsh climatic conditions of the gulf area. The mosque energy demand is determined by the particular use of mosque occupancy and schedule, with short intermittent periods, resulting in heat build-up during off occupancy hours and requiring high energy demand to operate the air conditioning system each time the mosque is reused. Therefore, reducing heat gains through the building fabric is primary to obtain large savings in energy consumption. This can be achieved through proper envelope design and construction.

The construction and architectural geometrical variables of envelope, evidently, influence the components of cooling load and electrical energy performance (Varzaneh et al., 2014). The use of wall and roof insulation was shown to offer significant reductions of cooling load and electricity demand (Numan et al., 2014; Budaiwi et al., 2013). On the other hand, the effect of solar radiation received by walls and roof or transmitted through glazed areas contribute greatly to the building cooling loads (Numan et.al, 1999; Almaziad et al., 2002). These loads can be minimized through the use of shading elements. Shading of building envelope's components and particularly glazing area was shown to offer greater savings (Freewan 2014; Sun et al., 2014). Other studies indicated that window shading only showed less than 1%

effect on the annual electric consumption of a mosque building (Budaiwi et al., 2013). This could be apparently attributed to the limited percentage glazed area to wall area for mosque buildings.

Various geometrical configurations for shading components are conventionally incorporated as architectural feature integral to mosque design. Traditional and historical mosque designs use the Riwaq, which is an arcade surrounding the open courtyard 'Sahn' of the mosque for provision of shaded prayer area, as illustrated in Figure 1. Shaded arcade can also be used as external surrounding for mosque buildings. This ensures maximum shading for external walls and glazed elements of building envelope and serves the double purpose for provision of extended external shaded prayer area. In addition, building roof is exposed throughout the day and continuously receiving solar radiation. Thus, the use of double roof for shading is realized as an effective technique for reducing the solar load on the roof, particularly in tropical regions. This serves the double purpose of providing roof shade as well as provision for extension of prayer area, effectively serving peak time's occupancy demand. The proposed roof shade can be achieved with any type of construction in the form of metal deck, timber, concrete or tensile structure.

Figure 1: Typical Riwaq use in historical mosques

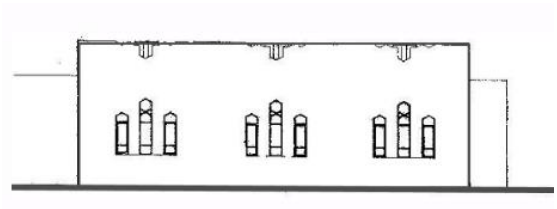
It must be noted that most mosque buildings, while they can be elegantly designed and constructed, are more often unable to accommodate all worshipers, particularly at peak times or Jumaa prayer (Friday prayer). Thus, arcades and double shaded roof can provide such useful spaces to meet peak demand for prayer area as well as for use when environmental conditions are convenient for outdoor use. This study considers the energy efficiency for mosque design, and realistically addresses architectural features through the

utilization of shading elements of arcades and double roof shade, and focuses on the energy performance and saving potentials for enhancing mosque design.

2. MOSQUE BASE DESIGN

Mosques in Saudi Arabia are generally built by governmental authorities as well by private individuals. This results in greater variability in the design, construction and materials commonly used, with mosque areas ranging from the small local to the large Juma mosques. The Technical Department of the Ministry of Islamic Affairs, Endowment, Da'wa and Guidance of the Eastern Province had established standard designs for mosques. Two main designs known as type "H" and "O" were extensively built during the past 2 decades representing the small local Jumaa mosque and the Friday, Jumaa mosque with larger floor area (MIAEDG, 1999). This study adopts the local mosque as typified standard reference base design, representing reference geometrical design base for systematic variations of shading configurations, and enables definition of the ranges for parametric studies and comparative energy performance evaluations.

The typified base mosque has a rectangular plan with a net floor area of 378 m2. Qibla orientation is a basic constraint of mosque design, showing a western direction in the eastern region with limited angular variability along the Gulf coast. The architectural floor plan layout for the base mosque is shown in Figure 2.



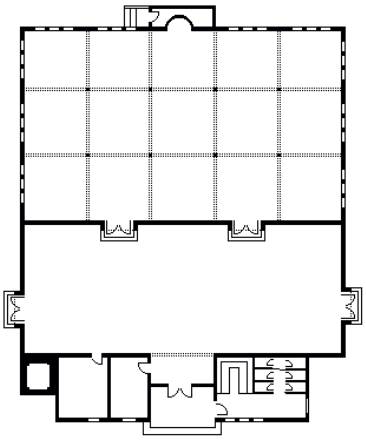


Figure 2: Plan and elevation of the base mosque design

A concrete frame structure with common concrete block wall filling is generally used in local mosque construction. In addition, single glazing systems are also common (Budaiwi et al., 2013). Air Conditioning systems

commonly used include window and wall unitary and split systems as well as roof top package terminal system. The main geometrical and constructional characteristics as well as A/C system specifications of the typified base mosque are summarized in Table 1.

Table 1 Characteristics and specifications of typified standard mosque designs
Source: MIAEDG (1999)

Geometry	Floor Area	378 m^2
	Glazing to floor area ratio:	0.10
Wall Construction	Uninsulated heavy weight conc. block with plaster	U-value=
Roof Construction	Reinforced concrete slab with built-up roof finish	U-value=
Floor Construction	Slab on grade + tiles + carpet	
Glazing Type	6 mm clear single glazing	
	Shading coefficient	0.95
Lighting System	Suspended fluorescent	6.4 W/m^2
No. of users	Av. no. of persons: regular prayer	4.8m^2/person
	Friday prayer	0.9m^2/person
Infiltration	Air change	0.75 ac/hr
A/C System	Package terminal air conditioner	OX system
	Thermostat setting: Cooling	*25.5°C*
	Heating	21°C
	Relative humidity	50%
	Heating source	Electric

3. SIMULATION STUDIES

Energy simulation models are considered powerful tools for realistic and practical exposure of the impact of architectural design parameters of mosques on its energy performance. Computer simulations enable an expanded scope of investigations and prompt consideration of wide ranges and combinations of parametric studies. This study uses the DOE 2.1E program, through Visual DOE 4 version. Simulations of mosque energy performance are conducted on hourly basis and for full year duration. Realistic representative primary input data are required for accurate simulations and reliable results. These comprise climatic variables, architectural geometrical design and constructional characteristics, occupancy, A/C specifications and operational use. Standardized conditions need to be defined for the purpose of parametric studies, and relate to the following:

- Climatic condition of Dammam area adopted by the study. The study deals with the Gulf region, with its characteristic maritime desert climatic condition, and typically represented by Dammam weather file of hourly values for a full year.

- Operational use: Mosque occupancy, lighting and A/C operation are directly determined by the fixed five times prayer schedule. A/C specifications are assigned in accordance with comfort requirement, as shown in Table 1. One-hour duration is assumed for regular prayers occupancy and two hours of corresponding A/C use. Occupancy is estimated based on partial mosque capacity for regular prayers and full capacity for Friday prayer.

4. PERFORMANCE INDEXATION

Assessment of the building energy performance need to be realized with representative tools of performance indicators for practical energy performance evaluation. The annual electrical energy consumption of a building is directly related to its cooling loads and A/C system capacity. In addition, the building annual cooling load describes the total heat gains of the building and directly relates to A/C system operation and electrical energy consumption. Heat gains contribution from building components such as walls, roof and glazed areas are also employed as relative contribution of envelopes'' components for comparative analysis. These indices are used to explain the variation in electrical consumption and illustrate the impact and effectiveness for the application of different shading configurations.

5. PARAMETRIC STUDIES

The range of parametric studies intended to explore the performance of added design features and architectural components that can provide double advantages for a practical usable space which can also insure advantageous shading for components of building envelope, thus enhancing mosque building energy performance. The range of configurations considered by studies are limited by the application of vertical and horizontal element that can be readily integrated with the typified standard mosque design and construction specifications. Six sets of parametric simulation studies are conducted with reference to shading configurations. The range of added shading design elements considered included:

5.1. Arcades: This represents the use of Riwaq or arcade on the all sides of the mosque except for Qibla side, defined earlier as the west wall for the gulf region. The arcade extends 5m from the exterior walls with a height of 4.2m, corresponding to mosque height. Within this configuration, a number of variations are investigated. These are illustrated in Figure 3 and include the following:

a. Base arcade: A 5m single row columns shaded arcade around 3 sides of the building, except for the Qibla facade, as illustrated in Figure 3b.

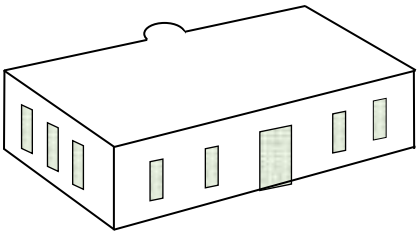
b. Extended front arcade: in this configuration, the front facade arcade with double width is used in the front of the mosque, representing typical historical designs, as illustrated in Figure 3c.

c. Arcade with vertical drop elements: exemplifying arch shading effect, vertical elements of 1.5m drop extending between external columns on the outer side of the arcades, as illustrated in Figure 3d.

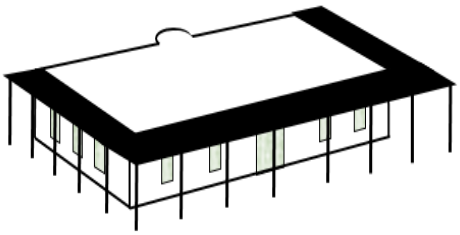
5.2. Double Roof: This assumes a horizontal large shading plane placed three meters above the whole roof area, resembling double roof geometry, as illustrated in Figure 3e.

5.3. Combined Shading: This configuration represents maximum shading configuration, both form extended arcades and roof shade together, as illustrated in Figure 3f.

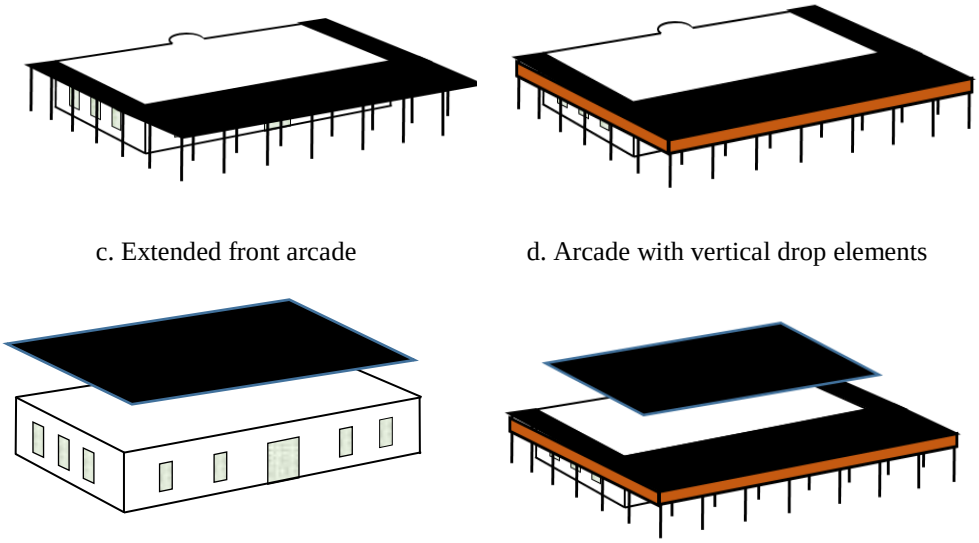
5.4. Shaded and Insulated Envelope: In this configuration ultimate shading design of arcade and double roof is combined with construction improvements through the use of wall and roof insulation as well as double glazed windows.



a. Base Case



b. Base arcade



c. Extended front arcade

d. Arcade with vertical drop elements

e. Double Roof

f. Combined Shading

Figure 3: Parametric variation of shading configurations

6. . RESULTS AND ANALYSIS

The potentiality and performance impact of application of proposed different shading configurations for mosque building are analyzed with reference to primary performance indicators. These indicators enable comparative performance evaluation reference to base building and illustrate the impact of application of different combinations of shading elements.

6.1. Impact of Base Arcade Shading

The use of single row of shaded arcade around sides and front facades provides shading by ensuring reduction of the radiation load to the external wall and glazing and subsequently induces reductions of all performance indicators as illustrated by the diagram of Figure 4. The total yearly sensible cooling load is reduced by 13.2%, mainly due to reduction in solar radiation form external walls and windows leading to reduction of their cooling load contribution.

While heat gains through opaque walls are reduced by about 24%, the biggest reduction comes from glazing heat gains amounting to about 35%. Consequently, A/C operation hours is reduced by 6.4%, with the increase of floating hours without A/C. This leads to reductions of A/C cooling loads by about 13% and 11.7% of its electrical energy demand. Adding the constant incidental electrical demand for lighting and fans results in a total reduction of annual building electrical demand by about 8.8%.

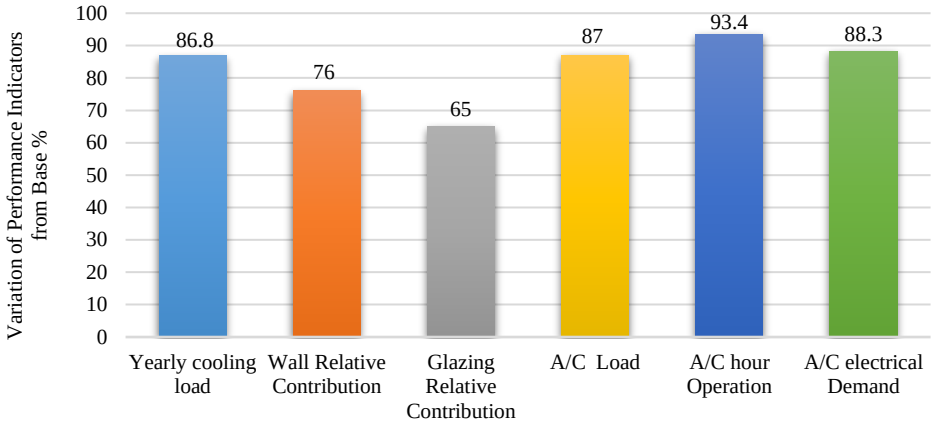


Figure 4: Relative variation of performance indices from corresponding indicators for unshaded base building for the case of single row arcade configuration.

6.2. Impact of Base Arcade with Extended Front Arcade Shading

The use of additional row for front arcade causes minor improvements to the case of single row, leading to limited performance improvement relative to base case. This adds about further variation ranging by an average of about 1.0% from that of a single row arcade for all indicators, as indicated by Figure 5. This brings reduction of building yearly and A/C cooling loads to 14.3% and 14.5%, respectively. The building overall reduction for electrical energy consumption and A/C consumption come to about 9.7% and 12.5%, respectively. Further increase of floating hours induces reduction of A/C hours of operation by up to 7.1%.

6.3. Impact of Arcade with Vertical drop elements

The additional use of vertical drop fins along the arcades shows only minor additional impact on further reduction of performance indicators due

to the shading action on facades' surfaces and glazing, as illustrated by the diagram of Figure 6. The yearly building loads and A/C cooling loads are reduced by 14.8% and 15.3%, respectively. Building overall and A/C electrical consumptions comes to 10.2% and 13%, respectively.

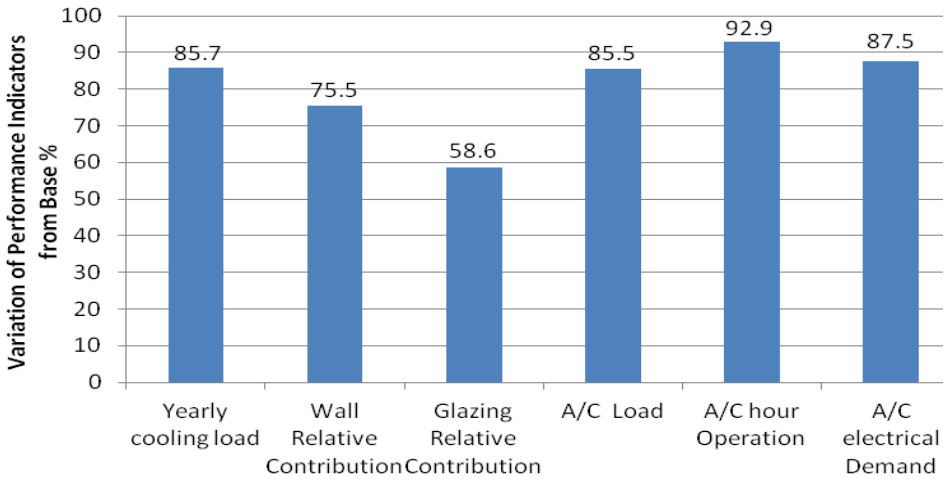


Figure 5: Relative variation of performance indices from corresponding indicators for unshaded base building for the case of single row side arcades with double row front arcade configuration

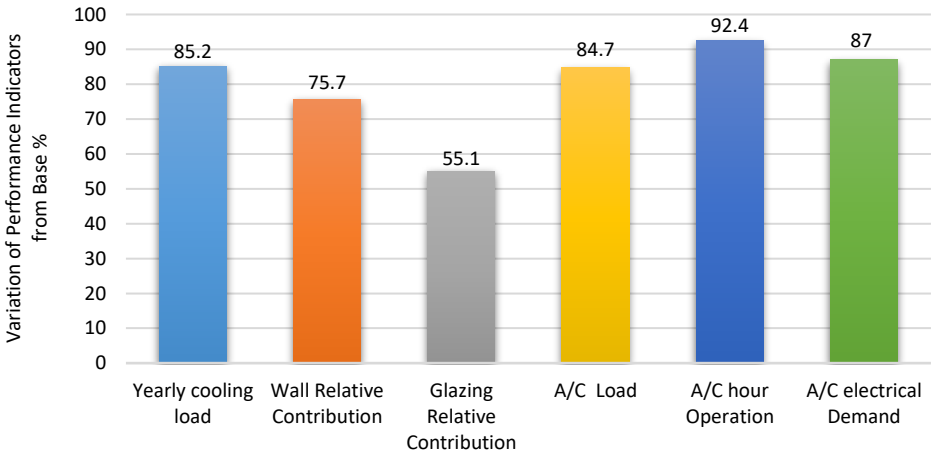


Figure 6: Relative variation of performance indices from corresponding indicators for unshaded base building for the case of double row front arcade with verical drop configuration

6.4. Impact of Double Roof Shade

The use of double roof shade only without arcade shows remarkable impact on performance indicators, with reference to base building without shading, as illustrated by Figure 7. The building yearly cooling load shows a reduction of about 15.9%, caused by the high reduction of heat gains from the roof component of about 45.7%. A/C cooling load is subsequently reduced by 10.7%. The overall building electrical energy consumption and A/C electrical energy demand are reduced by about 7.5% and 9.6%, respectively.

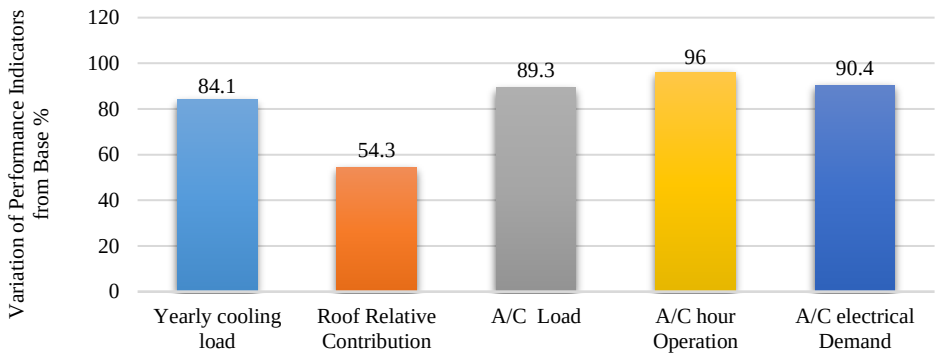


Figure 7: Relative variation of performance indices from corresponding indicators for unshaded base building for the case of double roof shade only Configuration.

6.5. Impact of Full Shade

The impact of application of full shade with arcades and double roof shade is illustrated in Figure 8, which indicates the relative percentage variation for each of the performance indicators from the corresponding indicators of the base unshaded building. The overall reduction of the building cooling load comes to about 30% and the A/C cooling load is reduced by about 25.7%. The overall building electrical energy consumption and A/C electrical energy demand are reduced by about 17.5% and 22.4 %, respectively.

6.6. Impact of Full Shade with Insulated Envelope

The combination of roof and wall arcade shade with conventional fabric insulation on walls and roof with double glazed windows shows the full potential for exploiting design and construction features for improving

environmental and energy performance of mosque buildings, as illustrated in Figure 9. The reduction of building cooling load comes to about 59.2% as compared to uninsulated unshaded base mosque and the A/C cooling load is reduced by about 31%. This is a direct reflection of the reductions of wall, roof and glazing heat gains due to insulation and shading. The overall building electrical energy consumption and A/C electrical energy demand are reduced by about 27.8% and 35.7%, respectively.

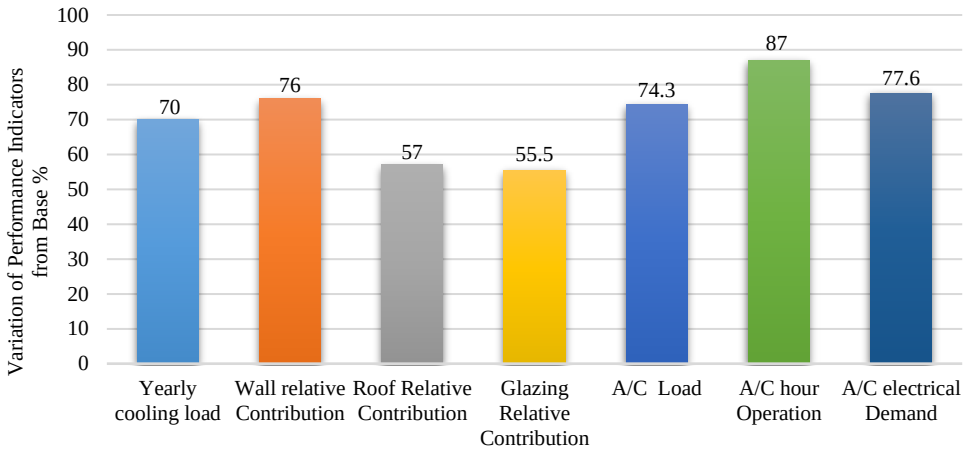


Figure 8: Relative variation of performance indices from corresponding indicators for unshaded base building for the case of double roof and arcades shading configuration

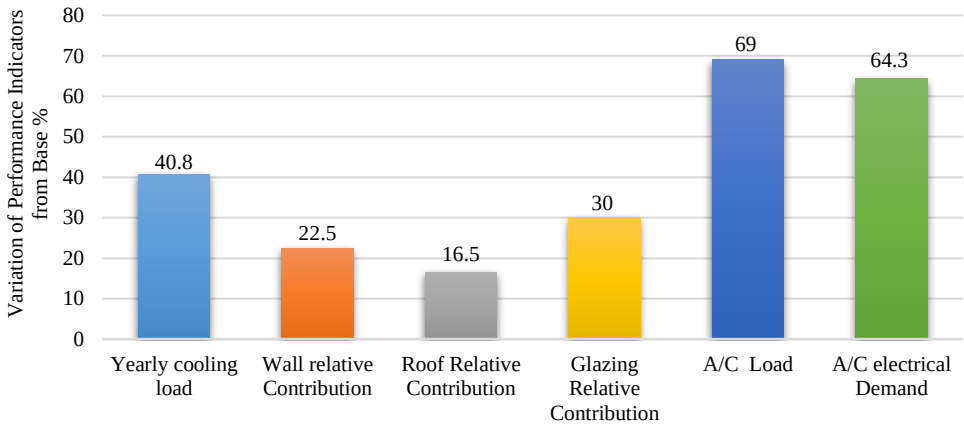


Figure 9: Relative variation of performance indices from corresponding indicators for unshaded base building for the full potential application of double roof, arcades shading configuration and fabric insulation.

The relative impact for different shading configuration is clearly illustrated by the variation of primary performance indices of building cooling load and A/C electrical energy demand, by Figures 10 and 11.

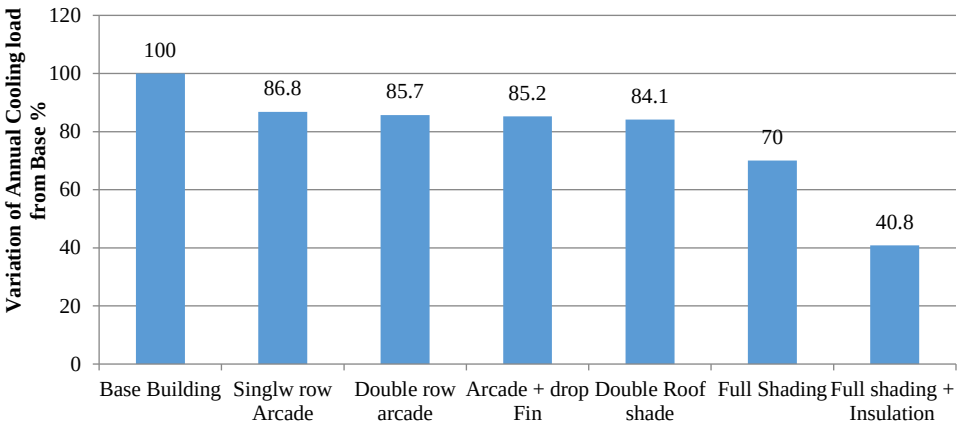


Figure 10: Relative variation of building cooling load performance index, relative to base case, for different shading configurations

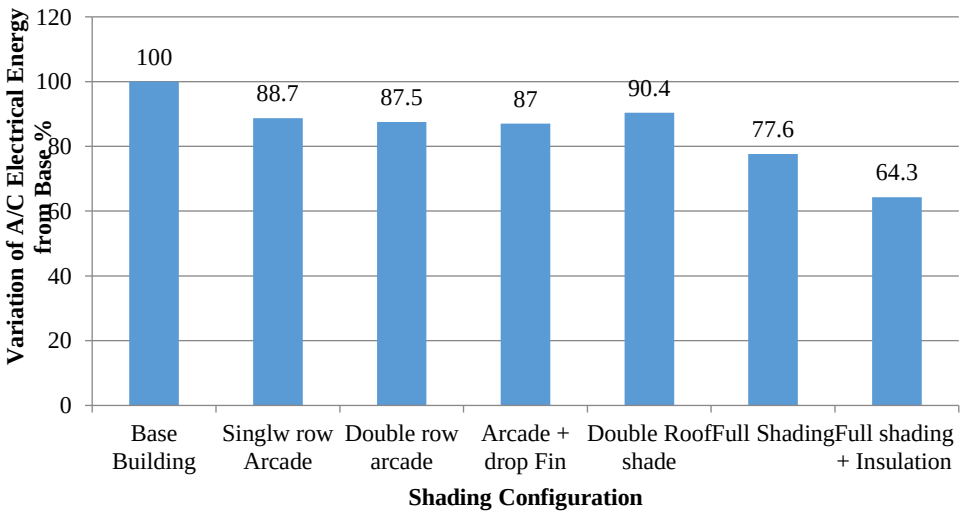


Figure 11: Relative variation of building A/C electrical energy demand performance index, relative to base case, for different shading configurations.

7. CONCLUSIONS

The design of mosque buildings should reflect the enshrined Islamic principles of sustainability and efficiency of usage of resources, through low energy consumption mosques. Energy simulation studies were conducted to measure the effect of additional architectural features by the use of arcade around the building and double roof design for shading purposes, on the energy performance of mosque buildings. These architectural features, while historically were an integral part of mosque design, can serve dual purposes. On the one hand, shaded mosque extensions serve as prayer areas during peak times and times when external environment is favorable, while at the same time provide greater savings of the building energy consumption through reduction of solar heat gain.

Results of the simulation studies showed that the effect of shading in general is high, providing substantial reduction in A/C electrical energy of up to 22.4 % and total building electrical demand by 17.5%. Basic arcade around three sides of the mosque produces savings of total electrical demand by about 8.8%. This reduction is only marginally improved when the arcade is further extended on one side or with vertical drop elements added to the arcade. On the other hand, shading of roof by the addition of double roof can also provide savings of up to 7.5% annually. The combination of arcade shade and roof shade with additional fabric insulation can provide maximum savings for building annual electrical and A/C demands by about 28% and 36%, respectively, as compared to unshaded and un-insulated mosque. These results prove the high potentiality for enhancement of mosques' energy performance and saving with the use of such architectural features and show added promising opportunities of usable space.

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MINIMIZING THE ENVIRONMENTAL EMISSIONS ASSOCIATED WITH ENERGY CONSUMPTION OF MOSQUE BUILDINGS IN SAUDI ARABIA

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Abstract

Saudi Arabia is considered as the largest Muslim country that witnesses high demand on construction of new mosque buildings. This demand is emerged from the rapid booming in the construction of new residential buildings. The revolution in construction results in increasing of domestic energy consumption which consequently increases the environmental emissions. The impact of high usage of energy on the surrounding built environment has to be investigated in order to propose some solution for reduction. Hence, this paper focuses on the minimizing environmental impact of mosque by suggesting various wall systems and performing energy simulation. A mosque building in AL Khobar city (Eastern province of Saudi Arabia) is selected for this study with operating period of 30 years in order to assess the environmental emissions caused by the energy usage. Eight wall systems are investigated, including; concrete block and precast concrete, with and without insulation. Environmental impact measures are analyzed; total energy, land emissions, water toxicity, air toxicity, and global warming potential. The energy simulation is performed by Autodesk Ecotect 2011 while the environmental impact is assessed using ATHENA® software. In addition, the future costs of environmental impact for the various alternatives are assessed according to the current practice and market price of CO2. The best wall system is found to be 25mm concrete block with 70 mm of polyurethane insulation, which could minimize the environmental impact by 33% compared to the base case scenario, and reduce the environmental cost by 270,000 SR.

Keywords

Environmental Emissions, air pollution, Life Cycle Assessment, Global Warming, Mosque, Energy Simulation, wall system.

تخفيض الانبعاثات البيئية الناتجة من استهلاك الطاقة المستخدمة في مباني المساجد بالمملكة العربية السعودية

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المستخلص

تعتبر المملكة العربية السعودية أكبر دولة إسلامية تشهد حاجة عالية ومستمرة لبناء المساجد. هذه الحاجة تنبع من النمو والازدهار المتجلي في بناء المباني السكنية. هذه الثورة في البناء ينتج عنها استهلاك كبير للطاقة المحلية مما ينتج عنه زيادة في الانبعاثات البيئية المصاحبة . يجب ان يكون هناك حصر للتأثير البيئي الناتج من عملية استهلاك الطاقة وذلك لإيجاد الحلول الممكنة لتخفيض تأثيرها. تقدم هذه الورقة حلولاً عملية لتقليل التأثير البيئي وذلك بفحص انواع مختلفة من الحوائط الخارجية لمباني المساجد وذلك باستخدام تقنية محاكاة الطاقة. تم إختيار مسجد العريفي في مدينة الخبر لإجراء الاختبارات وحساب التأثير البيئي المصاحب لاستهلاك الطاقة خلال تشغيل المسجد لمدة ٣٠ عام. ثمانية انواع من نظم الحوائط استخدمت في هذه الدراسة والتي تشمل الطوب الإسمنتي ، الخرسانة مسبوقة الصب المعزولة وغير المعزولة. تم قياس وتحليل الاثار البيئية التالية: الاستهلاك الكامل للطاقة , انبعاثات الارض, تلوث الماء , تلوث الهواء , واخيرا مقدار الاحتباس الحراري وتأثر طبقة الأوزون. تم في هذه الدراسة عمل محاكاة الطاقة باستخدام برنامج الايكوتيكت ٢٠١١ بينما تم إستخدام برنامج أثينا لقياس الأثر البيئي الناتج من استخدام انظمة الحوائط الخارجية المختلفة للمسجد الذي عملت عليه الدراسة. تم حساب تكلفة الأضرار البيئية المستقبلية عن طريق حساب تكلفة ثاني أكسيد الكربون في الاسواق العالمية. أفضل نظام حوائط هو الطوب الاسمنتي المعزول بمادة البوليوريثين حيث يمكنه تقليل الأضرار البيئية بما يعادل ٣٣% مقارنة بالوضع الراهن للمسجد بينما يمكن تقليل التكلفة البيئية بما يعادل ٢٧٠ الف ريال.

الكلمات الدالة

الانبعاثات البيئية , تلوث الهواء , تقييم دورة الحياة, الاحتباس الحراري, المسجد, محاكاة الطاقة, نظام الحوائط

1. INTRODUCTION

Building sector has a major role on environmental impact and energy resource depletion. Buildings have indirect and direct consumptions of domestic energy. Direct consumption includes several stages such as construction, operation and maintenance and destruction, while the indirect energy include that consumed in extraction and production of construction material, and for transportation and technical installations (Sharma et al., 2011). The environmental impact is due to the dangerous emissions and greenhouse gas associated with the whole life cycle stages of a project. According to a study by the United Sates' Department of Energy (DOE), buildings are responsible for 40.2% of the primary energy consumption in the US (DOE, 2015).

Therefore, the major role of buildings in minimizing energy consumption and the associated environmental emissions, is very clear. However, the recent scientific challenge is to use the life cycle approach for the realistic and precise assessment of the environmental impact. The life cycle assessment (LCA) tool has been popular in the last decade, due to its complete and systemic approach to environmental evaluation.

The LCA tool provides a comprehensive assessment of environmental emissions and it is more useful in the conceptual design phase. LCA technique for buildings still have some limitations and challenges, and the assessment of life cycle environmental emissions of a building is somehow difficult because of many circumstances and varieties involved (Mer'eb, 2008). Therefore, predicting life cycle as "from-cradle-to-grave" for such buildings is very complicated to conduct accurately, such as 30 years. Furthermore, most of the buildings utilized in the LCA examples are still in the inventory analysis stage, e.g. determining parameters such as energy consumption or outputs released back to the environment (Li, 2006).

Victoria (1996) conducted a research on the environmental emissions of building materials. A comparison of the energy consumed over all life cycle stages of residential buildings in various four states found that wooden buildings consumed less energy than concrete and steel buildings. LCA was performed on a one-family home modeled with two types of exterior envelopes: insulating concrete form (ICF) and wooden frame. The result showed that the environmental impact was worse for the wood-frame home compared to the ICF house (Medgar, 2006).

LCA was applied to estimate the energy consumption and the environmental impact during the construction stage for two typical office buildings, one with concrete frame and the other with a steel frame. The concrete frame building had more associated energy consumption while the steel-frame building contributed more volatile organic compound (Guggemos, 2005).

Townsend and Wagner (2002) conducted a research in applying sustainable timber products in comparison with synthetic materials such as aluminum, concrete and steel for construction purposes. The results of the research clearly confirmed that wood was the best building material according to the environmental criteria. Alshamrani (2016) employed LCA for low-rise office building with several structure and envelope types.

The study proved that the highest environmental impact occurred in the operating stage (91%) compared to the other stages. For the overall life span, precast concrete buildings showed the best performance in terms of energy consumption, global warming potential, and water, air, and land emissions. However, the literatures show that there is a lack of studies on applying LCA technique on mosque buildings, which requires research attention particularly in Saudi Arabia.

2. METHODOLOGY

The methodology of this paper consists of three main stages: input (alternatives), process (energy simulation and environmental assessment), and output (selection) as shown in Figure1. Eight wall systems are investigated in this study; concrete block with various thickness and precast concrete panels with and without insulation result in eight different tested alternatives including the base case scenario.

The process includes energy simulations for the operating energy, which are performed for the various alternatives by using Autodesk Ecotect 2011 software. Furthermore, the investigation includes environmental impact assessment components and measures such as global warming potential, total energy usage, pollutants to water, land and air, and natural resources use, are measured in this study. Figure 2 displays the detailed sections for some of the various tested alternatives.

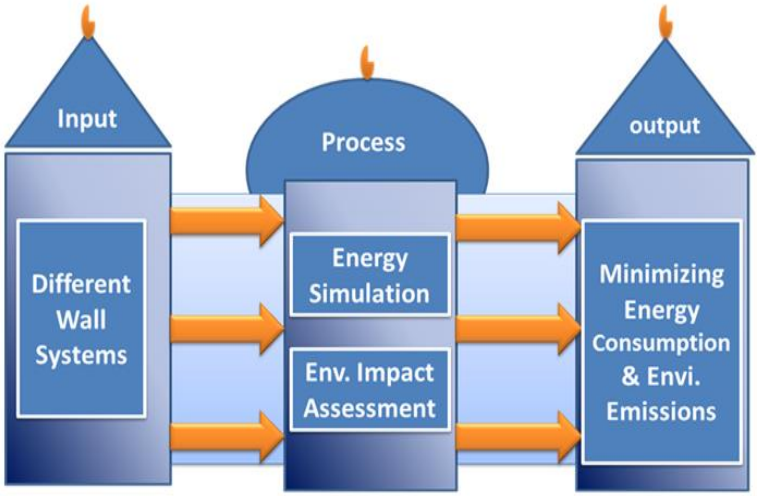

Figure 1: Research Methodology

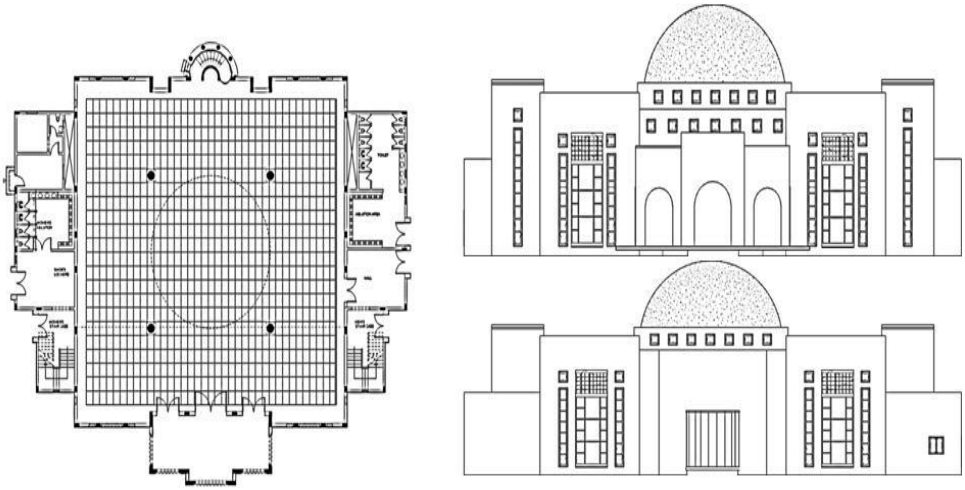

Figure 2: Alarifi Mosque floor plan, Front and Rear Elevations.

This study is conducted on Al-Arifi mosque in Aljisr district, located in AL Khobar city, Saudi Arabia. The mosque consists of two floors with total floor plan area of 1370 m2 as shown in Figure 2. The floor height is 7.2 m and the praying area can accommodate about 996 worshipers. Eight wall systems are investigated, including concrete block and precast concrete, with and without insulation. Table 1 shows the detailed information about wall types, their conductivity and U values. Alternative 1 represents the base case scenario.

Table 1: Various Tested Wall System

Wall Type	Material	Thickness (mm)	Conductivity (W/m.K)	U-Value* (W/m².K)
1	Plaster	12	0.52	2.569
	Concrete block	200	1.35	
	plaster	12.5	0.52	
2	Plaster	12	0.52	0.439
	Concrete block	100	1.35	
	Polystyrene	50	0.008	
	Concrete block	150	1.35	
	plaster	12.5	0.42	
3	Plaster	12	0.52	0.425
	Concrete block	100	1.35	
	Polyurethane	50	0.028	
	Concrete block	150	1.35	
	plaster	12.5	0.42	
4	Plaster	12	0.52	0.331
	Concrete block	100	1.35	
	Polystyrene	70	0.008	
	Concrete block	150	1.35	
	plaster	12.5	0.42	
5	Plaster	12	0.52	0.32
	Concrete block	100	1.35	
	Polyurethane	70	0.028	
	Concrete block	150	1.35	
	Plaster	12.5	0.42	
6	Precast concrete	175	1.046	0.387
	Air gap	10	5.56	
	Rock wool	100	0.2	
	Plaster	15	0.42	
7	Brick	100	0.81	1.538
	Air gap	50	5.56	
	Concrete block	150	1.35	
	Plaster	12.5	0.42	
8	Terracotta Tile	20	1	1.92
	Air gap	10	0.28	
	Concrete block	250	0.62	
	Plaster	15	1.5	

The first step in assessing the environmental impact is to perform the operating energy simulation. The energy performance of the various wall systems is measured by performing hourly energy simulations to calculate the monthly electricity consumption. The energy simulation is done utilizing the Autodesk Ecotect 2011 software. This simulation is performed based on identifying some energy input (normalized and variable) parameters that affect the energy consumption of mosque building as shown in Table 2. Figure 3 shows the simulated model for Alarifi Mosque in AL Khobar which is utilized to perform the energy simulation.

Table 2: Input data for simulation

Physical characteristics of the Building	
No. of floors	2
Gross area	1370 m²
Conditioned area	1285.35m²
Floor height	Prayer hall: 7.2 m Underneath the dome: 10.8 m mezzanine floor: 3.2 m Services: 3.6 m
Orientation	West - East Axis
Thermal Zones	Multi-zones
Wall area	North: 306 m² South: 440 m² East: 305 m² West: 304.5 m²
Glazing	Double-glazed 6/12/6
Roof	200 mm concrete, 50 mm polyurethane insulations
Glazing area	North : 11.1 m² South: 11.85 m² East: 12.25 m² West: 10.8 m²
Inflation rate	0.2 ach
Ventilation rate	7.5 L/s/person
Lighting	16 W/m^2
HVAC	Central System
Set point	(22-24 C) Summer, (20-22 C) Winter
No. of occupants	996

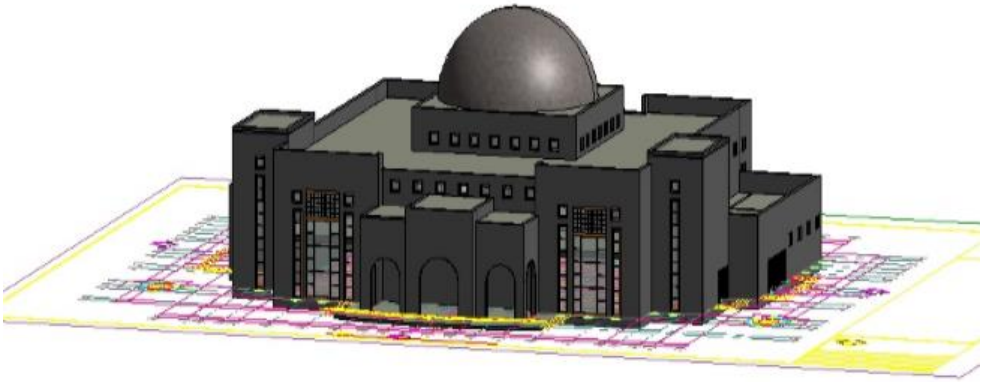

Figure 3: 3D model of the simulated Mosque

The developed prototype model for the energy simulation is used in this test as well to assess the environmental impact associated with the different wall systems. ATHENA® 2011, is the impact estimator software used to perform this test based on the life-cycle assessment method (Athena Institute, Canada). This tool incorporates ATHENA's databases, which cover many of the building wall systems and structure types. Since environmental impacts are assessed based on the type and bill of materials as indicated in Table 2, the software requires the data of the annual energy consumption that was calculated by the energy simulation software. Eight various wall systems are investigated during 30 years of operation.

3. RESULTS

3.1. Energy Consumption

The energy simulation is performed on a prototype model by using Ecotect software for the two- floor mosque building in AL Khobar city with total gross area of 1370m2. The results show that the peak electricity consumption occurs in July and August due to high temperatures that cause high energy consumption due to space cooling, equipment and lighting. The results of the energy simulation show that higher annual energy consumption is recorded for the base case scenario. The building with non-insulated block wall consumes 292,300 KWh while building with wall system 5 (250 mm concrete block with 70 mm polyurethane insulation) consumes 220,000 KWh as shown in Figure 4. The total energy consumption over 30 years of

operation is varied between (7.69E+07MJ - 1.02E-08MJ) as shown in Table 3. The mosque constructed by wall system 5 (250 mm concrete block with 70 mm polyurethane insulation.) can reduce the total energy consumption by 2.52E+07MJ.

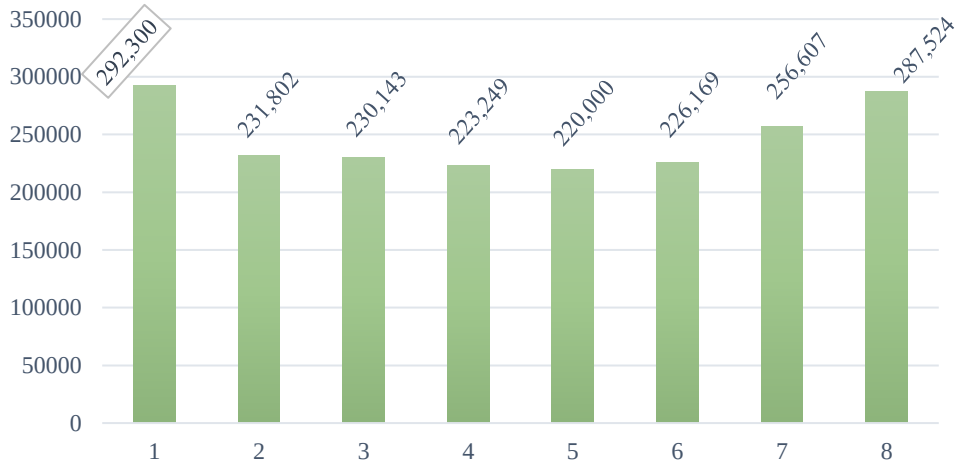

Figure 4: Annual Energy Consumption for Tested Wall Systems (KWh)

Table 3: Total Assessed Emissions for Each Alternative

Alternative	Air Emissions (index)	Land Emissions (index)	water Emissions (index)	Total Energy (MJ)
1	7.30E+07	7.13E+05	9.67E+10	1.02E+08
2	5.79E+07	5.66E+05	7.67E+10	8.10E+07
3	5.75E+07	5.62E+05	7.62E+10	8.04E+07
4	5.58E+07	5.45E+05	7.39E+10	7.80E+07
5	5.50E+07	5.37E+05	7.28E+10	7.69E+07
6	5.65E+07	5.52E+05	7.49E+10	7.90E+07
7	6.41E+07	6.26E+05	8.49E+10	8.97E+07
8	7.18E+07	7.02E+05	9.52E+10	1.00E+08

3.2. Air Emission

Wall system 5 (250 mm concrete block with 70 mm polyurethane insulation) contributes the least to overall air emissions while the non-

insulated wall system (base case) contributes the highest air emission. Non-insulated wall system and the 70mm of polyurethane insulation system contribute73 and 55 million (indexed) air emissions, respectively, while precast concrete wall building contribute 56.5 million (indexed) as presented in Table 3. Applying the polyurethane insulation system minimizes the overall air emissions by 33% (18 million indexed),

3.3. Water Emission

Water emission records the highest indexed number of emission compared to air and land emission. This indicates that the energy consumption has more impact to water. Wall system 5 (250 mm concrete block with 70 mm polyurethane insulation) contribute the least to overall water emissions while the non-insulated wall system (base case) contributes the highest water emission. Non-insulated wall system and the 70mm of polyurethane insulation system contribute 95 and 72billion (indexed) water emissions, respectively, while precast concrete wall building contribute 75 billion (indexed) as presented in table 3. Applying the polyurethane insulation system minimizes the overall water emissions by 33% (23 billion indexed).

3.4. Land Emission

Land emission records the least indexed number of emission compared to air and water emissions. This indicates that the energy consumption has lower impact to land compared to others. Wall system 5 (250 mm concrete block with 70 mm polyurethane insulation) contribute the least to overall land emissions while the non-insulated wall system (base case) contributes the highest land emission. Non-insulated wall system and the 70mm of polyurethane insulation system contribute713 and 537thousands (indexed) land emissions, respectively, while precast concrete wall building contribute 552 thousands (indexed) as presented in table 3. Applying the polyurethane insulation system minimizes the overall land emissions by 33% (176,000indexed).

3.5. Global Warming and Ozone Depletion Potential (GWP)

GWP is expressed on an equivalency basis relative to CO2 emissions in kg. The highest global warming emission is generated during the operating stage due to the high energy consumption during this stage compared to other

stages. Wall system 5 (250 mm concrete block with 70 mm polyurethane insulation) produce the lowest global warming potential impact while the non- insulated wall system (base case) produces the highest global warming potential impact as shown in Figure 5.

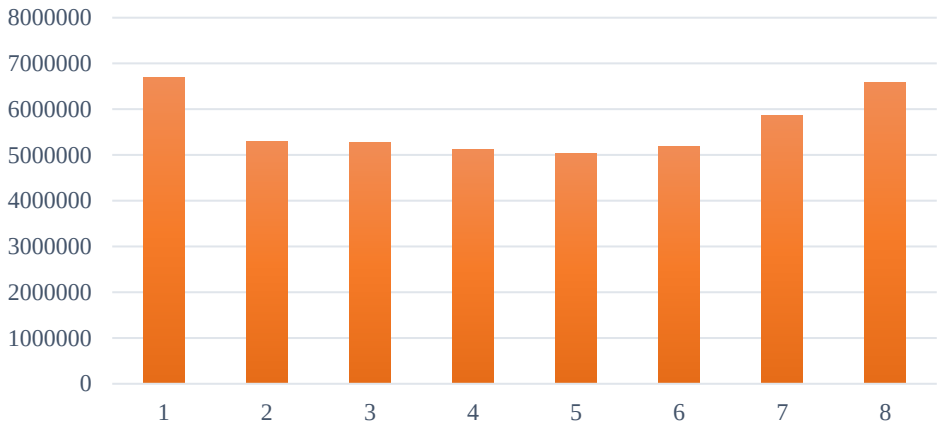

Figure 5: Global Warming Potential (kg CO2 eq.)

Non-insulated wall system and the 70mm of polyurethane insulation system produce6.69 and 5.04 million (kg of CO2 eq.), respectively, while precast concrete wall buildingproduces552 thousands (indexed) as presented in table 4. The highest ozone depletion is produced by the non-insulated wall system, 3.26 million kg CFC-11 eq) as presented in Table 4. The overall result shows that the environmental impact can be reduced by 33% if the wall system 5 is applied as shown in Figure 6. Adding 70 mm of polystyrene insulation to the wall system and the insulated precast concrete system reduce the environmental impact of 31% and 29%, respectively compared to the base case scenario.

Table 4: Global Warming and Ozone Depletion Potential

Wall System	1	2	3	4
Primary Energy Consumption MJ	9.17E+07	7.27E+07	7.22E+07	7.00E+07
Weighted Resource Use kg	7.24E+06	5.74E+06	5.70E+06	5.53E+06
Global Warming Potential (kg CO2 eq)	6.69E+06	5.30E+06	5.27E+06	5.11E+06

Acidification Potential (moles of H+ eq)	2.38E+06	1.89E+06	1.88E+06	1.82E+06
HH Respiratory Effects Potential (kg PM2.5 eq)	1.33E+04	1.06E+04	1.05E+04	1.02E+04
Eutrophication Potential (kg N eq)	5.71E+01	4.53E+01	4.50E+01	4.36E+01
Ozone Depletion Potential (kg CFC-11 eq)	3.28E-06	2.60E-06	2.58E-06	2.51E-06
Smog Potential (kg NOxeq)	1.03E+03	8.19E+02	8.13E+02	7.89E+02
Wall System	**5**	**6**	**7**	**8**
Primary Energy Consumption MJ	6.90E+07	7.09E+07	8.05E+07	9.02E+07
Weighted Resource Use kg	5.45E+06	5.60E+06	6.35E+06	7.12E+06
Global Warming Potential (kg CO2 eq)	5.04E+06	5.18E+06	5.87E+06	6.58E+06
Acidification Potential (moles of H+ eq)	1.79E+06	1.84E+06	2.09E+06	2.34E+06
HH Respiratory Effects Potential (kg PM2.5 eq)	1.01E+04	1.03E+04	1.17E+04	1.31E+04
Eutrophication Potential (kg N eq)	4.30E+01	4.42E+01	5.02E+01	5.62E+01
Ozone Depletion Potential (kg CFC-11 eq)	2.47E-06	2.54E-06	2.88E-06	3.23E-06
Smog Potential (kg NOxeq)	7.77E+02	7.99E+02	9.06E+02	1.02E+03

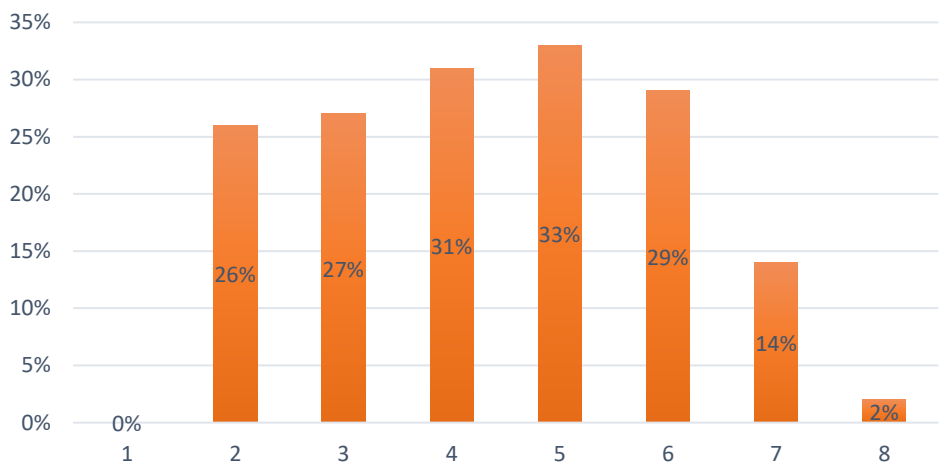

Figure 6: Minimizing the Environmental Emission by Each Wall System.

4. CONCLUSION

Environmental impact assessment is conducted in this study on two-story mosque building in AL Khobar city, Saudi Arabia. There is lack of applying the environmental impact assessment technique on mosque buildings, so the current study will open doors for further research. The results show that the highest global warming emission is generated during the operating stage due to the high energy consumption.

Water emission is recorded to be the highest (affected by the energy consumption) compared to air and land emissions. It is also shown that the environmental impact can be reduced by 33% if polyurethane insulation is applied on the wall system. Adding polystyrene insulation to the wall system and the insulated precast concrete system, reduce the environmental impact by 31% and 29%, respectively compared to the base case scenario.

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EXPLORING THE CHALLENGES IN UTILIZATION OF BIM IN MAINTENANCE MANAGEMENT OF MOSQUES

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Abstract

Defects occur in various forms, at different extents, in all types of buildings irrespective of age. Thus, every building whether old or new, requires continuous care and protection to limit deterioration. Efficient maintenance management approaches using advancements in information and communication technology are essential in extending the life of mosque buildings and avoiding the need for potentially expensive and disruptive repair works, which may affect their basic functions. Although the adoption of Building Information Modeling (BIM) in construction industry is currently accelerating rapidly, the focus still remains strongly in the design and construction processes. Since the early introduction of BIM, it has been claimed that BIM would bring significant benefits to building maintenance management. However, most of the documented, quantifiable benefits of BIM are related to design and production of buildings and there is relatively little hard evidence of BIM benefits in operation and maintenance activities.

Similarly, despite the promise of using BIM during the whole life cycle of a building, there are only few studies that report the actual uses of BIM and other information systems in Facility Management, without clear focus on building maintenance management. Considering the fact that Mosques play significant roles in the spiritual, moral and social growth of the Muslims all over the world, and the need to apply BIM technology in the maintenance management of mosques, this paper contributes to the discussion by exploring the challenges in utilization of BIM in maintenance management of mosques. Questionnaire survey and interviews were used to obtain data for the study. It was found “lack of awareness of BIM potential in maintenance”, “lack of technical background for maintenance personnel”, “lack of clear consensus on how to implement or use BIM”, “non-availability of as-built documents of the Masjids”. As a matter of urgency, a framework for full utilization of BIM in mosque maintenance management should be prepared to provide guideline to mosque custodians and maintenance personnel to efficiently maintain the mosques in their care. It is expected that findings of this paper could help towards preparing an integrated BIM-based Maintenance Management Model for Mosque buildings.

Keywords

BIM; facility management, maintenance management, mosque building.

استكشاف التحديات للإستفادة من نظام نمذجة معلومات البناء BIM في إدارة صيانة المساجد

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المستخلص

تحدث العيوب في جميع أنواع المباني بأشكال وبدرجات مختلفة، بغض النظر عن عمرالمبني. وهكذا، كل مبنى سواء كان قديما أو حديثا، يحتاج إلى حماية ورعاية مستمرة للحد من تهالكه. أصبحت نماذج إدارة الصيانة الأكثركفاءة بإستخدام تكنولوجيا المعلومات والاتصالات المتقدمة ضرورية لزيادة العمر الإفتراضي لمباني المساجد ولتجنب الحاجة لأعمال الترميم والتي تكون باهظة الثمن وغالبا ما تؤثر على وظائفه الأساسية وقد تفسد شكله المعماري. على الرغم من أن إستخدام نظام نمذجة معلومات البناء (BIM) في صناعة التشييد يتزايد حاليا بسرعة إلا أن التركيز لا يزال قويا فقط في عمليات التصميم والبناء ومنذ بداية ظهور ال BIM في صناعة التشييد، زاد التفكير أن BIM من شأنها أن تجلب فوائد كبيرة لإدارة الصيانة بالمباني ومع ذلك، فإن معظم الفوائد القابلة للقياس الكمي والموثقة ل BIM ، ترتبط بتصميم وتشييد المباني وهناك أدلة قليلة نسبيا عن فوائد BIM في أنشطة التشغيل والصيانة. وبالمثل، على الرغم من الاستخدام الواعد ل BIM خلال دورة الحياة الكاملة للمبنى، فإن هناك دراسات قليلة فقط سجلت الاستخدامات الفعلية للBIM وغيرها من نظم المعلومات في إدارة المرافق دون تركيز واضح على إدارة الصيانة للمباني.

وبالنظر إلى حقيقة أن المساجد تلعب أدوارا مهمة في النمو الروحي والمعنوي والاجتماعي للمسلمين في جميع أنحاء العالم، والحاجة إلى تطبيق تكنولوجيا BIM في إدارة صيانة المساجد، فإن هذه الورقة تساهم في النقاش من خلال استكشاف التحديات التي تواجه الإستفادة من BIM في إدارة صيانة المساجد. وقد تم الحصول على بيانات الدراسة باستخدام الاستبيان والمقابلات. وقد تبين من الدراسة "عدم وجود ادراك لإمكانية استخدام BIM في الصيانة"، "عدم وجود خبرة تقنية لأطقم الصيانة" ، "عدم وجود إجماع واضح حول كيفية تنفيذ أو استخدام BIM "، "عدم توفر الوثائق عن مراحل بناء المساجد". وقد خلصت الدراسة إلي أنه ينبغي ضرورة وضع إطارعمل للإستفادة الكاملة من نظام BIM في إدارة صيانة المساجد وتقديم الإرشادات للقائمين علي المساجد وأطقم الصيانة للعمل بكفاءة لصيانة المساجد. ومن المتوقع أن تساعد النتائج التي توصلت إليها هذه الدراسة علي إعداد نموذج إدارة صيانة متكامل باستخدام نظام BIM لمباني المساجد.

الكلمات الدالة:

نمذجة معلومات البناء BIM ، إدارة المنشآت ، إدارة الصيانة ، مبني المسجد

1. INTRODUCTION

The mosque undeniably remains one of the most evident symbols of Islamic civilization's essential unity (Shrestha and Shrestha, 2014). Today, mosques have become architecturally distinctive and the technique of their architecture provides a way of understanding the connection between Islam and culture (Freek, 2004; Wiryomartono, 2009). Mosques are regarded as fundamental cultural heritage elements that strengthen the identity of Islamic societies and nations, which the people would always want to keep, safeguard, and pass them on to future generations.

The increasing consciousness in the religious and cultural significance of mosques necessitates for the proactive conservation of these valuable assets. Defects occur in various forms, at different extents, in all types of buildings irrespective of age. Thus, every building whether old or new, requires continuous care and protection to limit deterioration.

Remarkably, of all the methods of building conservation, maintenance remains the most important, pragmatic, sustainable and philosophically appropriate method of building conservation. Mosque buildings deserve the best maintenance management practice in order to continuously care and protect them from being demolished so as to prolong their life span and functions. Reactive maintenance practices have however become critical issues to buildings.

Thus, the use of advancements in information and communication technology together with efficient maintenance management approaches are considered essential in extending the life of mosque buildings and avoiding the need for potentially expensive and disruptive repair works, which may affect their basic functions.

The construction industry has been making considerable efforts in the last decade to harness the advancement in information and communication technology and utilize it for construction business. Most noticeable of these efforts is the adoption of Building Information Modeling (BIM) by many construction companies during their projects' planning, procurement, preconstruction, construction and post construction stages. BIM is an intelligent 3D model-based process that equips engineering, and construction

professionals with the insight and tools to more efficiently plan, design, construct, and manage maintenance of buildings and infrastructure.

2. IDENTIFICATION OF THE PROBLEM

Although the adoption of BIM in construction industry is currently accelerating rapidly, the focus still remains strongly in the design and construction processes. Since the early introduction of BIM, it has been claimed that BIM would bring significant benefits to building maintenance management. However, most of the documented, quantifiable benefits of BIM are related to design and production of buildings and there is relatively little hard evidence of BIM benefits in operation and maintenance activities. Even most large project owners in the US who have been early adopters of BIM, have used BIM more in managing their construction projects than implemented it into their maintenance management activities.

Similarly, despite the promise of using BIM during the whole life cycle of a building, there are only few studies that report the actual uses of BIM and other information systems in Facility Management, without clear focus on building maintenance management. Considering the fact that Mosques play significant roles in the spiritual, moral and social growth of the Muslims all over the world, and the need to apply BIM technology in the maintenance management of mosques, this paper explores the challenges in utilization of BIM in maintenance management of mosques.

3. METHODOLOGY

According to Cohen and Manion (1994), the approaches in collecting data in a survey research method are questionnaire and interview. In this research, the questionnaire approach was given preference for the purpose of achieving the objective of the research. The questionnaire approach is suitable for this research because questionnaires are cost effective method of data collection in a survey research as travelling to so many respondents across the Eastern Province of Saudi Arabia to conduct interview would be expensive (Burton and Bartlett, 2005). Besides, it is faster to conduct survey using questionnaire approach (Mujis, 2004).

Since this research is expected to be completed within a short time frame; using other survey research approaches might delay the completion time. In order to ensure that the respondents completed the questionnaires, the questions were made simple and short so that it was easy for the respondents

to understand. More so, the questionnaire was largely closed ended questions which do not require much thinking and consultations to answer. On an average, a set of questionnaire takes less than ten minutes to complete.

3.1. Sampling the Respondents

For the purpose of this project, a judgmental sampling was adopted because of how specialized the subject under investigation was; only respondents with the specific knowledge and experience on the subject were invited to participate. The basis for the adoption of a judgmental sample was the identification of a specific group of respondents that have the appropriate knowledge around the issues investigated. Thus, the judgmental sampling adopted allowed the selection of respondents whose experience permit an understanding of BIM and its application in design stage, construction stage and maintenance management stage in the Saudi Arabian construction industry, which was very valuable for this research. Moreover, the adoption of judgmental sampling helped to eliminate respondents who did not fit the requirements.

The sampling frame for some of the respondents was formed from a recent list of participants of a Conference organized by Saudi Council of Engineers, which was held in Dammam. It was strongly assumed and believed that the participants have wider experience and are competent to provide meaningful and unbiased information. Other respondents were selected based on judgmental sampling as highlighted earlier. These are mostly experts directly responsible for architectural & structural design, project management, construction management, and facilities management in their respective organizations. Thus, the respondents would respond in an informed and competent manner.

Eventually, a list of ninety respondents was drawn comprising consultants, architects, and engineers. In administering the questionnaires, the questionnaire was largely closed ended questions, which assess the respondents' perception of the level of influence the pre-determined factors have on potential utilization of BIM in mosque maintenance management. The respondents were asked to rate the list of factors based on a 5-point Likert scale where; 1 = not at all influential; 2 = slightly influential; 3 = Moderately influential; 4 = very influential; and 5 = extremely influential. In many previous studies, similar scales have been adopted by various authors (e.g. Kometa et al., 1994; Chan and Kumaraswamy, 1997; Naoum, 1998; Assaf et

al., 1999; Abdul-Hadi, 1999; Tam et al., 2000; Odusami, 2002; Frimpong et al., 2003; Wanous et al., 2003; Zeng et al., 2005; Enshassi et al., 2010).

3.2. Method of Analyzing the Factors

Severity index and reliability statistics were used to analyze the ratings of the factors for assessing awareness and preparedness levels of the respondents.

3.2.1. Severity Index

A non-parametric technique widely used by engineering and technology management researchers for analyzing structured questionnaire response data involving ordinal measurement of attitudes is the relative index ranking technique (e.g. Olomolaiye et al., 1987; Bubshait and Al-Musaid, 1992; Proverbs et al., 1997). One form of this, the severity index analysis (Elhag and Boussabaine, 1999), uses weighted percentage scores to compare the severity of the factors under study. Severity index was used to rank the factors for assessing awareness and preparedness using frequency and severity index analyses. In this procedure, frequency analysis was first carried out to determine the frequency of response of different selection factors. These are then used to calculate severity indices by means of the formula:

$$\text{Severity Index} = [\sum \boldsymbol{w}]/[\text{k}\times\text{N}] \times 100\%$$

The Index ranges from zero to one ($0 \leq \text{index} \leq 1$) and is multiplied by 100 to transform it to percentage, where $w =$ weighting given to each question by the respondents and ranges from 1 to 5 where 5 is Very Low and 1 is Very High. $k =$ highest weight (5 is the highest in this survey); $N =$ total number of respondents; $n_1 =$ number of respondents for not at all influential; $n_2 =$ number of respondents for slightly influential; $n_3 =$ number of respondents for Moderately influential; $n_4 =$ number of respondents for very influential; and $n_5 =$ number of respondents for extremely influential.

3.2.2. Reliability Test

Reliability is an important consideration in survey research method as it indicates how reliable a research instrument or method is. Though questionnaires are widely considered as some of the approaches used for collecting data in survey research method (Cohen and Manion, 1994), they are subject to measurement errors which could be systematic or random (Pett

et al., 2003). Systematic error consistently and predictably reoccurs on repeated measures of the same questionnaire under the same respondent conditions which affects the validity of the questionnaire. De Vaus (2002) pointed out that there are many methods of determining the reliability of measures which include the test-retest, internal consistency, parallel-forms, panel of judges' methods among others.

However, there is no single method that is appropriate for all situations. De Vaus (2002) however emphasized that when dealing with multi-item measures, the internal consistency measure is the best method to adopt as it does not encounter the problems of the test-retest method. The internal consistency of a questionnaire refers to how well the items that make up the questionnaire fit together (Pett et al., 2003).

If a given set of items are comparatively similar, it is likely that the correlations among the items that make up the set will be high and the questionnaire that contains these items will be considered as having a high internal consistency (Pett et al., 2003). The internal consistency measures indicate reliability using a coefficient ranging from 0 to 1; a higher value (0.7) of the coefficient indicates that the set of questions are highly reliable (De Vaus, 2002).

Cronbach's coefficient alpha is the most suitable and widely used internal consistency measures because the strength of the coefficient gives the most thorough analysis of patterns of internal consistency by examining how groups of variables are related to groups of other variables and the coefficient does not rely on just one split-half coefficient but on all the possible combinations of splits (De Vaus, 2002). Dewberry (2004) pointed out that Cronbach coefficient alpha of 0.7 is mostly considered as being the minimum level acceptable.

If the coefficient is less than 0.7, it signifies that the items are unlikely to be reliably measuring the same thing. A generally accepted rule of thumb for explaining internal consistency using Cronbach's coefficient alpha was provided by George and Mallery (2003 p. 231) as: Greater than 0.9 = Excellent; Greater than 0.8 = Good; Greater than 0.7 = Acceptable; Greater than 0.6 = Questionable; Greater than 0.5 = Poor; Less than 0.5 = Unacceptable.

4. SURVEY RESULTS ANALYSIS AND DISCUSSION

This Section is primarily concerned with the data interpretations, presentations of results and discussion of the survey findings. The survey data was analyzed by using two different computer packages: PASW Statistics 18 (Predictive Analytics Software) which was formerly known as SPSS Statistics 18 (*Statistical* Package for the Social Sciences) and Microsoft Excel windows application package. These packages were combined to complement each other and to facilitate analysis, interpretations and discussions of research findings. While the PASW was used to produce descriptive and inferential statistics, the Microsoft Excel was used to produce illustrative statistics.

4.1. Summary of the Questionnaires Returned

A total of ninety questionnaires were distributed to selected sample of built-environment experts in Dammam, Khobar, Jubail, Riyadh, and Jeddah. Thirty-six questionnaires were completed, received and analyzed for this study. A plausible explanation on why the entire completed questionnaires were useable was because the respondents are experienced. The thirty-six questionnaires returned represent a response rate of 40%, which is considered satisfactory for questionnaire survey.

Compared with other similar surveys in the areas of engineering and technology management, e.g. 21% by Proverbs et al. (1999), 30-40% by Aibinu and Jagboro (2002), 27% by Sodangi et al., (2014), the obtained response rate of 40% for this survey is considered to be very good. Measures of goodness or fitness of the data were conducted through Reliability test. Muijs (2004) and Hinton et al. (2004) pointed out that a test score of more than 0.90 is statistically considered excellent; 0.70- 0.90 is high, 0.50–0.70 is moderate while below 0.50 depicts a low reliability or validity rate of the variables.

4.2. Demographic Characteristics of the Respondents

In this part of the questionnaire, the questions were addressed to the respondents to obtain information on their respective profiles. Purposely, this part identifies the respondents' professions and level of professional experience. Figure 1 shows the distribution of respondents' professional background. It is clear from the table that the highest proportion of the

respondents is Architects (33%) then followed by Civil Engineers (25%). The Building and Construction Engineers and Facilities Managers make up the remaining 36%. By and large, the composition of these respondents indicates that theoretically, the chosen respondents have the competence to give reliable feedback to the questionnaires.

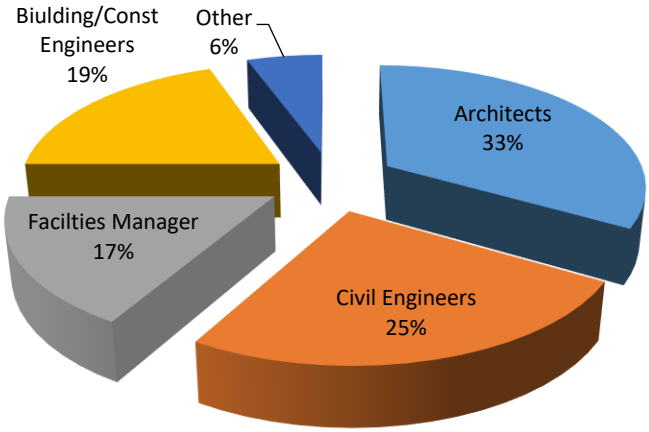

Figure 1: Distribution of Respondents' Profession

Figure 2 shows the distribution of respondents' professional experience. Remarkably, 25% of the respondents have over 20 years of professional experience while 17% have between 10 and 20 years. These results strongly indicate that a large proportion of the respondents have satisfactory professional experience to provide required information in highlighting the factors that influence the adoption of BIM in maintenance management of mosques in Saudi Arabia. Moreover, the respondents have the competence to give reliable feedback to the questionnaires and their responses are considered vital for this survey.

4.3. Determining Severity Index

Severity index was used to rank the factors influencing project performance using frequency and severity index analyses. In this procedure, frequency analysis was first carried out to determine the frequency of response of different selection factors. These are then used to calculate severity indices by means of the formula:

$$\text{Severity Index} = [\sum \boldsymbol{w}]/[k \times N] \times 100\%$$

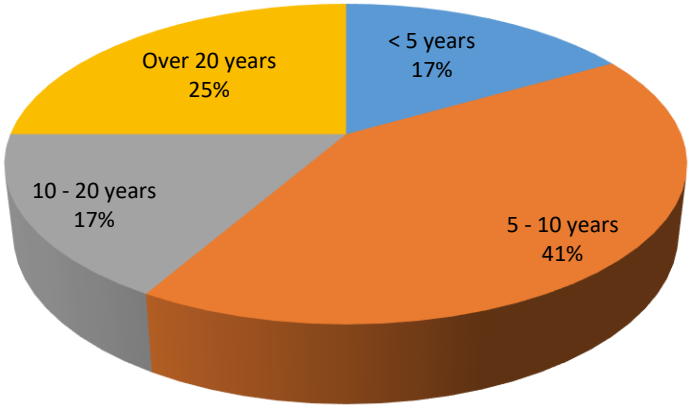

Figure 2: Distribution of Respondents' Professional Experience

The Index ranges from zero to one ($0 \leq$ index ≤ 1) and is multiplied by 100 to transform it to percentage, where $w =$ weighting given to each question by the respondents and ranges from 1 to 5 where 5 is 'extremely influential' and 1 is 'not at all influential'. $k =$ highest weight (5 is the highest in this survey); $N =$ total number of respondents; $n_1 =$ number of respondents for not at all influential; $n_2 =$ number of respondents for slightly influential; $n_3 =$ number of respondents for Moderately influential; $n_4 =$ number of respondents for very influential; and $n_5 =$ number of respondents for extremely influential.

Table 1 shows the summary of the severity indices and ranks for factors influencing the adoption of BIM in maintenance management of mosques in Saudi Arabia. Before now, Idrus (2010) defined the severity index scale as: 40% and below - very low severity; 41 to 59% - low severity; 60 to 69% - moderate severity; 70 to 79% high severity and 80% upwards - very high severity. From the table, it could be seen that more than half of the factors have severity indices.

These high values of severity index indicate the high level of influence the factors have on adoption of BIM in maintenance management of mosques in Saudi Arabia.

Table 1: Severity Indices of factors influencing the adoption of BIM in maintenance management of mosques in Saudi Arabia

Factors	Symbol for Factors	*n*1	2*n*2	3*n*3	4n4	5*n*5	∑w	5 * N	Maximum Severity Index	Severity Index Threshold	Severity Index Obtained	Rank
Awarding maintenance contracts to unqualified contractors	A	3	12	0	24	120	159	180	1.00	0.70	0.88	5
Lack of technical background for maintenance personnel	B	0	0	0	48	120	168	180	1.00	0.70	0.93	2
Lack of clear consensus on how to implement or use BIM	C	3	6	9	12	135	165	180	1.00	0.70	0.92	3
Non-availability of as-built documents of the Masjids	D	0	0	0	72	90	162	180	1.00	0.70	0.90	4
Lack of awareness of BIM potential in maintenance	E	3	0	9	24	135	171	180	1.00	0.70	0.95	1
Cultural barriers toward adopting new technology for building maintenance	F	0	24	45	36	0	105	180	1.00	0.70	0.58	11
Takes longer time to development BIM Model of the existing Masjid	G	3	6	18	36	75	138	180	1.00	0.70	0.77	7
Nonchalant attitude towards mosque maintenance	H	0	30	27	48	15	120	180	1.00	0.70	0.67	9
Not usually required by mosque custodians	I	3	12	9	12	90	126	180	1.00	0.70	0.70	8
Insufficient information on past maintenance records	J	3	6	18	12	105	144	180	1.00	0.70	0.80	6
Low level awareness of the heritage values of the Mosques	K	3	6	0	84	15	108	180	1.00	0.70	0.60	10

A closer look at the table would show that the maximum severity index obtainable is 1.00 while 0.70 was set as severity index threshold. This is in accordance to the interpretation of severity index scale given by Idrus as mentioned earlier, where high severity index starts from 70% - 100% i.e. 0.7 – 1.00. While Table 1 provides details about the severity indices and ranks of the factors, Figure 1 on the other hand provides a clearer picture of the factors that have high severity and those that have otherwise.

From the polar graph (Figure 3), it could be observed that only Factors F, H and K have their connecting points within the smaller (inner) polygon, which indicates that these factors do not have high severity. The boundary of the smaller (inner) polygon was taken as the severity index threshold i.e. the starting point at which severity level is regarded as high. Any connecting point above this boundary is considered high severity while below indicates moderate or lower severity. The portion in-between the boundaries of the smaller (inner) and bigger (outer) polygons represents an area with high severity.

Any factor that has its connecting points within this portion is clearly marked as a high severity factor. Similarly, a factor that has its connecting point close to the boundary of the bigger (outer) polygon will always have a very high severity index usually around 0.90 and above. Thus, the factor requires close attention by the relevant stakeholders concerned. Based on this clarification, it can be easily deduced now from Figure 1 that all the factors with the exception of F, H, and K have high severity indices.

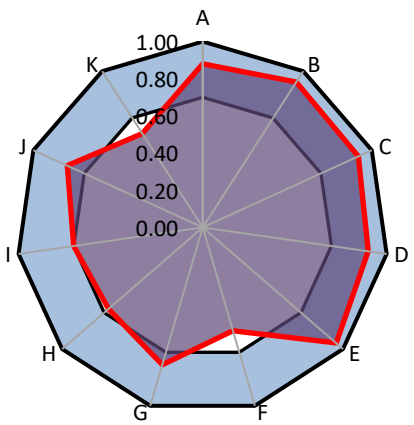

Figure 3: Distribution of Severity Level of factors influencing the adoption of BIM in maintenance management of mosques in Saudi Arabia

As expected, among the top most severe factors that influence the adoption of BIM in maintenance management of mosques in Saudi Arabia as obtained from the respondents are Factor E – 0.95 (Lack of awareness of BIM potential in maintenance), Factor B – 0.93 (Lack of technical background for maintenance personnel), Factor C – 0.92 (Lack of clear consensus on how to implement or use BIM), and Factor D – 0.90 (Non-availability of as-built documents of the Masjids).

The lack of awareness of BIM potential in maintenance is indisputably the top most rated factor that influences the adoption of BIM in maintenance management of mosques in Saudi Arabia. This is not surprising to consider the fact that even in the main stream construction industry, the level of awareness for BIM adoption in the Kingdom's construction industry remains very low let alone its adoption in building maintenance management.

Sodangi et al. (2015) reported the serious low level of BIM awareness among construction companies in Saudi Arabia highlighting that only some few 'big' construction companies use BIM in their major construction projects. Even in these, the usage is usually restricted to the most elementary functions. This suggests that BIM application in the Kingdom's construction industry is, to some extent, done without much experience. The authors further highlighted that many construction companies in the Kingdom do not use BIM in their projects and are actually lagging behind due to lack of awareness and guidance.

Although the adoption of BIM in construction industry is currently accelerating rapidly in some developed economies, the focus still remains strongly in the design and construction processes. Since the early introduction of BIM, it has been claimed that BIM would bring significant benefits to building maintenance management.

However, most of the documented, quantifiable benefits of BIM are related to design and production of buildings and there is relatively little hard evidence of BIM benefits in operation and maintenance activities. Even most large project owners in the US who have been early adopters of BIM, have used BIM more in managing their construction projects than implementing for their maintenance management activities.

The other most rated factor by the respondents is "lack of technical background for maintenance personnel". This is quite logical in the sense that

most custodians of masjids responsible for managing the maintenance of the masjid buildings in the Kingdom have no technical background. This makes it difficult to consider adopting technology especially BIM in taking care of the buildings.

Maintenance personnel with sound technical background and ability to apply modern information technology in maintenance management of masjids would not find much difficulty in utilizing BIM in managing the maintenance of mosques. Other top rated factors with extremely high level of severity include “lack of clear consensus on how to use BIM” and “non-availability of as-built documents of the mosques”, which require close attention of all stakeholders involved in mosque maintenance management. As a matter of urgency, a framework for full utilization of BIM in mosque maintenance management should be prepared to provide guidelines to mosque custodians and maintenance personnel to efficiently maintain the mosques in their care.

4.4. Reliability Test

Table 2 displays the overall Cronbach’s alpha obtained from the reliability analysis. As the results show, the overall Cronbach’s alpha for the eleven items is 0.85, which is considered ‘excellent’ by George and Mallery (2003) and indicates very strong internal consistency among the nine items. In essence, this means that respondents who tended to select high scores for one item (factor) also tended to select high scores for the others.

Similarly, respondents who chose low scores for one item (factor) tended to select low scores for the other items (factors). Therefore, knowing the score for one item (factor) would enable accurate prediction of the scores for the other items (factors). However, this ability to predict scores from one item (factor) would not be possible when the Cronbach’s alpha is low.

Table 2 Reliability Statistics

Number of Items	Cronbach's Alpha
11	0.85

As in any research work based on surveys, the study is subjected to certain biases and limitations. Bias is any influence, condition or set of conditions that singly or together distort the data from what might have been obtained under the condition of pure chance.

Bias may arise in all stages of surveys - designing the questionnaire, selecting the sampling frame, selecting the sampling method, and selecting a suitable sample size (Leedy, 1989, p. 213). The use of judgmental sampling method in selecting the sample helps to reduce bias by offering the researcher some degree of control.

As it was a structured questionnaire survey, the assessment of the factors was restricted to only the selected respondents. Although the sample size may seem small, this study provides valuable information that can be used in highlighting the critical issues that require urgent attention in adopting BIM for maintenance management of mosques.

Despite the above limitation, the authors are of the opinion that the severity of the factors influencing the utilization of BIM in maintenance management of mosques in the ranking order obtained from this study, adequately represent the views of the stakeholders in the Saudi construction industry.

5. CONCLUSION

Following a desk study and interviews on factors that influence the adoption of BIM in maintenance management of mosques in Saudi Arabia, eleven key factors were identified as being related to the subject under study. A structured questionnaire survey was conducted across the construction industry to obtain data for the subject under study. Altogether, thirty-six questionnaires were returned fully completed, representing about 40% of the original number distributed and considered to be a very good response rate.

A non-parametric method was used to analyze the data and from this, a consensual ranking of the factors was produced. The study has shown that the questionnaire survey is an effective instrument for determining the extent to which the pre-determined factors influence the adoption of BIM in maintenance management of mosques in Saudi Arabia, as evident by the ranking produced by the severity index analysis, and supported by the reliability test that have been applied.

The severity indices of the factors reveal that “lack of awareness of BIM potential in maintenance”, “lack of technical background for maintenance personnel”, “lack of clear consensus on how to implement or use BIM”, “non-availability of as-built documents of the Masjids” were the most critical

factors that affect adoption of BIM in maintenance management of mosques in Saudi Arabia.

As a matter of urgency, a framework for full utilization of BIM in mosque maintenance management should be prepared to provide guideline to mosque custodians and maintenance personnel to efficiently maintain the mosques in their care. It is expected that findings of this paper could help towards preparing an integrated BIM-based Maintenance Management Model for Mosque buildings.

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METAMORPHOSIS OF MOSQUE SEMIOTICS FROM SACRED TO SECULAR POWER METAPHORISM

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Abstract

Compared with its status in Islamic history as portrayed by early Muslim historians, the mosque today has become a distinctive phenomenon, perceived as an identity vessel of contemporary Islamic architecture that conveys sacred metaphysical meanings. Several factors, as scrutinized in this paper, contributed to this change. Following a western style-type methodology of inquiry, mosques as religious/ sacred architecture corresponding to churches in western architecture received particular significance. Their history, formation, elements, geometry, and ornaments were extensively scrutinized.

Since the advent of modernity in the Islamic world with its supremacy of rationality and renunciation of the metaphysical, Muslim societies have become increasingly secularized; hence, the relationships of the sacred-secular and the divine based-demythologized knowledge have been deformed. The mosque was glossed over as the sole contemporary sacred Islamic edifice that bears metaphysical/ religious connotations with cultural continuity, however, in an altered sense. Its architecture, meanings, function and uses have gone through a process of metamorphosis, particularly the State mosque. The contemporary mosque as such is facing a "semiological deterioration."

The function, connotation, and uses of contemporary State mosques (such as Mohammad Ali mosque in Cairo (1828), Hassan II mosque in Casablanca- Morocco, the Grand Mosque in Kuwait, Sheikh Zayed Grand mosque in Abu Dhabi, King Hussein mosque in Amman-Jordan, among others) for purposes other than worship reveal evidence of a collapse of the traditionally accepted mosque semiotics. They are in effect symbolic statements and communicative messages of their rulers' power and national sovereignty, with a subsidiary role for worship. As such, contemporary State mosques have given precedence to the secular political connotations over the sacred religious ones, where the inherent sacredness in such grand mosques is used as a symbolic tool representing the state power and authority; i.e. the sacred has turned into a secular power-metaphor. This led to a state of mosque semantic confusion, or what can be referred to as a "crisis of meaning," accompanied by a loss in the deeply-rooted collective cultural codes of the sacred.

This paper investigates the metamorphosis that took place in the semiological connotation of the contemporary mosque, with a special focus on grand State mosques, and its effects on the architecture of the contemporary mosque.

Keywords

State mosque, semiotics, sacred-secular, power metaphor, symbol, sign.

التغير في مدلولات المسجد المعاصر
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المستخلص

لقد أصبح المسجد اليوم بخلاف وضعه في التاريخ الإسلامي ظاهرة معمارية ذات معالم مميزة. إذ ينظر البعض للمسجد على أنه رمزاً ومعلماً رئيسا من رموز العمارة الإسلامية وممثلاً لهويتها المعاصرة التي تتضمن في ثناياها معاني ميتافيزيقية دينية. فمنذ انتشار الحداثة في العالم الإسلامي تحولت المجتمعات الإسلامية إلى مجتمعات ذات صبغة لادينية (secular)، ولم يعد البعد الديني (sacred) يشكل المحرك الأساس لنظام حياتها ما أدى إلى تغير جذري في العلاقة بين الديني-اللاديني في هذه المجتمعات. وقد صاحب هذا التغير في مفهوم "الديني" تغيراً في رموزه ومدلولاته كيفية التعبير عنها وقراءتها. فظهر المسجد بأثر ذلك كالمبنى المعاصر الوحيد الذي يحمل دلالات ميتافيزيقية دينية ولكن بصبغة معاصرة. لذا تم التركيز على عمارته حتى تحول إلى مبنى صرحي مميز، كما هو الحال في العديد من مساجد الدولة في العالم الإسلامي. بذلك وفي ضوء تغير الرموز الدينية الموروثة codes في المجتمع، فإن المسجد المعاصر يشهد نوعاً مما يمكن تسميته بالتخبط السيميائي أو تخبط المدلول.

إن التغيرات الحديثة في وظيفة، ودلالات، واستخدامات مساجد الدولة المعاصرة (مثل مسجد محمد علي في القاهرة (١٨٢٨)، مسجد الحسن الثاني في الدار البيضاء المغرب، المسجد الكبير في الكويت، مسجد الشيخ زايد الكبير في أبو ظبي، مسجد الملك حسين في عمان - الأردن) لأغراض أخرى غير العبادة إنما تشكل دليلاً على انهيار السيميائية المؤسس لها ثقافياً في المجتمعات المسلمة التقليدية. إذ تتضمن عمارة مساجد الدولة المعاصرة رموزاً لدعم السلطة الحاكمة والهوية الوطنية (ذات الرمز الديني)، مع دور ثانوي للعبادة. أي أنه تم استخدام الرمز الديني لدعم أغراض ورموز لا دينية، فتم بذلك تغيير طبيعة العلاقة بين الديني واللاديني في المجتمات المسلمة المعاصرة، ليحل الأخير في الأولوية مكان الأول ويكون وسيلة لإظهار الأخير ما أدى إلى حالة من الإرباك السيميائي أو ما يمكن تسميته ب "أزمة المعنى."

تبحث هذه الورقة في التحول الذي حصل في مدلولات المسجد المعاصر بأثر التغير في مفهوم "الديني" وما ارتبط به من تأسيس لرموز ثقافية جديدة في المجتمعات المسلمة، وأثر ذلك في تطور عمارة المساجد المعاصرة، مع التركيز بشكل خاص على مساجد الدولة الكبرى.

الكلمات الدالة

مسجد الدولة، المدلول، الديني-اللاديني، دلالات القوة، التمثيل، الرمز.

1. INTRODUCTION

Compared with its status in Islamic history as portrayed by early Muslim historians, the contemporary mosque has witnessed substantial metamorphosis, especially in its role, function, meaning, architecture and style. It has become today a distinctive architectural phenomenon of remarkable significance and value, perceived as a visual symbol and identity vessel that conveys metaphysical meanings. This is related, as this paper argues, to changing the perception of the "sacred" in Muslim societies and its relationship with the "secular." Many grand mosques have been built accordingly as iconic architecture, particularly State mosques. Such a metamorphosis altered mosque's semiology, and consequently, people's related collective memory.

This paper investigates the metamorphosis that took place in the concept of the sacred and its impact on changing the status of the mosque, its semiological connotation and expressive forms, with a special focus on contemporary grand State mosques.

Starting from the Prophet's mosque in Medina, the importance of the mosque, as revealed in early Islamic history books1, was attributable to its role and function as a place of worship and a political, social and economic center. Adoption and conversion of pre-Islamic temples into mosques such as the Umayyad mosques in Damascus, Homs and Aleppo indicate that mosques existed to accommodate certain uses and functions with no special value given to its architecture.

This fact is evident in many historical and geographical records of Muslim cities where mosques are mentioned with reference to their function and the events that took place in them and not to their architecture or building style.2 Al-Istakhri (d. 957 AD), for example, in his book Masalik Almamalik, described Istakhar city as: "one of the oldest and most famous cities in Faris; it is the seat of Faris's king, and it has a mosque ….". The mosque in this case existed in a major city; however, it was mentioned in a flat manner, with no reference to its architecture. This implies that it was an ordinary building with no iconic distinctiveness.

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1 Such as Al-Baladhuri, Attabari, al-Maqrizi, and Al-Maqdasi.

2 With the exception of some eras in Islamic history where mosques constituted a political symbol of power, marking a new era of mosque architecture.

In the middle ages of Islamic history, the mosque experienced progressive reduction in its status as a prominent public and political facility in the city; it lost its political value and became merely a sacred worshipping and social place. This was due to the emergence of the palace as a secular political center as well as the differentiation of functions which resulted in the emergence of new related building types such as the madrasa.

Today the role and architecture of contemporary mosque, compared to its status in early Islamic history, went through substantial metamorphosis. It lost its political and social role completely to become merely a sacred worshipping place; however, its architecture became remarkably prominent. It turned into a contemporary iconic building type that connotes visual symbolism. But why did such a metamorphosis occur? How did it affect people's perception and collective memory of mosques? And does this metamorphosis yield to establishing a futurist heritage of mosque architecture and semiology? Some of the reasons for such a metamorphosis are explained next.

2. HISTORIOGRAPHY OF ISLAMIC ARCHITECTURE: EUROCENTRIC MODEL

Historiography refers to "the study of the way history has been and is written – the history of historical writing." It refers to "the study of the methodology of historians in developing history as an academic discipline" (Wikipedia). The field of historiography has developed in the West in the 19th century into a mature, authoritative and dignified field. However, disregarding all sources of Islamic historiography as those exemplified by Ibn Khaldoun, orientalists in their studies of Islamic history (in the 19th c.) employed the Europocentric paradigm of historiography, a matter that impacted such studies to be profoundly modelled after their Western counter-studies epistemologically; in terms of approaches followed, themes discussed and methodologies adopted (Allahham, 2004). Islamic history as such was identified as following a linear chronological progression, divided according to the western concept of historical periodization into successive rigid dynasties (e.g. Caliphs, Umayyad, Abbasid, etc.).

Likewise, "Islamic Architecture" (as named by orientalists) was perceived as a non-western, culturally-specific architecture with religious self-identification. As an architecture associated with Islam, and in analogy with Western historiography of architecture, mosques as absolutely religious/

sacred buildings related to Islam corresponding to churches in western architecture received special significance.

Architecture historiography, as distinguished by Leach (2010), has several approaches to reading history: style and period, biography, geography and culture, type, technique, theme and analogy. Complied with the same sequential periodization of Islamic history, orientalists classified Islamic architecture according to the western-centered “style and period” approach with reference to the successive Islamic political dynasties. They set forth the present widely accepted terms of style/period-related architecture such as Umayyad architecture, Mamluk architecture, Ottoman architecture, and so on, where each term refers to a distinct architectural style within a linear chronology. In that respect, mosques were studied following the “building type” approach as an architectural building-type (sacred) marked by dynasty (period)-related style (Mamluk mosque, Fatimid mosque,).

Thus, they were examined as having conceptually comparable attributes of Western architecture. Despite their traditional settings as entirely intermeshed within Muslim cities and societies, mosques were studied as architectural objects detached from their surrounding environments; their genealogy, formation, elements, geometry, ornaments were extensively scrutinized.

In his book “Arabic Architecture and Monuments of Cairo” Pascal Coste (1818-1826) documented a selection of monuments from Cairo focusing on mosque architecture from the Mamluk period. Later on he designed two mosques in the style of Mamluk architecture in Cairo and Alexandria which were never built; however, they might be considered as new exemplar of historicizing Islamic architecture in modern times. Coste borrowed some distinctive elements from Mamluk architecture, which he employed in his designs (Rabbat, 2010). Ar-Rifai mosque in Cairo was built following the same perspective by the Hungarian architect Max Herz (1869-1912) in the style of the Mamluk Sultan Hasan mosque-madrasa in Cairo.

3. MODERNITY: DIVINE-BASED KNOWLEDGE VS. RATIONALITY

Since the advent of modernity in the Islamic world with its supremacy of rationality and renunciation of the metaphysical, Muslim societies became increasingly secularized; hence, their understanding of the inherited meanings

of Islam as a religion has changed, a matter that impacted the relationship between Muslims and their places of worship (mosques).

The once absolute authorities of religion are no longer the prime sources for one's self-identity. The so- called "end of history" or the "end of grand meta-narratives" initiated by modernity have disturbed the deeply-rooted traditional relationship of the sacred-secular, bringing about new critical formations. Several factors have led to such metamorphosis.

Two types of knowledge prevailed in Muslim societies can be discerned as: the "divine-based" knowledge existed in Islamic history based on Islamic divine principles and value-system, and the desacralized knowledge namely "rationality" emerged in the modern era, based on scientific reasoning. With the prevalence of the divine-based knowledge in early Muslim societies, the sacred (holy) quality or value was an innate part of society's nature; since it pervades all dimensions of life, it has been accepted and practiced by Muslims instinctively as part of the religion.

Hence, the power of the sacred was the dominant component of the cognitive map of Muslim community. Art (and architecture) in that context, as Nasr contends (2006), was related to the necessities of life and spiritual needs of the user; art was produced not for art's sake but for the sake of life itself. "Art in fact is none other than life, integrated into the very rhythm of daily existence and not confined to the segregated space of museums or rare moments of the annual calendar …In a traditional civilization, … there is no distinction between the sacred and the secular both of which are embraced by the unifying principles and share the symbols of the tradition in question" (p.178).

With the dominance of modern rationality promoted by capitalism and colonization over the past divine-based knowledge in Muslim societies, the dichotomy of the sacred-secular emerged, leading to normalizing the secular (anti-traditional) at the account of the sacred which lost its authorities in Muslim societies and withdrew to the private domain to reside in worship places only (mosques).

This resulted in diminishing the power of the sacred and the preeminence of the power of the secular, causing a loss of the deeply rooted cultural codes and creating a sematic confusion in the perception of the sacred, thus reshaping Muslim community's collective memory following the new secular-based system of semiology. Since the first quarter of the 20th century, such a disturbed relationship between the sacred and the secular became a

subject of interest in the academic comparative study of religions (Britannica online).

In that perspective, the mosque today, categorized as "religious architecture" as opposed to "non-religious" architecture of modern times, became the sole contemporary sacred Islamic edifice that bears metaphysical/ religious connotations with cultural continuity. In this context, "religious architecture" is typified to be devoted to religious themes and functions. However, employing such a modern expression of "religious architecture" to describe contemporary mosques has its limitations. It is appropriate as a category only in the context of modernism where architecture of everyday life is produced based on desacralized knowledge of rationality and is considered part of the secular.

This very term embodies a declaration of the eclipse and confinement of religion into limited domains where it can be practiced and celebrated. In reflection of the disturbed sacred-secular relationship, the mosque's architecture, function, uses and meaning in Muslim societies have gone through a process of metamorphosis; from a main public edifice into merely a worshipping place that has no substantial role in people's lives except for performing prayers.

Although traditional mosques maintained a central role in Muslim societies, they function today as sacred places detached from their secular surroundings. In this respect, Nasr (2006) differentiates between contemporary mosques' non-traditional religious architecture and "sacred architecture" of traditional times. This affected the semiological connotation of the contemporary mosque as well as people's cognitive perception of the concept of the sacred per se. This is particularly epitomized in contemporary grand mosques, specifically State mosques.

4. THE SACRED-SECULAR RELATIONSHIP: THE METAMORPHOSIS

Early mosques, beginning from Prophet Mohammad's mosque in Medina, were built in a very simple form: prayer hall with adjacent court built, as in later mosques, in the same ordinary architectural style and with building materials prevalent in society. However, they embodied a transcendent sacred character that was accepted and shared by all members of the Muslim community. In a sacred-based society, the sacredness of the mosque was but a part of the intrinsic concept of the sacred prevailed in the Muslim society, which contributed to shaping its solidarity and collective memory.

Authentically, sacred places ought to have had the power to evoke an effective response, and many sacred places do it precisely.

The sacred then maintained its authority and power over secular in Muslim societies where all aspects of life were governed by sacred principles; however, the sacred was in many cases manifested in a secular guise such as ideas, symbols and edifices. The mosque, as a manifestation of the sacredness, became sanctified over time, gaining special sacred significance, not because of its architectural style or form, but because of the many functions it delivered for believers.

The sacred action of prayer and worship in the mosque establishes the relationship between sacred (divine) and secular (human world). As Otto and Van der Leeuw stated, the forms (part of which is the mosque) through which the sacred is expressed are secondary and are simply reactions to the sacred (Britannica Encyclopedia online, 2016). Mosque architecture as such can be viewed as a secondary secular expression of the metaphysical quality of the sacred; therefore, at early Islamic times, not much attention was paid to its aesthetic qualities and style.

At the time when Muslims attempted to establish their distinctive identity from people of other religions, they used many architectural elements from previous civilizations in their mosques, a matter that indicates that early mosques' architectural style was of marginal importance. This connotes that places are sacred because of the religious functions they perform, and not because of the peculiar physical or aesthetic qualities they have.

Today, amid a secular culture and the confinement of the sacred within particular spaces and symbols, the distinction of mosque as a sacred space and its reference to the ultimate context of the culture are often expressed in the conviction that sacred space is not arbitrary. It is, as Brereton asserts, objectively "different from the surrounding area, for it is not a place of wholly human creation or choice. Rather, its significance is grounded in its unique character, a character that no purely human action can confer on it" (Brereton, 2005).

This shift in modern consciousness regarding the sacred, represented in Brereton's and some other scholars' viewpoint, establishes what might be considered as, in contrast to its traditional perception, the modern perception of the mosque as a distinctive sacred space, separated from its living surrounding. It embodies a metamorphosis in the meaning of the sacred per se. The tradition articulated by Friedrich Schleiermacher and developed by

Rudolf Otto links the perception of holiness to religious emotions. This view of the sacred space as a lens for meaning led to exploiting the architecture of the mosque to convey certain (political in many cases) connotations and symbols as the case in many contemporary grand state mosques. The contemporary mosque as such is facing what can be depicted, using Arkoun's words (1994), a "semiological deterioration."

5. GRAND (STATE) MOSQUES: CHANGING SEMIOTICS: FROM THE SACRED TO SECULAR POWER METAPHOR

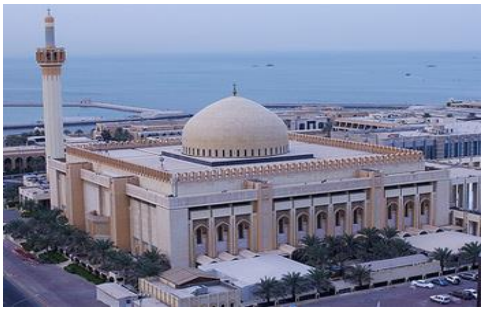
Starting from the Umayyad era, the relationship between politics and architecture has been evident. Powerful leaders and ruling regimes have used the built environment as an expressive form of power and authority. However, since the culture was sacred-oriented, manifestations of such acts were directed towards secular buildings; therefore, the concept of the ruler's palace as a secular building emerged, followed by establishing new cities with names of their rulers, such as Wasit city of Al-Hajjaj, Baghdad of Al-Mansour, Samarra of Al-Mutasim and Al-Mutawakiliyyah of Al-Mutawakkil.

This trend is reversed today. That is, in a secular culture, expression of power and identity is transpired within sacred buildings, mainly mosques. Put differently, we can think of the culture as having two layers, sacred and secular; if one layer is strong, power as a secular capitalist entity is manifested in the built environment through the other layer. As such, the sacred-secular inclination of the culture has a converse relationship with the sacred-secular type of edifice that acts as a physical sign vehicle for expressing power. Today this is very clear in grand state mosques.

Building mosques with impressive monumental architectural images (such as the Grand Mosque in Kuwait City, King Hassan II Mosque in Casablanca, and Sheikh Zayed Grand mosque in Abu Dhabi (Fig.1)) to demonstrate the power of their rulers and support their regime through a representative image of national identity (of an Islamic stance) as a prime purpose with a subsidiary role for worship has become a prevalent phenomenon in many countries today. State mosques are grand structures commissioned by government authorities to express the state's commitment to Islam or to stand as a symbol of national purpose (Serageldin, 1990). Architectural iconism and monumentality is being sought by their patrons to distinguish them from the surrounding built environment.

King Hassan II Mosque in Casablanca

Sheikh Zayed Grand mosque in Abu Dhabi



The Grand Mosque in Kuwait city

King Abdullah Mosque in Amman, Jordan

Fig.1: Examples of State mosques.

This approach to mosque architecture started in the 19th century when the sacred was subjugated by secularism. In 1828AD, Mohammad Ali of Egypt sought to show his power through building a mosque in Cairo as prestigious as that of Ottoman sultans (Arkoun, 2002, p.270). Mosques in this category have been exploited for certain political ends.

These mosques are defiled of their true purpose; they in effect constitute symbolic statements of power and communicative messages of their rulers' power and national sovereignty rather than signs of piety. The state mosque can be seen, as Hold and Khan (1997) maintained, as one of the means by which legitimization of political authority occurs through reference to Islamic symbols. Although believers who perform prayers in such mosques are not in many cases aware of the real political message embodied in those mosques, it unconsciously affects their perception of the sacred.

By evoking the nationalistic (Islamic) emotions of the masses and maneuvering their sentiments, governments aim to maintain their status and position in society. In that respect, Lefebvre (2002) says that societies, namely the hegemonic class, produce their social spaces through which they

practice power. He states that "social space … becomes the metaphorical and quasi metaphysical underpinning of a society, by virtue of a play of substitutions in which the political realms symbolically (and ceremonially) exchange attributes- the attributes of power; in this way the authority of the sacred and the sacred aspect of authority are transferred back and forth" (2001, p.143).

Such a change in the function, connotation, and uses of contemporary state mosques reveals evidence of a collapse of the traditionally accepted mosque semiotics, demonstrating a semiological metamorphosis of contemporary mosque architecture. In semiological terms, the traditional mosque's signified denotative and connotative meanings were consistent; the former pertains to the function of the mosque as a common public and worship place, while the latter represents its sacred meaning as the house of Allah. This was reflected in the visual image of the signifier (physical architecture) which was of secondary significance compared to its signified feature.

However, in the contemporary secular culture the denotative meaning was reduced to the mosque's role as a worship place in which people can gather only at certain times, thus its denotative meaning has changed from being a place attached to people's lives uninterruptedly, into an as-needed place with limited role in people's lives, specifically worship.

The degraded denotative meaning of the contemporary mosque was compensated for by intentional new meaning. The mosque's connotative meaning as a sacred place was expanded and used to symbolize a higher level or "second order" (to use Barthes expression (Gottdiener, 1995) secular connotation.

The traditionally accepted sacred connotation of the mosque has been exploited as a sign vehicle to express the power of its patron or government and to promote an identity to support and legitimize their rule. This can be regarded as a simulacrum (a sign that refers to other signs), according to Baudrillard (1981). As such, contemporary State mosques have given precedence to the secular (simulacrum) political connotations over the

sacred religious ones, where the inherent sacredness in such grand mosques is used as a symbolic tool representing the state power and authority; i.e. the sacred has turned into a meta-cognitive (according to Barthes) secular power-metaphor. The simulacrum connotative layer is expressed through the signifier per se by means of its architecture as a communicative agent.

Architecture is used as an advertising sign of the secular politicization of the contemporary state mosque, repetitiously emitting cognitive messages of the patron's intentions to the worshippers.

This metamorphosis in the mosque's semiology has been intentionally naturalized and normalized in Muslim societies to become part of their cultural recognized codes. The contemporary mosque, hence, is facing a semantic confusion or what can be described as a "crisis of meaning," resulted from disturbing the deeply-rooted collective cultural codes of the sacred.

Accordingly, the conventional signifier-signified relationship of the mosque has been transformed. Although the signifier-signified elements of the traditional mosque had a reverse relationship with its sacred-secular character, today they have a positive relationship where the strength of the former is expressed through that of the latter; the more iconic the signifier, the more sacred it is.

Grand state mosque in most cases are consciously designed as impressive and identifiable edifices characterized by massive size and significant location, and are usually separated from their urban surroundings. Hence, with such physical characteristics, state mosques in most cases act as a distinct building type that is not integrated with the community it serves, a matter that leads to a breakdown in the inhabitants' physical relationship with their mosques. They are basically an expression of hegemony, conveying their patrons' political power and strength to the subject populace, to consolidate their authority. This metamorphosis has turned the signifier into an untruthful simulacrum, or what some refer to as a mosque of Dirar as opposed to the mosque of piety, as mentioned in Surat al-Tawba [9:107-109]:

> "*And [there are] those [hypocrites] who took for themselves a mosque for causing harm and disbelief and division among the believers and as a station for whoever had warred against Allah and His Messenger before. And they will surely swear, "We intended only the best." And Allah testifies that indeed they are liars [107] Do not stand [for prayer] within it - ever. A mosque founded on righteousness from the first day is more worthy for you to stand in. Within it are men who love to purify themselves; and Allah loves those who purify themselves [108] Then is one who laid the foundation of his building on righteousness [with fear] from Allah and [seeking] His approval better or one who laid the foundation of his building on the edge of a bank about to*

collapse, so it collapsed with him into the fire of Hell? And Allah does not guide the wrongdoing people" [9:109]

In the above verses, two types of mosques are distinguished according to the intention of their patrons, or semiologically, their higher order connotative meaning. As was the case in traditional mosques, the connotative meaning of the mosque should match straightforwardly with its worshipping purpose, i.e. its denotative and connotative meanings should be in line. If the connotative meaning deviates from the denotative meaning and embodies hypocrisy or a tendency to attain good reputation (untruthful simulacrum), as in many contemporary state and grand mosques, then, according to many Muslim scholars as Al-Qurtubi declared, consider it as Masjid Dirar that is not based on righteousness and piety.

6. CONCLUSION

The metamorphosis that the contemporary mosque is experiencing today as a religious edifice with symbolic connotations and architectural iconism is but an effect of the changes that occurred as a result of modernity in the concept of the sacred and its relationship to the secular in contemporary Muslim communities. Such conceptual changes led to altering the deep-rooted cultural codes to be replaced by new intentional codes, used today as icons of communication in mosque architecture. It's a mutual process; the contemporary mosque is affected by the changing cultural codes as well as it affects them.

In response to the secularization of contemporary Muslim societies, the sacred in many cases among which is the contemporary mosque is subjugated to the secular. The mosque today consists of two layers; the manifested layer which represents the visual signifier, and the embodied layer that represents the denotative and connotative meanings. Such a composition did not exist in traditional mosques; however, in contemporary mosques, the signified (secular) is prioritized to reflect the embodied layer.

The sacred part of the latter layer which lies in the denotative meaning is reduced to its function as a worship place, whereas the connotative higher order meaning is dedicated to serve as a secular metaphor (of power in state mosques). In that sense, what the audience receives as a sacred sign is a simulacrum, or an untruthful representation.

Despite the today's increasing concern and debates about the contemporary mosque and the several attempts to establish a contemporary

mosque architecture characterized by heritage continuity, the metamorphosis that occurred in the status of the contemporary mosque is apparently leading the future of mosque architecture. It is in fact leading, against the calls, to disruption with the Islamic heritage and yielding to establishing a futurist (new) mosque heritage. So how can the status of the mosque be recovered, yet maintain its continuity with its inherited heritage? This can be achieved, as suggested here, by reviving the sacred-secular relationship as existed in traditional Muslim communities, as the foundation of the contemp. mosque.

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THE IMPACT OF DOME SHAPE ON SPEECH TRANSMISSION INDEX (STI) IN MOSQUES

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Abstract

The curved roof surface of domes is one of the key landmarks in the architectural style of mosques, as most of the mosques in different eras have a unique centralized dome as part of the roof form and structure. Most of the contemporary mosques keep this unique feature as part of the design regardless of its acoustical effect, even though different solutions (such as amplifiers) exist to overcome the acoustical quality problems in the prayer hall. The sound quality in contemporary mosques varies according to many variables such as the geometric form of the building, the internal finishing materials and the roof shape. These three variables have a great impact on the sound quality which can be enhanced and have direct positive impact in case of accurate calculations and conscious design solution. The paper aims at defining the different variables affecting the acoustical quality in mosques and focuses on the effect of dome shape on the sound and energy distribution in the space. The acoustical quality is studied by using computer simulation, measurements and numerical calculations. Analytical calculations are performed to investigate sound ray reflections due to the dome geometry and proportions. The model analysis is based on the investigation of the Speech Transmission Index (STI) inside the prayer hall, which affects the prayers and Quran recitation. Finally, basic recommendations and design guidelines are presented.

Keywords

Speech Transmission Index, Acoustics of Domes, Acoustics in Mosques.

تأثير أشكال القباب علي معامل الإنتقال الصوتي داخل المساجد

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المستخلص

تعتبر القباب احدي العناصر المعمارية الهامة والمميزة للمساجد علي مر العصور، وهي احدي العناصر التي تكسب المساجد طابعا خاصا. وقد تنوعت اشكال وتصاميم تلك القباب علي مدار العصور المختلفة في الحضارة الاسلامية وتنوعت اشكالها لاسباب تشكيلية وأخري انشائية. وقد حرصت المساجد في العصر الحديث علي الابقاء علي هذا العنصر التشكيلي المميز بغض النظر عن تأثيرة الوظيفي علي الفراغات الداخلية خاصة فيما يخص البيئة الصوتية ومستوي جودة الصوت داخل المسجد والتي تتأثر بالعديد من المتغيرات الأخري خلاف القبة مثل شكل المسجد ومواد النهو والتشطيب الداخلية.

وتهدف هذه الورقة البحثية الي دراسة المتغيرات التي تؤثر علي جودة البيئة الصوتية داخل المساجد وخاصة القباب لما لها من تأثير مباشر علي شكل وتوزيع الموجات الصوتية في الفراغ الداخلي وما يترتب عليه من جودة البيئة الصوتية.

سيتم اجراء هذه الدراسة من خلال برامج المحاكاه والتحليل الرقمي، حيث يتم دراسة وتحليل القباب باختلاف اشكالها ونسبها وتأثيرة علي حركة الموجات الصوتية وخاصة معامل الانتقال الصوتي، وأخيرا سيتم اجراء هذا التحليل من خلال دراسة معامل الانتقال الصوتي في وضعين أساسيين: الأول هو وضع الامام أثناء الصلاة والثاني هو وضع الخطيب علي المنبر.

الكلمات الدالة

معامل الانتقال الصوتي، القباب والصوتيات ، الصوتيات داخل المساجد.

1. INTRODUCTION

A dome which is defined simply as “A hemispherical or semi-elliptical roof, built of stone, timber, metal or glass.” is considered one of the key features in Islamic architecture, especially in mosques. Many civilizations, prior to Islamic civilization, adopted the dome as a roofing method in their important buildings; for instance, the Romans used it in a monumental approach in the Pantheon, and the Byzantines used it to cover their monumental buildings.

The first domed building constructed in the Islamic civilization was the Dome of the Rock in Jerusalem (691). The dome was constructed from wood due to the practicality of using this material in churches previously. Wood made the dome structure lighter but had to be covered with copper or lead sheets for the shiny monumental appearance and protection from weather conditions (Avner, 2010). During the Fatimid, Mamluk and Ottoman eras, domes became the dominant feature in mosques, although it was also used in other public buildings.

When explicating the importance of domes in Islamic architecture, Grube (1995) wrote: “The dome appears to be a general symbol, signifying power, the royal city, the focal point of assembly; it can therefore serve both religious and secular purposes. Its outward visible appearance does not truly help us to understand, interpret or identify any building”.

Previously, domes were placed over the Mihrab in mosques to show the direction to Mecca. In later eras, the dome moved to the central position over the prayer hall, as seen in most mosques today. “The dome is, of course, a cosmic symbol in every religious tradition; and symbolically, in Islam the dome represents the vault of heaven in the same way as the garden prefigures Paradise” (Grube, 1995).

2. GEOMETRIC PARAMETERS OF MOSQUES

As worship spaces, mosques have basic common design elements. “Most of mosques have typically a simple rectangular form covered with a dome, walled enclosure with a roofed prayer-hall”. The long side of the rectangle is always oriented towards the holy mosque in Makka and to its right an elevated floor (Minbar) that is used by the Khatib (the scholar who gives sermons) to deliver the religious "Friday" speech preceding the prayers. Figure 1

illustrates congregation performing daily individual or group prayers listening to Friday speech.

The dome shape and finishing materials of mosques differ from one country to another. “Walls are sometimes covered with marble tiles or wooden boards or panels tongued and grooved to compose a vertical pattern” (Abdou, 2003). “The floor area is always carpeted. Plastered and painted concrete ceilings with simple to elaborate decorations and /or inscriptions are commonly used” (Abdou, 2003).

All these parameters directly affect the quality of the acoustical experience inside the mosques that could be measured in terms of characteristics such as clarity, reverberation time, speech transmission index, and so on. This research will study the Speech Transmission Index inside the prayer hall in relation to the dome form.

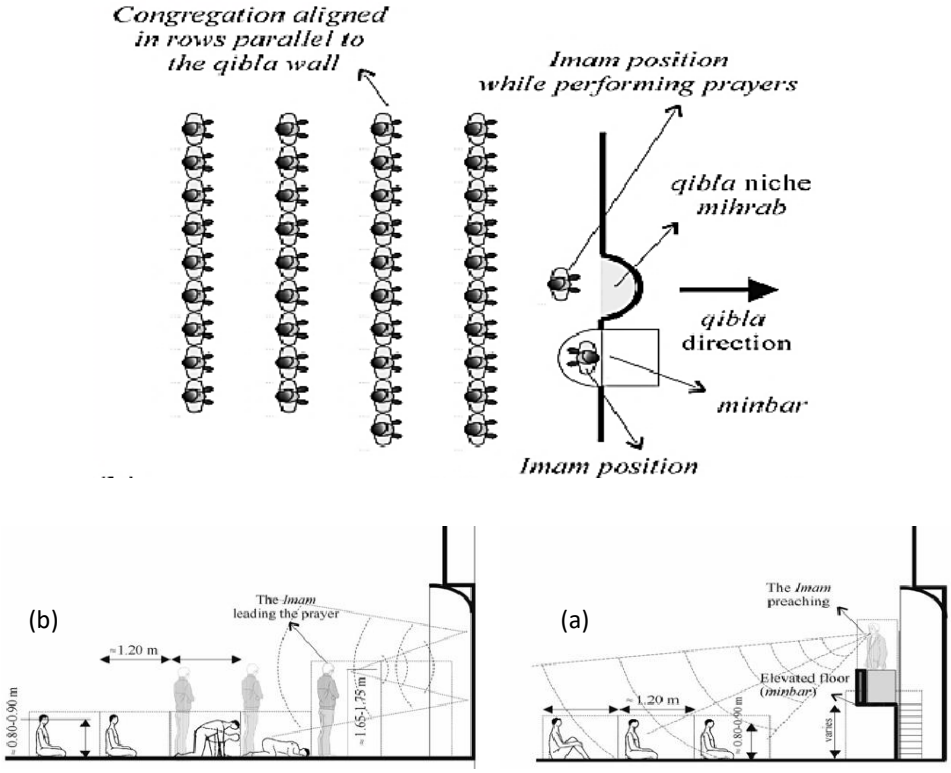


Figure 1: a) congregation performing daily prayers, b) congregation listening to Friday speech.

3. SPEECH TRANSMISSION INDEX (STI)

Speech transmission index (STI) is an objective criterion characterizing speech transmission. Loss of speech signal transmission is caused by reflections, interference and background noise (Golas, 2009). “To ensure good speech intelligibility, the envelope of the signal should be preserved, allowing the various frequency bands to contribute to speech quality” (Kuttruff, 1991). According to Barnett (1999), The STI reference value varies from 0 to 1 in the order of ‘bad’ to ‘excellent’ (Figure 2), and an STI of at least 0.5 is desirable for most applications.

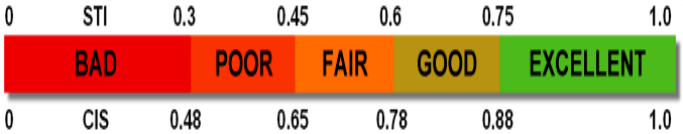


Figure 2: STI reference values according to Barnett 1999.

Measurements will be performed by using Bruel & Kjaer (B&K) speech transmission meter type 3361. The transmitter type 4225 will be located at the position of Imam (one who leads the prayer) on the Minbar, while the receiver type 4419 will be moved around, following the prearranged grid points.

4. RESEARCH METHOD

The main research aim is studying and exploring the effect of dome shape on the Speech Transmission Index STI in mosques. This aim could be achieved through computer in-situ measurements and simulations that were carried out by using ODEON Room Acoustics software, which was released by the Technical University of Denmark (Naylor, 1993). The calculation method of this software is based on prediction algorithms including the image-source method and ray tracing. “The ODEON Room Acoustics software also takes into account the statistical properties of the room’s geometry, materials and absorption” (Rindel, 2000). In this study, a 3D Model of the mosques with a dome was obtained by using CAD Software.

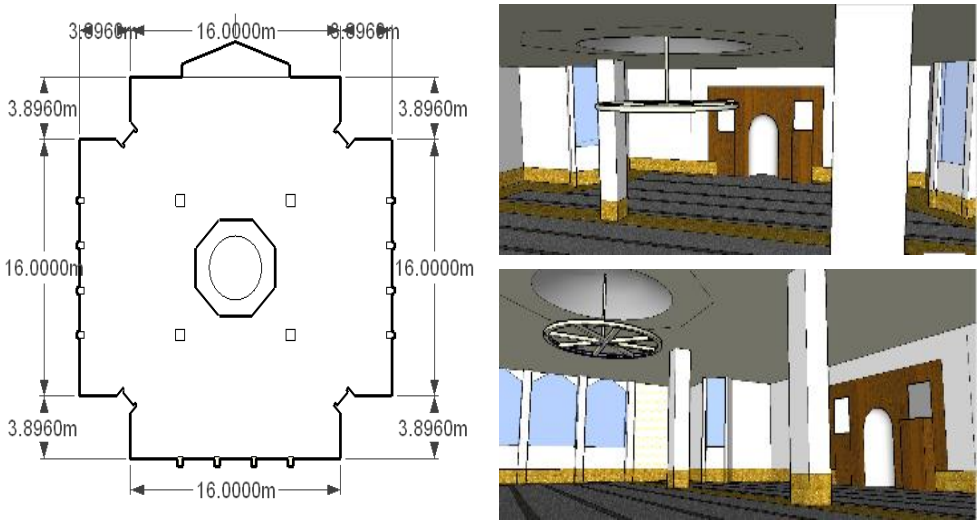
The model was imported to the ODEON Room Acoustics Program. Two point sources and receivers were specified for each activity; first source represented the Imam and second source represented the Khatib, which are activated depending on the activity. Different materials with different sound

absorption coefficients have been assigned. After selecting the calculation parameters, the receiver surfaces have been divided into grids surfaces (0.96 m2) for each person praying. To obtain the results of different acoustical parameters, the contour maps and cumulative distribution graphs for the calculated parameters have been obtained for all surfaces. This process was repeated and simulated in four different dome forms. Speech Transmission Index STI has been measured and simulated in the empty mosque.

The first activity indicated the prayer mode; for this, the source was the Imam at the Mihrab facing towards the Mihrab set at a height of 1.65m. The second activity was the preaching mode and the recital of the Holy Quran. The source was the Khatib at the Minbar facing the worshippers. The receiver height for this activity was the seating level, approximately 0.80m. For the two different activities, speech related parameters were analyzed.

4.1. Case study Selection

The computer simulation and measurements have been conducted on a typical mosque (Dammam University mosque in the old campus), by using various dome shapes. The size of the mosque corresponds to the community mosque with prayer hall area of 23 m × 23 m and ceiling height of 4.8m (Figure 3). For the simulation, the interior surface finishes of the Dammam University mosque were selected. The interior materials consisted of carpet and marble tiles for the main floor, painted plaster wall, glass with metal frames for windows and painted plaster for ceiling.



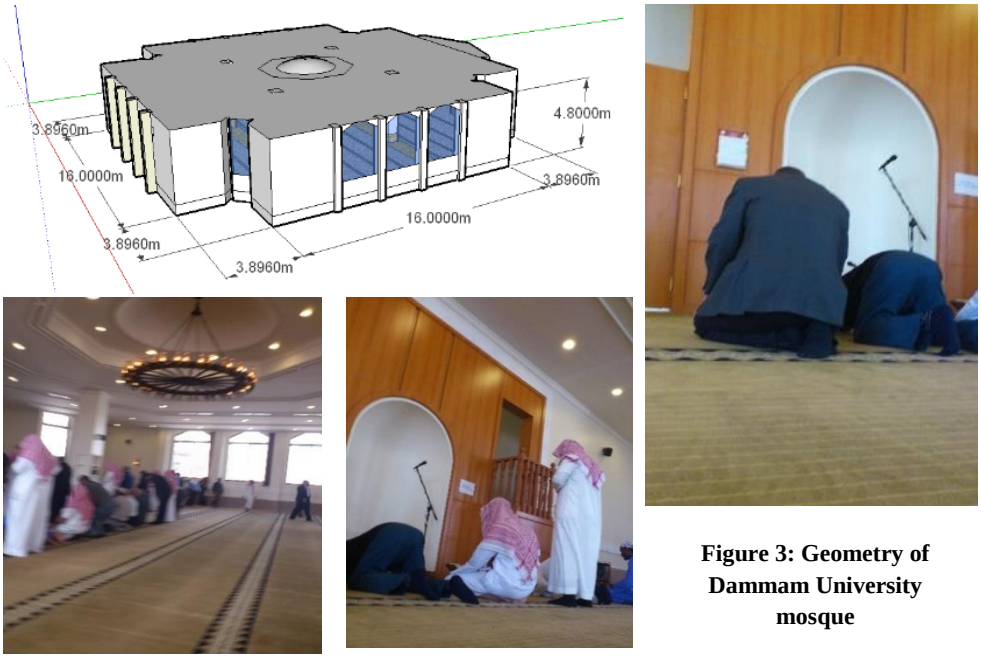


Figure 3: Geometry of Dammam University mosque

All walls are covered with marble of one-meter in height. The Mihrab wall is covered with wood. The absorption coefficients of used materials are presented in Table 1. As shown in Figure 4, there are four dome shapes to be used as parameter, which are considered the most popular domes in different mosques, comprising of: (a) Saucer dome, (b) Drum dome, (c) Onion dome and (d) Pointed dome. All domes have a 4m diameter and do not contain windows. The dome height depends on its shape.

4.2. Sound Source and receiver points

Two different scenarios were examined by the simulation and experimentation. The first scenario discusses the case where worshippers are performing the prayer behind the Imam. The Imam recites in a standing position facing the Qibla and uses a raised voice without using any Electro-acoustic sound system. “The background noise in the mosque is assumed to reach a Noise Criterion (NC) rating of NC30” (religion spaces).

The worshippers were assumed to be standing listening to the Imam as is usually the case during performing the “Daily” prayers. Their ear height was taken to be 1.65m from the floor. In the second scenario, the Khatib was

assumed to be delivering the Friday speech in a raised voice, without the aid of a sound reinforcement system, from the Minbar which is elevated about 1.25 meters from the mosque floor. The mouth height was around 2.80m from the floor. The worshippers were seated on the floor listening to the sermon during Friday prayer.

Table 1: Sound absorption coefficient in octave bands

Surface	Material	125 Hz	250 Hz	500 Hz	1k Hz	2k Hz	4k Hz
Walls 1m &Mihrab	Cladding of Marble Tiles	0.01	0.01	0.01	0.01	0.02	0.02
Walls	Painted plaster surfaces on brick	0.013	0.015	0.02	0.03	0.04	0.05
Floor	Carpet heavy on concrete	0.02	0.06	0.14	0.37	0.60	0.65
Corridors	Marble	0.01	0.01	0.01	0.01	0.02	0.02
Mihrab wall	8mm wood veneer on 50mm studs	0.28	0.22	0.17	0.09	0.10	0.11
Windows	Glass, ordinary glass window	0.35	0.25	0.18	0.12	0.07	0.04

Saucer dome Drum Dome Onion dome Pointed dome

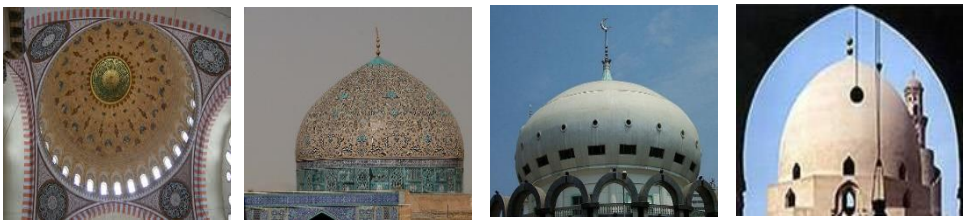


Figure 4: Four different principal domes.

Their ear height was about 0.80m from the mosque floor. Measurements and simulation have been realized when the mosque was assumed empty. Figure 5 demonstrates the positions of sources and receiver points (with 0.96m spacing) for all configurations.

Imam Position Khatib Position

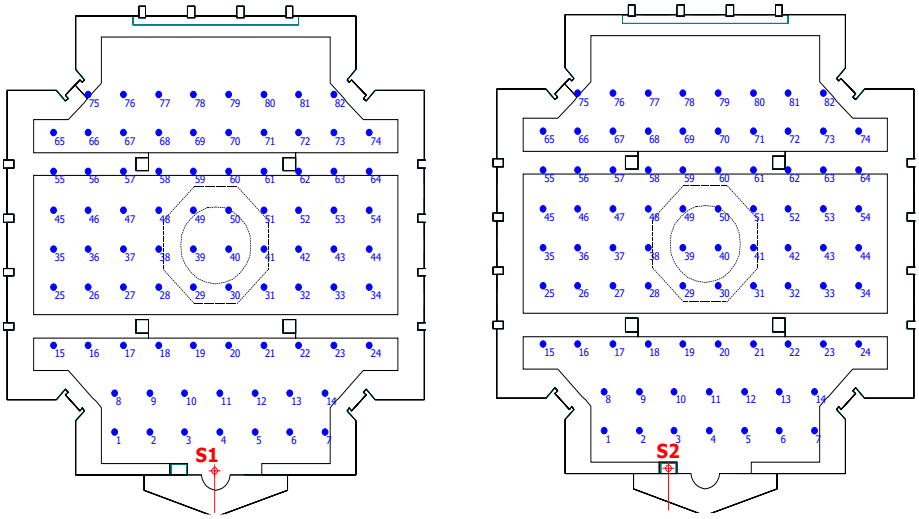


Figure 5: Sound Source and receiver points

4.1. Measurements process and outputs

The experimental results were obtained by using a measurement based on the mathematical impulse or Dirac delta function. DIRAC PC software was used for measuring a wide range of room acoustical parameters. Based on the measurement and analysis of impulse responses, DIRAC supports a variety of measurement configurations.

The acoustical parameters of the mosque have been measured by using the DIRAC room acoustics system, analyzer type 2250, a B&K power amplifier type 2734, a reference Omni Power Sound Source Types 4292 and ½ inch B&K microphone type 4134.

Measurements had been carried out, in octave bands, for the frequency range 100Hz to 8 kHz. The Sound source was positioned at the front of the mosque, at Imam and Khatib positions, and a sound level meter was moved, in turn, to each measurement position. DIRAC, running on a laptop, switches on the speaker test signal and instantly calculates the speech intelligibility and room acoustics parameter indices from the sound level meter microphone signal (Figure 6).

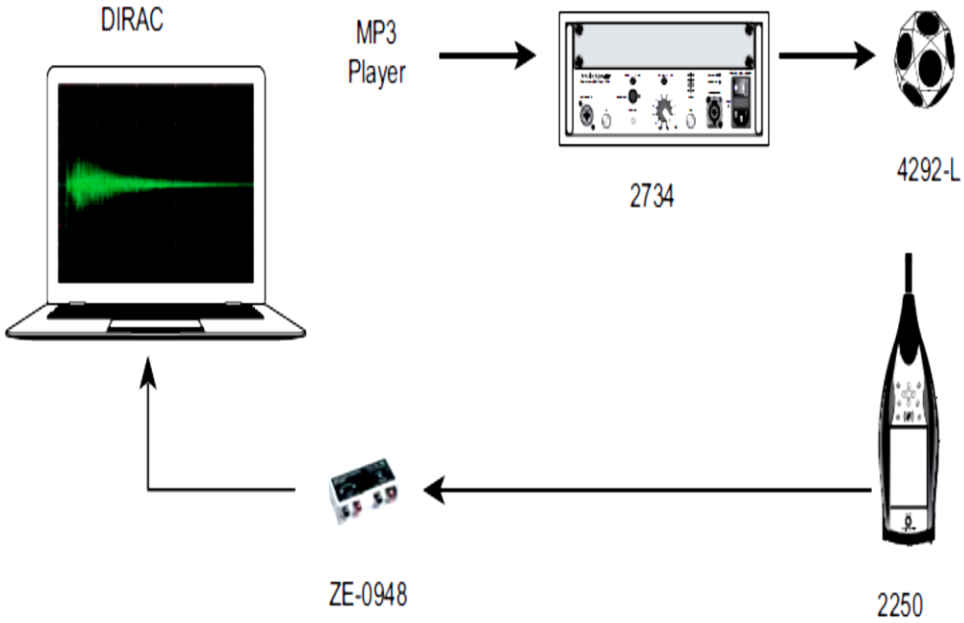


Figure 6: Measurements process and outputs

5. RESULTS AND DISCUSSION

5.1. STI measurement in Imam Position

The Speech Transmission Index is an objective, physical measure of speech transmission quality. The STI is a 0 to 1 index, indicating the degree to which a transmission channel degrades speech intelligibility. This means that perfectly intelligible speech, when transferred through a channel with an associated STI in 1, will remain perfectly intelligible.

The closer the STI value approaches zero, the more is the information lost. Speech Transmission Index (STI) for all domes as a function of the distance from the sound source is presented in Figure 7. For the first activity mode, STI is around 0.42, which is considered poor. The best values have been found at locations just around the source or Imam and at the 1st row where the STI is considered fair and good. In general, STI values obtained by the saucer and pointed domes are greater than those obtained by the drum and onion domes.

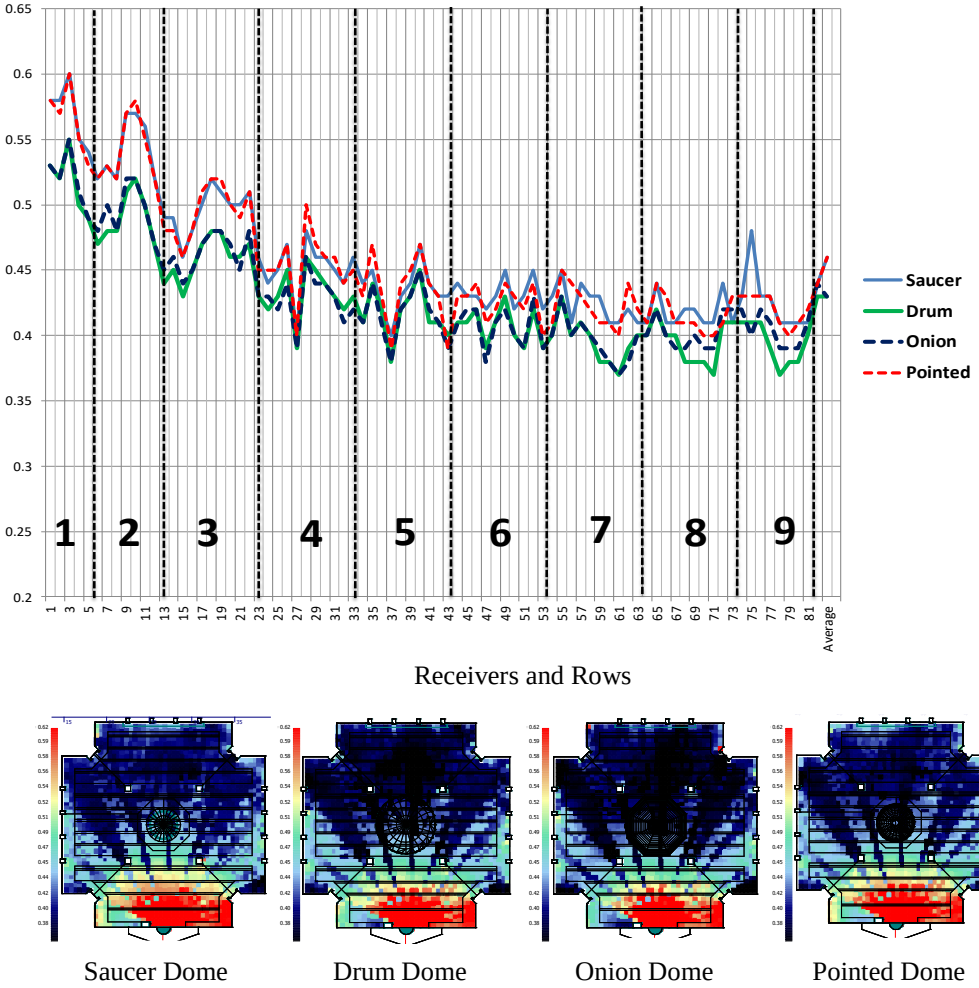
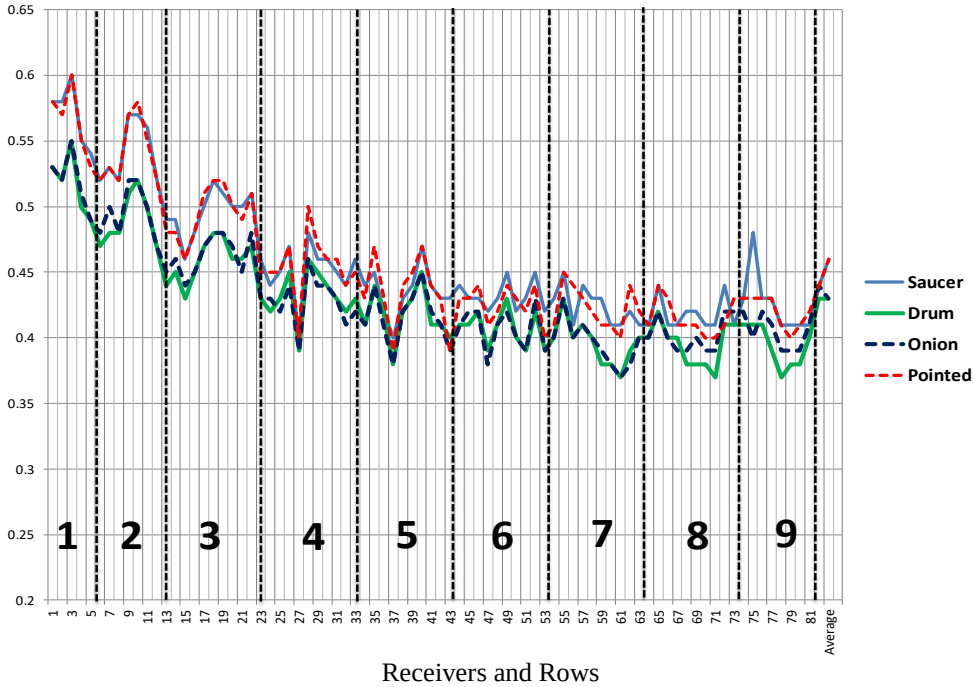
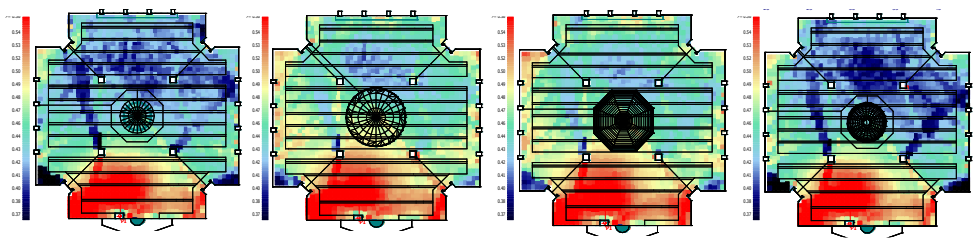


Figure 7: STI for the mosque at Imam Position, when the mosque is assumed empty

5.2. STI measurement in Khatib Position

As presented in Figure 8, STI ratings are indicated on the value colored scale bar in each case. The zones in the mosque which exhibited STI values less than 0.43 are the green and blue-colored grids. As can be seen, the zones of “Poor” STI rating are located in the center of the rear half of the floor area with some other “Poor” zones near the middle of the side walls, back columns zones and the far front corners. As the 1st scenario, STI values obtained by the saucer and pointed domes are greater than those obtained by the drum and onion domes.





Saucer Dome Drum Dome Onion Dome Pointed Dome

Figure 8: STI for the mosque at Khatib Position, when the mosque is assumed empty

6. CONCLUSIONS

The dome has always been one of the major features in mosque's architecture that directly affects the sound quality inside the prayer hall. This sound quality has been tested and simulated in the university of Dammam mosque as a case study by using four principal dome shapes as a variable parameter in correlation with the fixed mosque shape and volume. The dome-acoustic effect was measured according to each parameter in two main scenarios: The Imam position and the Khatib position. All results according

to the four dome shape parameters and the different scenarios can be summarized in the following Table.

SCENARIO	IMMAM POSITION				KHATIB POSITION			
DOME SHAPE	Saucer dome	Drum dome	Onion dome	Pointed dome	Saucer dome	Drum dome	Onion dome	Pointed dome
(STI)	(+)	(-)	(-)	(+)	(+)	(-)	(-)	(+)

According to the Table above, it is clear that both Saucer and Pointed domes had the optimum and desired acoustic effect inside the mosque in both scenarios (Imam position and Khatib position). Both domes met the theoretical standards and benchmarks according to the mosque shape, materials and volume to maintain the acoustical comfort. However, both Drum and Onion domes did not maintain the better sound qualities due to higher or lower values than the desired levels. According to the results, it is quite obvious that domes, as an Islamic architectural feature, can have a direct impact on the sound quality. This impact could be positive or negative. The results reinforce the idea that good dome design in mosques is the key element of the acoustic performance inside the prayer hall.

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ARTIFICIAL NEURAL NETWORK BASED MODEL FOR ESTIMATING CONSTRUCTION COST OF MOSQUE BUILDINGS IN KSA

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Abstract

This paper presents an artificial neural network (ANN) based model for purposes of estimating construction cost of Mosques building in KSA. One hundred and twelve, 112 data set for actual construction cost of completed mosques project were used for training and development of the ANN model. The input layer of the model involved ten variables; Location index, Density of population, Area of building, Height, Construction method, Mosque type, and available facilities. The total construction cost is the output. The optimal network for the model was selected by conducting a systematic search among a large number of networks with different network architectures and parameter values. Probabilistic Neural Network Model was chosen and found to have high accuracy. The performance of the model over the validation sample shows that the model has accuracy of 97%. The ANN model was considered to be effective. The results of this study demonstrate that it is feasible to use ANN for estimating construction cost of Mosque buildings at design stage for the purpose of feasibility analysis. Data used for developing the ANN model was limited, so the results are encouraging for further research with more data cases. The models were evaluated based on the ANN prediction only; other means of evaluation were not used, such as sensitivity analysis. The study provides a simple, yet effective means of predicting construction costs of Mosque building projects in KSA by using ANN model.

Keywords

Artificial Neural Network (ANN), KSA, Construction, Cost prediction, Mosques buildings

نموذج لتقدير تكاليف تشييد مباني المساجد في المملكة العربية السعودية بإستخدام شبكة الاعصاب الصناعية

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المستخلص

تقدم هذه الورقة نمذجة باستخدام شبكة الاعصاب الصناعية لغرض حساب تكاليف التشييد لمباني المساجد بالمملكة العربية السعودية. تم تدريب وتطوير النمذجة على بيانات تكاليف مائة واثنا عشر مسجد في أماكن متعددة في المملكة. تحتوي مدخلات النمذجة على عشرة متغيرات مؤثرة منها : الموقع او المدينة , الكثافة السكانية في المنطقة , مساحة المسجد , إرتفاع المسجد , طريقة التنفيذ, نوع المسجد , المرافق التابعة للمسجد. وتعتبر مخرجات النمذجة هي حساب تكاليف التشييد. تم التوصل عبر النمذجة المختلفة لعدة شبكات أن الشبكة الأمثل هي التي تأخذ الاعتبارات المعمارية والمتغيرات المذكورة كاملة. تم اختيار شبكة الاعصاب الصناعية الاحتمالية ذات الدقة الأكثر. مؤشر أداء الدقة يشير الى ان النمذجة المختارة ذات فعالية ودقة تصل الى ٩٧% والذي يعكس بدوره جودة عملية النمذجة.

وتشير النتائج الى جدوى استخدام هذه الطريقة من النمذجة لتقدير حساب تكاليف التشييد لمباني المساجد بالمملكة. وبسبب محدودية عدد بيانات تكاليف مشاريع المساجد فانه يفضل ان يتم جمع بيانات اكثر للحصول على دقة أكثر. تم تقييم النمذجة لحساب تكاليف مباني المساجد في المملكة باستخدام شبكة الاعصاب الصناعية فقط دون عمل تحليل مقدار التحسس للبيانات. يقدم هذا البحث نمذجة مبسطة وفعالة لحساب تكاليف التشييد لمباني المساجد بالمملكة باستخدام تقنية الشبكة العصبية الصناعية.

الكلمات الدالة

شبكة الاعصاب الصناعية, المملكة العربية السعودية , التنبؤ بتكاليف التشييد, مباني المساجد

1. INTRODUCTION

Estimating construction cost of any project at early stage is an important element of conducting feasibility study and budget management and allocation. Construction cost of Mosque buildings is a function of number of users, area, quality, and construction and structure system. The Saudi Arabian government and individuals spend millions for mosque buildings. The feasibility study can be successful and realistic only when actual costs of previous project is used with modification of some factors such as time and location. This is because, the absence of accurate cost estimation can lead to overrun in construction phase.

The literature indicated that for the purposes of future planning and budgeting, infrastructure, user cost allocation, and financial forecasts, infrastructure agencies seek knowledge of the annual expenditure levels for running their assets. Often, this information is expressed in dollars per unit dimension of the infrastructure and is estimated by using observed data from historical records (Wubeshet, 2015). Globally, a lot of work has been done in the area of cost prediction, but locally, in KSA there is a lack of real work in the same area specifically in governmental agencies. Hence, there is a great need to develop simple framework and model which can be easily standardized and used. The model proposed here can be easily implemented by practitioners and would be of benefit to governmental agencies for different purposes.

2. OBJECTIVES AND SIGNIFICANCE OF THE RESEARCH

This paper presents an artificial neural network (ANN) based model for purposes of estimating construction cost of Mosques building in KSA. Neural Network (NNs) tools have become tool of choice for a wide variety of applications across many disciplines. It has been recognized in the literature that regression and neural network methods have become competing model-building methods (Smith and Mason, 1997). Potential benefits of this research include:

1- To provide a simple tool for improving the future estimation of construction cost and other cost for better and more accurate budget allocation.
2- More accurate prediction of future cost estimation, which results in improved budgetary control.

3- Contributes to opening doors for further studies in future cost estimations in construction projects in the public sector.

3. LITERATURE REVIEW

3.1. Application of ANN in cost estimation

A vital consideration with any method of estimating is the accuracy by which anticipated cost can be predicted (Ashworth and Skitmore, 1982). Recently, a new breed of tools, neural networks (NNs), has evolved based on artificial intelligence offering an alternative approach for cost estimating. Recent research demonstrated the potential use of this technique in construction (Moselhi et al., 1992) and their superior performance over traditional regression analysis (Garza and Rouhana, 1995). The efficacy of using ANN for forecasting has been amply demonstrated.

This is because of their flexibility in providing a computing framework and universal approximations for various functions with high degree of accuracy, particularly with big data (Tsoukalas and Uhrig, 1997). ANNs learn from examples and are not required to estimate statistical parameters, as such; any input type or statistical distribution can be used in ANN models. Even though the ANN concept was developed 50 years ago, it has only been in recent decades that ANN application software has been developed (Rohani et al., 2011). ANN is a type of nonparametric models with capability and abstractions that can be translated into knowledge (Khashei et al., 2008), and it is characterized by a nondeterministic input-output mapping relationship between inputs and outputs (Rohani et al., 2011).

ANNs have also been used in applications including traffic forecasting, tourist travel and arrival predictions, passenger demand forecasting, and freight modeling (Karlaftis and Vlahogianni, 2011). Sian et al. (2010) sought to predict maintenance costs by developing four NN models, comparing result(s) with regression to identify which model has the least error. Four main factors were argued to affect costs (age, floor; classroom; and elevator number). Four models were classified based on the number and type of variables in each model, concluding that the prediction accuracy of ANNs modelling is better than a regression. The applications of NNs range from signal processing in telecommunications to pattern recognition in Medicine, Business, and Engineering (Lippmann, 1987). Liang et al. (1992) Markowitz, and Yih used NNsmeta model in Operations Management. Yarlagadda

(2000), among others, used NNs in manufacturing processes and operations modeling.

3.2. ANN Architecture Neural network (NN):

Is a computer system that mimics the learning process of the human brain (Kim and An, 2007)? NN is able to accomplish that based on a simplified model of the biological neurons in the human brain and the relationship between them. ANN is modeled in a mathematical form to execute a certain intelligence as that of the human brain for application in the field of engineering or other fields (Kim et al., 2004). Figure 1 illustrates the structure of a NN. Essentially, the system comprises three sets of layers. These layers are classified as input, hidden, and output layers. Each set of layers equally contains neurons. Neurons are the determinants of optimal value via a summation and transfer function. Neurons deliver a set of inputs – usually an output from another neuron – into the input layers. Each set of the delivered input data is multiplied by the connection weight. Weighted inputs produce output results that are further modified by the transfer function. However, the major advantages of an NN are as follows:

1- ANN can be utilized to create complex nonlinear function estimation models; and
2- Does not enforce any limit on the number of attributes (Deng and Yeh, 2010).

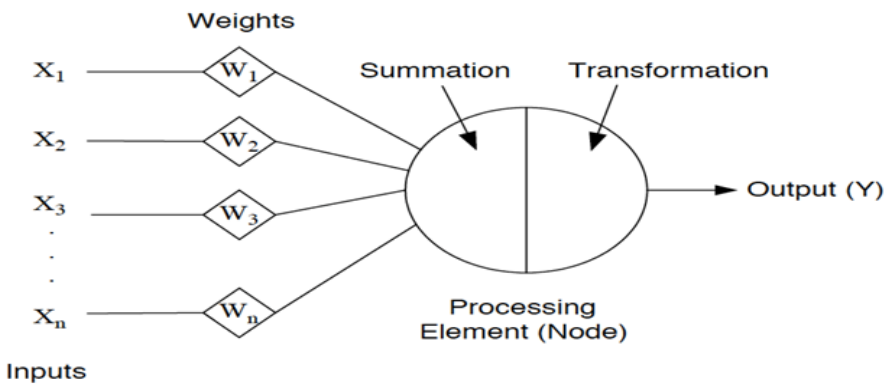

Figure. 1: Neural networks

The major drawback of NN as cited in the previous research is its slow nature when it comes to black box techniques and knowledge acquisition

process (Hegazy et al., 1994). Each neuron receives at least one input(s), processes the inputs, and produces only one output. The major segments of information processing in the Neural Network are: Inputs, Weights, Summation Function (weighted average of all input data going into a processing element (PE)), Transformation function and Outputs, as illustrated in Fig. 1.

4. PROPOSED ANN- BASED MODEL

4.1. Overview of the developed model

In an effort to develop a practical and user-friendly tool for estimating cost of Mosque buildings in KSA, an ANN based model is developed. The proposed system incorporates Artificial Neural Network Module (ANNM). Microsoft Excel based NN is used to build, train, validate and test the developed model.

4.2. Inputs Data (Factors Influencing the construction cost of mosque buildings)

Factors influencing the construction cost of mosque buildings were identified from interviewing experts from different discipline. In this study, only factors related to architectural design were used to develop the proposed model for prediction construction cost of mosque buildings. The identified factors were used as inputs to build the proposed model, which are:

- Location (Region & City)
- Area (Square Meter)
- Density of Population (High, Medium, or Low)
- Mosque Type (Jamie, Mosque)
- Construction Type (New Construction, Rebuilding)
- Height of mosque (Double Height, Single Height)
- Available facilities such as:
    - Housing of Imam and Moadhen (caller of prayers)
    - Female prayer area
    - Toilets, and ablution space
    - Library or dead laundry

4.3. Data collection for Estimating Construction Costs

Due to poor documentation of previous completed Mosque building, therefore the required data was collected from ministry of Islamic affairs. The collected data consists of seven parameters influencing Mosque construction cost, defined as input data in the developed ANN model, and one parameter representing construction total cost, defined as output in the developed ANN model. Real construction costs of 112 successfully accomplished Mosque projects from over fifteen cities across the KSA formed the data utilized in this application. A total of seven inputs and one output variables were gathered from collected data.

However, the year of construction and other building's features were not utilized as input variables. This was due to the difficulty that hindered the collection of extracted variables from the cost data. Data gathered from the 112 mosque buildings was randomly divided in to three categories.

The three categories were, 20% testing data, 20% cross-validation data, and 60% training data. The collected data was filtered and incomplete data points were removed before analysis. Ultimately, 112 data point were used to build the ANN Model to predict the construction cost of Mosque buildings in KSA. The collected data was organized in Microsoft Excel worksheets to allow an easy application of the software used to build the model.

4.4. Developed ANN based model for estimating construction cost

Predicting conceptual construction cost of mosque building at early stage of the project life is a difficult task. This difficulty is attributed to many factors influencing the mosques' construction cost and the shortage of information required at the early stage. In this paper, ANN is chosen to develop conceptual cost estimate tool due to its capabilities of solving such difficult task. The methodology applied to develop the model involves the following stages as depicted in Figure 2:

1- Data collection
2- Data filtering
3- Define the input data into neural network software
4- Set the model parameter (training, testing, and validation)
5- Build the network

6- Train the network built in step 5

7- Test and validate the network

8- Repeat the steps 5-7 and select the network with the highest accuracy (Figure 3 depicts the selected model for estimating construction cost)

The Neuro-Solutions software was used to develop, train, validate, and test the developed model. It is Excel sheet based software, which selects the best models by conducting a systematic search among a large number of networks with different network architectures.

The data related to the factors influencing the construction cost was defined as input data while total construction cost was entered as an output variable. The training cases were randomly selected and were used to train the network and compute the weights of the inputs. The test cases were used to measure the performance of the selected ANN model.

Several network structures with different number of nodes in the hidden layer were trained and tested. This strategy was chosen to find the best performing network architecture among different models. The optimal network for the model was selected by conducting a systematic search among a large number of networks with different network architectures and parameter values.

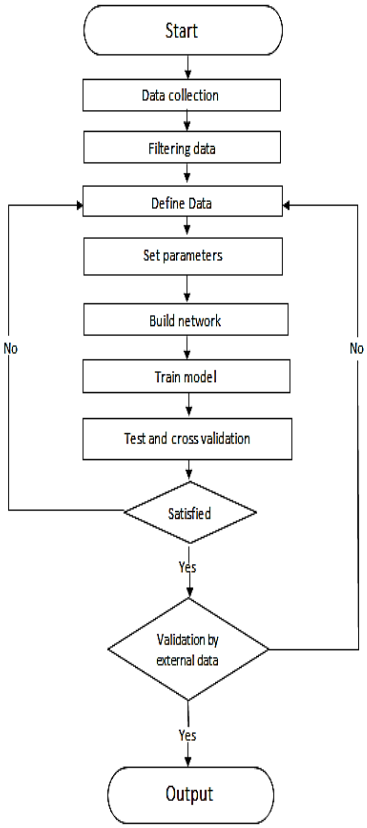

Figure 2: Developed prediction model for mosques construction cost

Table 1 shows a sample of the actual data collected to build the model. Figure 3 shows the selected parameters to train and test the developed model.

Table 1: Sample of data collected to build the model

		Population							Con		
project #	(S)city	Height	Density	Female PR	Housing	Died W	wodhoa	Class	stru	Area	Cost
1	Raniah	1	1	1	1	0	1	1	1	2900	***3,152,625***
2	Skaka	2	1	1	0	0	1	2	1	225	***543,909***
3	Skaka	2	1	1	0	0	1	2	2	225	***543,638***
4	Skaka	1	1	1	0	0	0	1	2	936	***1,890,000***
5	Alshannan	2	1	1	0	0	1	2	1	422	***807,455***

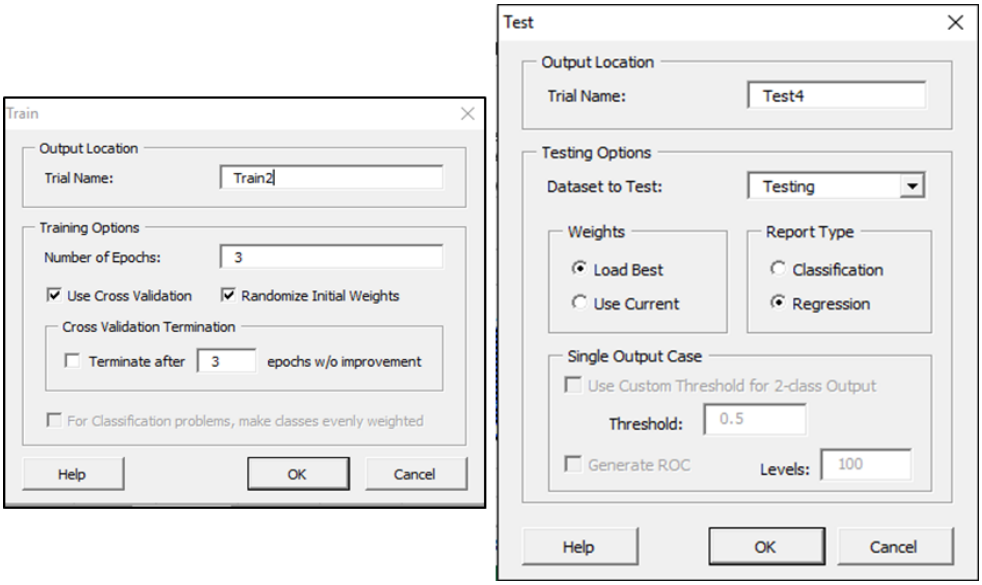

Figure 3: Selected parameters to train and test the developed model.

Table 2 depicts the performance of the top three searched models, while Table 3 represents the performance Metrics of the best selected model. The following setting is used as stop trading conditions; (1) MSE on training subset must be less than 0.04; (2) Maximum allowed number of iterations: 9000.

The training stop reason was the maximum number of iterations was achieved. The ANN model was used to predict actual construction cost for selected Mosque from historical Data. ANN model has performed well (Table 4). The ANNs model is able to estimate the total construction cost with an average accuracy of 96 per cent.

Table 2: Summary of the top three networks

	Training			Cross Validation			Testing		
Model Name	RMSE	r	MAE	RMSE	r	MAE	RMSE	r	MAE
LinR-0-B-L (Linear Regression)	41720.732	157426.88	24849.11	2375507.5	6644685.3	1336840.7	4067690	17073916	1217568.6
MLPR-1-B-L (Regression MLP)	17825.439	64077.038	8492.5443	1910942	5103592.4	1223083	1937786.7	7307073.1	1125439.8
PNN-0-N-N (Probabilistic Neural Network)	525359.13	3113214.6	221258.24	760847.96	2309599.5	421837.98	176354.99	515347.67	112209.3

Table 3: Performance Metrics of the developed model

	Training	Cross Val.	Testing
RMSE	525359.1	760848	176355
Correlation (r)	3113215	2309600	515347.7
Min Absolute Error	0.021935	0.04182	0.011124
Max Absolute Error	4310.933	4489.391	4489.391
Mean Absolute Error (MAE)	221258.2	421838	112209.3

5. PERFORMANCE OF THE DEVELOPED MODEL

As presented in Table 4, the developed model provides reasonably good result with accuracy of 96%. The accuracy could be improved if more data was available. Table 5 summarizes the actual and forecasted costs, and Figure 4 shows the results provided by the developed model compared with the actual estimation.

Table 4. Summary report of model performance

P Performance	Cost
RMSE	176354.9939
NRMSE	0.017483567
MAE	112209.3042
NMAE	0.011124261
Min Abs Error	4489.39137
Max Abs Error	515347.6662
Max Abs Error	0.966282242
Score	96.43627293

Table 5. The results for ANN model (Actual vs. Forecasted)

Act. Cost	Forecasted	Act. Cost	Forecasted
672000	692750	630000	625510
473000	623277	608192	634622
630000	625510	525000	631866
630000	625510	3152625	3468646
630000	625510	543901	576117
473000	623277	543638	562005
685000	634622	1890000	1374652
473000	623277	807450	759388
456225	561995	404956	715722

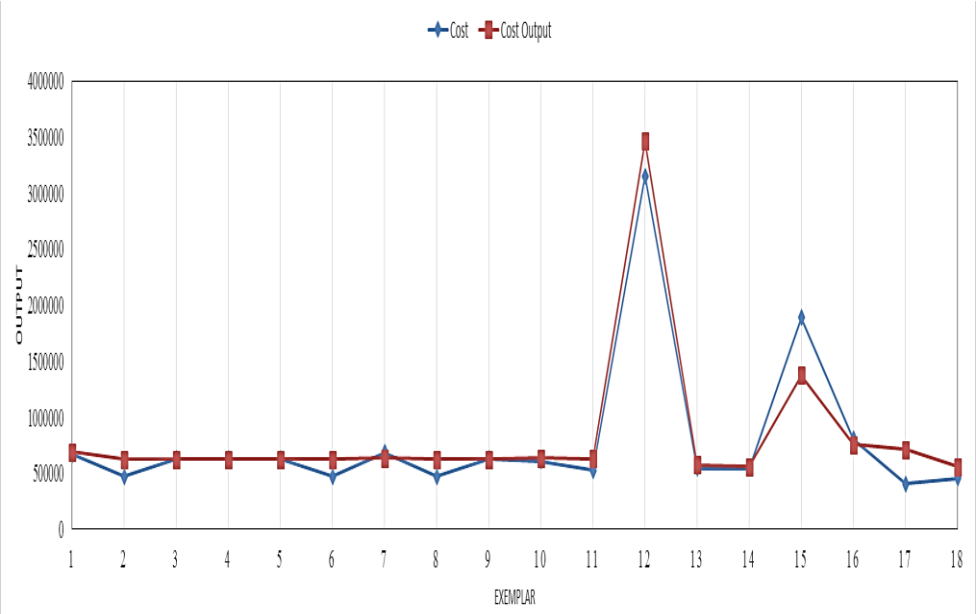

Figure. 4: Desired cost estimate and actual cost

6. CONCLUSIONS AND RECOMMENDATIONS

Artificial neural network was used to develop a prediction model for construction cost of mosque buildings in the kingdom of Saudi Arabia. The ANN based model developed in this study has generated satisfactory results. The developed model represents 97% of the actual costs data of 112 mosque buildings in different cities in Saudi Arabia. The best ANN model. identified in this study has shown that it is possible to apply the methodology and framework for the best utilization of actual historical cost records to estimate future cost efficiently; the technique needs only basic information in the form of input variables.

The presented model can help budget planners to provide reasonable estimates for construction costs of mosque buildings. The methodology presented in this paper can be applied to develop models for other cost relevant to Mosque buildings such as life cycle costing and estimating running and operation cost.

Furthermore, once the ANN model was built, tested and verified, sensitivity analysis can be conducted to evaluate the influence of each variable to construction cost. Sensitivity analysis provides indicator to the influence of individual input variables. Through sensitivity analysis, variables that do not have significant effect could be taken out of the NN model and key variables could be identified.

Finally, although limited amount of data was used for developing the ANN model, the results are encouraging for further research with more data inputs and cases. The accuracy of the prediction model will improve significantly. Another limitation is related to the unavailability of a comprehensive database that analyzes costs of mosque buildings.

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EFFECT OF MIHRAB GEOMETRY ON THE ACOUSTIC PERFORMANCE OF MASJID

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Abstract

This study aims to identify the best Mihrab geometry with respect to acoustical performance of Masjid (Mosque). Mihrab (prayer niche of Imam) geometry has an impact on daily prayer recitation and orders, because the imam (prayer leader) is facing this semicircular shape. The Sound Pressure Level (SPL) has been simulated to compare different known designs and types of mihrab geometries, by ODEON. Thus, this study focused on the evaluation of acoustical performance of common/known Mihrab geometries, in order to identify the best geometry with respect to the acoustical performance.

Keywords

Mosque Acoustics, Prayer niche, Mihrab Geometries.

تأثير شكل المحراب على وضوح الصوت بالمسـاجد

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المستخلص

في هذه الدراسة يقوم الباحث بالتركيز على اشكال المحراب المعروفة على مر الزمن من بداية الاسلام الى عصرنا الحاضر آخذا بعين الاعتبار الحقبات الزمانية والمكانية والعمارة السائدة. الهدف هو معرفة تأثير شكل المحراب على جودة الصوت للمأمومين في الصلوات الخمس اليومية. الباحث قام بأختبارات الصوت بالمسجد المذكور بالدراسة وتمت محاكاة تصميم مسجد وقياس الـ SPL. تمت المحاكاة للتصميم والقياسات ببرنامج ODEON برسم ثلاثي الابعاد مشابة للمسجد الذكور للتاكد من صحة القياسات بالموقع ومطابقتها ومن ثم مقارنة اشكال المحاريب بعد اعادة منسوبها ليتماثل مع التصميم لمقارنة اداء الشكل صوتيا فقط. الدراسة هذي لم يتم دراستها من قبل ولم يتم مقارنة الاشكال هذه وكذلك لم تدرس على حدة. بنهاية البحث وبعد المقارنة سيتم تصنيف الاشكال والخروج بافضل شكل من ناحية الاداء الصوتي.

الكلمات الدالة

الصوتيات بالمساجد, صوتيات الفراغ, اشكال المحاريب.

1. INTRODUCTION

Mosque (Masjid) is a word describing the 'place for prostration', and was used by the early Muslims for houses of worship (Buhlfaia 2006). It is always situated in the center of cities and neighborhoods. Mosques are exclusively essential structures in every Muslim community, and they normally have a certain size and location in relation to the public. In general, they could be categorized as large national mosques, major landmark buildings, community focal point, and small local neighborhood mosques. Although their uses are clearly varied, they also have several consistent characteristics (Utami 2005). Literature on this subject could be divided into three major categories

First category focused on the analysis of existing building which are single mosques and church cases, comparisons between mosques and comparisons of mosques to churches or chapels. For instance, one of the most recent studies by Carvalho and Freitas (2011) discussed the Reverberation Time and RASTI on Lisbon mosque and compared to another studies done for other Catholic churches & mosques within volume average.

They found that RT was average at 500-1k Hz but a little higher when compared to recommended values. The 2nd category studied the mosque architectural features and floor plan geometries and materials. Abdou (2013) and Eldien (2012) presented wide analyses on most common mosque floor plans geometry in order to measure the effect of the floor plan geometry on acoustic performance. A simulation had been realized for common worships. They concluded that the square floor plan is the best in terms of acoustics.

The 3rd category aimed to propose acoustical parameters and design guidelines. A document published by the Diocese of Columbus (http://www.colsdioc.org/) provided acoustical recommendations for the construction and renovation of churches and chapels. It clarified the most important factors for acoustical design such as the basic requirements for good acoustics in churches, the elements of good natural acoustics for worship, the physical provisions for sound sources sound isolation, the mechanical system noise control, the sound reinforcement systems acoustics and the design/building process. Also, it proposed an acoustical checklist for a typical church building process.

In our study, we will focus on the mosque mihrab geometries known throughout the Islamic Architecture history. Mihrab shapes developed

through nine periods (rom 650 to 1922) from Umayyad nation to Ottoman period. These nine geometries will be simulated on an existing mosque situated at University of Dammam's new campus. The current design will be simulated by Odeon, and then each shape will be rescaled to the same current mihrab in order to compare the acoustical performance of all geometries.

2. METHODOLOGY

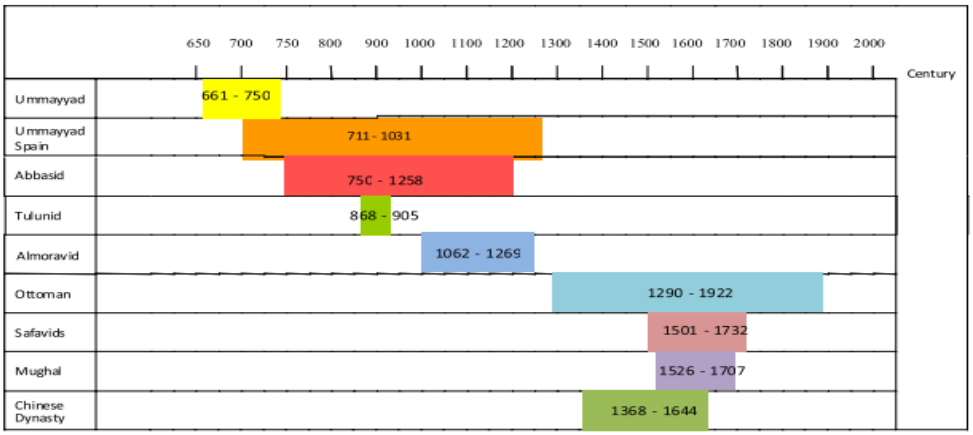
The simulated scenario is the daily prayer hall when the mosque is empty by following ISO acoustic standards and procedures (building acoustics measurements standards ISO 140 and ISO3382). We have developed a three dimensional design of the University of Dammam mosque in order to import into the simulation tool (ODEON) and for ten mihrab geometries.

All mihrab data have been collected from previous studies. Mihrabs's height and width were fixed. Sound Pressure Level (SPL) values were analyzed in order to select the best mihrab geometry in terms of acoustical performance.

2.1. Mihrab Development Throughout Islamic History

Islamic architecture was developed throughout Islamic empire expansion; the massive Islamic land from eastern Asia towards Africa and some parts of Europe has influenced mosque components architecture such as Mihrab, Minarat and Quba (Othman 2011) . Table 1 shows each Islamic period that contributed on mosque architecture and development.

Table 1 Medieval Timeline
Source: (Othman 2011)



Each Islamic Period in Table 1 has a masterpiece mosque (landmark) of the nation describing their architecture and culture. Table 2 presents the famous mosque mihrab geometry in each period and related information.

Table 2 Development of Mihrab throughout Islamic Empire

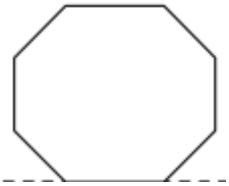
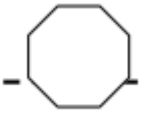
Period	Nation	Mosque	Mihrab Floor Plan	Mihrab Elevation
661-750	Ummayyad	Great Mosque of Damascus		
711-1031	Ummayyad Spain	Great Mosque of Cordoba		
750-1258	Abbasid	Abu Dulaf Mosque		
868-905	Tulunid	Mosque of Ibnu Tulun		
1062-1269	Almoravid	Great Mosque of Tlemchen		

Table 2 continued Development of Mihrab throughout Islamic Empire

Period	Nation	Mosque	Mihrab Floor Plan	Mihrab Elevation
1290-1922	Ottoman	Üç Serefeli Mosque		
1501-1732	Safavids	I-Shah Mosque		
1526-1707	Mughal	Moti Mosque		
1368-1644	Chinese Dynasty	Great Mosque of Xi'an		

2.2. Modeling Configurations

The computer simulation has been conducted on a typical mosque (Dammam University mosque), by using various mihrab geometries as summarized in Table 2. The size of the mosque corresponds to the community mosque with prayer hall area of 28 m × 28 m and ceiling height of 4.95 m (see Figure1). One worship scenario is examined in the simulation. The congregation (worshippers) is performing the prayer behind the Imam who is

reciting in a standing position facing the Qibla niche using his raised voice. It is natural that persons delivering speech without the aid of Electro-acoustic sound system tend to raise their voice.

The background noise in the mosque is assumed to reach a Noise Criterion (NC) rating of NC30 (religion spaces). The worshippers are assumed to be also standing listening to the Imam as is usually the case during performing the “Daily” prayers. Their ear height is taken to be 1.65 m from the floor. Measurements and simulation have been realized when the mosque is assumed empty. Figure 2 demonstrates the positions of Sources and receiving points for all configurations. These parameters were simulated in 121 different point positions indicated in Figure 12. These points were measured for ten mihrab geometries including base case (see Table 2). The distribution is on a 2.4 m grid. Each receiver point is 1.65 m high.

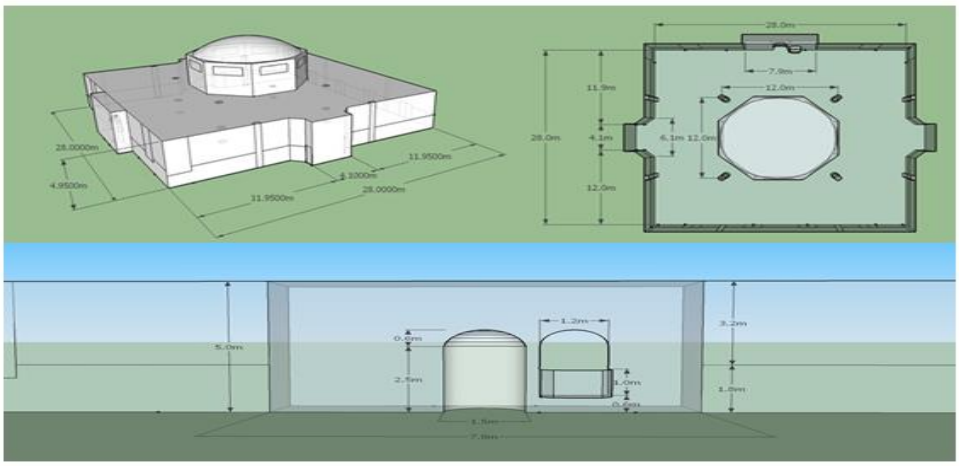


Figure 1 Dammam University Mosque Dimensions

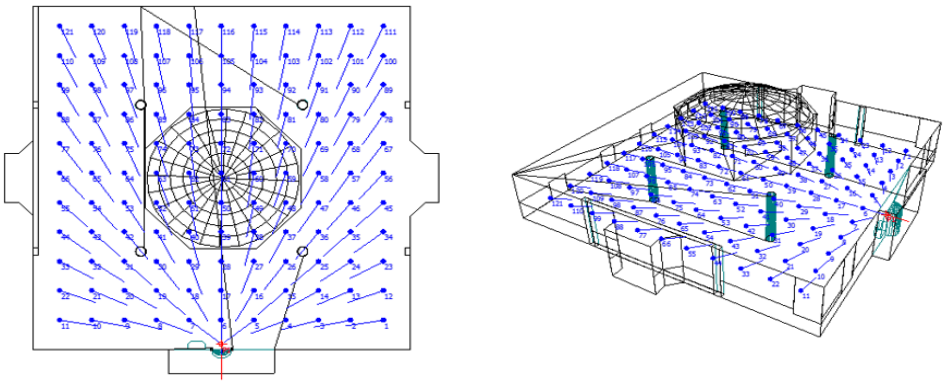


Figure 2 Sound Receiver Points and Source

3. RESULTS AND DISCUSSION

3.1. SPL analysis for UOD mihrab geometry.

Figure 3 shows the SPL contours values for the UOD mihrab. We can observe that the SPL values decrease with the distance from the sound source. The SPL values range from 73 dB to 65 dB at 1kHz. In general, the maximum values are located at the areas near the mihrab and at the two sides. In general, this case has a noticeable increase of SPL value at the most critical point, which is behind the sound source. In addition, the impact of minbar is low, and 35% of mosque area has low db. Moreover, the yellow hatched area is about 510 m2 which is equivalent to approximately 65% of masjid floor plan. This mihrab geometry is more suitable for rectangular and square floor plans, once the sound distribution is homogenous all over the floor plan.

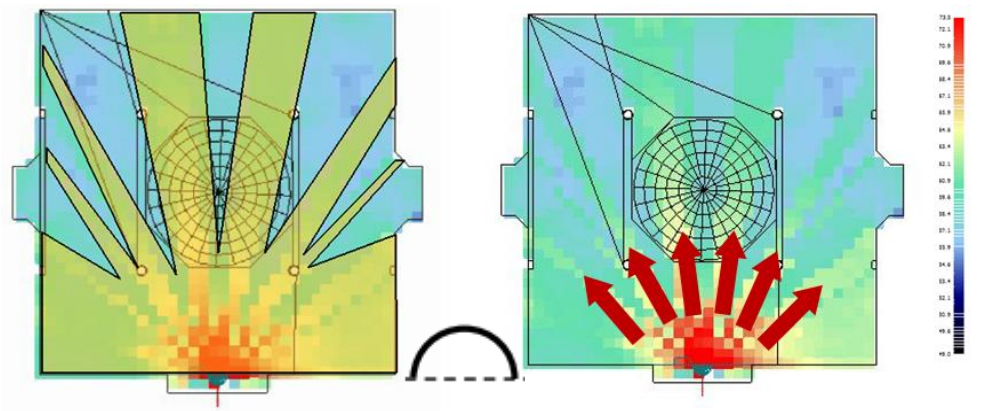


Figure 3 SPL contour values for UOD mihrab at 1 kHz

As shown in Figure 4, first row has the highest SPL value due to its relative position to the source. For the second and the third row, we can notice that points 5 and 7 have comparatively less values due to mihrab shape. Moreover, there is a decrease of SPL values from point 7 to 11 due to the masjid minbar.

A noticeable decrease of SPL values at the middle of the rows (behind sound source) at the 4th row due to the mosque's dome. Moreover, SPL values increase at the left and right side walls because of the impact by side entrances. At the 8th row, the highest value of SPL is located near the center which is created by nature of the mihrab sound distribution.

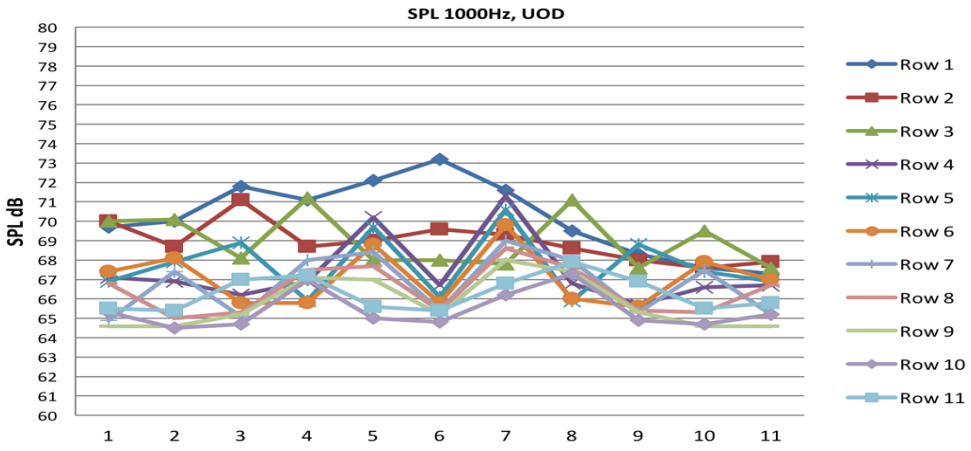


Figure 4 SPL at 1000Hz for UOD mihrab all over floor rows.

3.2. SPL analysis for Otthman's mihrab geometry

As presented in Figure 5, SPL values is better than the previous shape, where it ranges from 79 dB to 66 dB at 1kHz. In general, we found that the maximum SPL values were located at the middle of the row closest to the sound source. Impact of minibar is obvious at area 1. In addition, area 2 has a very low dB value due to mihrab sound distribution.

Thus, this area could be supported by sound reinforcement system (SRS) for proper sound level coverage. Moreover, the yellow hatched area is about 470 m2 which is equivalent to 59% of overall masjid floor plan. This mihrab geometry is more suitable for rectangular floor plan once the direction of the sound is towards the plan’s longer direction.

In Figure 6 we can observe that the first row has the highest SPL value. This is due to the sound source position. For the 1st row, the SPL values decrease with the distance from the sound source. We can see the impact of columns at points 3 and 9, where SPL values increase due to the sound reflection.

For the 2nd row, the SPL values decrease by 8% due to the distance from the sound source. In general, this type of mihrabs diffuse the sound energy towards three directions, the center and the near sides. The maximum effect of this mihrab is found at the 1st and 2nd rows and at the center area.

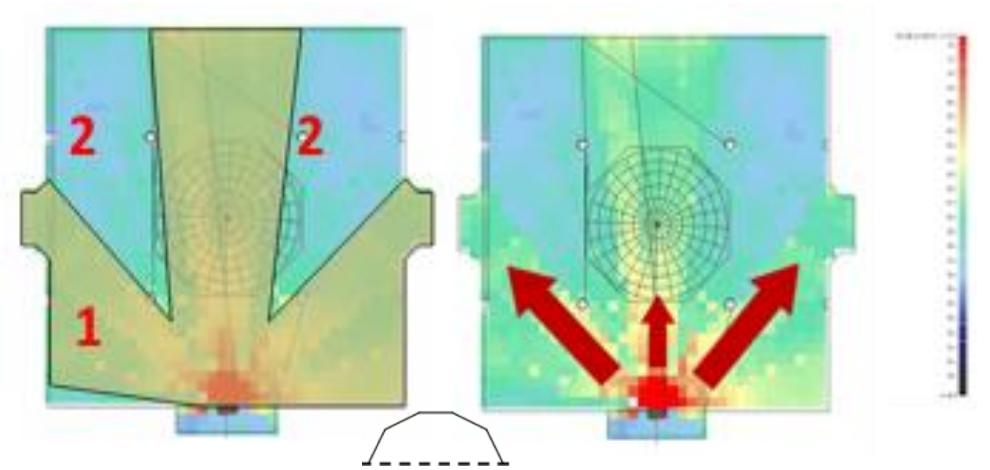


Figure 5 SPL contour values for the Otthman mihrab at 1 kHz

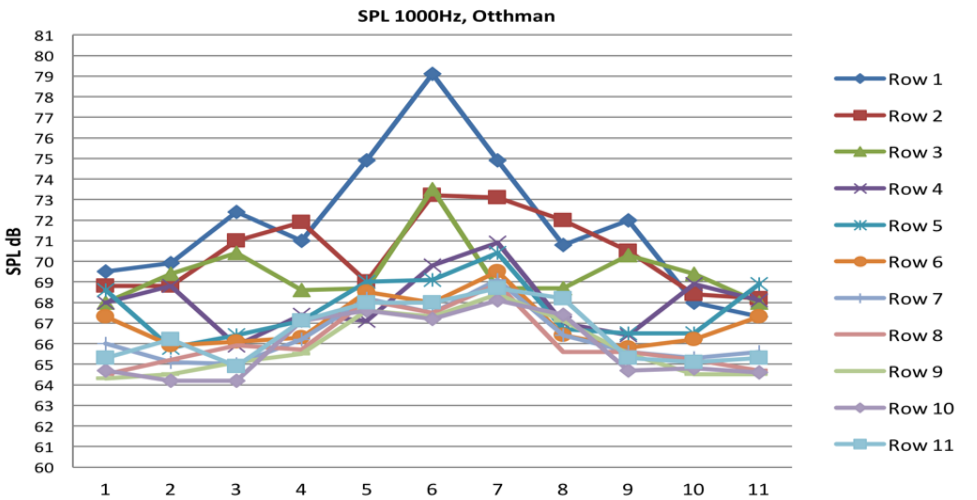


Figure 6 Otthman's SPL at 1000Hz for Otthman's mihrab all over floor rows

3.3. SPL analysis for Chinese mihrab geometry.

Figure 7 shows SPL contours for the Chinese mihrab. SPL values range from 76 dB to 65 dB at 1kHz (see Figure 8). 62% of mosque floor area has an acceptable SPL (yellow area). This mihrab shape provides a homogeneous sound diffusion. This mihrab geometry is a good sound distributor for the square and the rectangular mosques. The sound effect of this mihrab is approximately the same as the Otthman's mihrab.

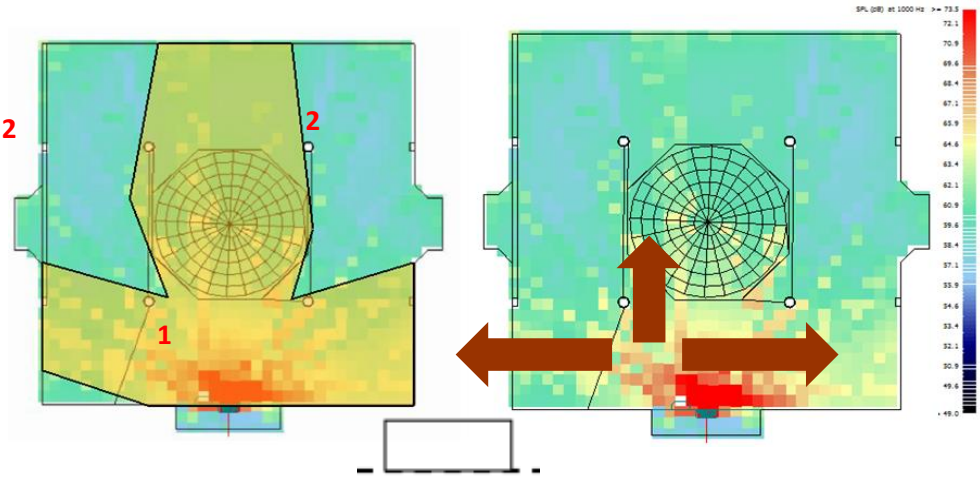


Figure 7 SPL contour values for the Chinese mihrab at 1 kHz

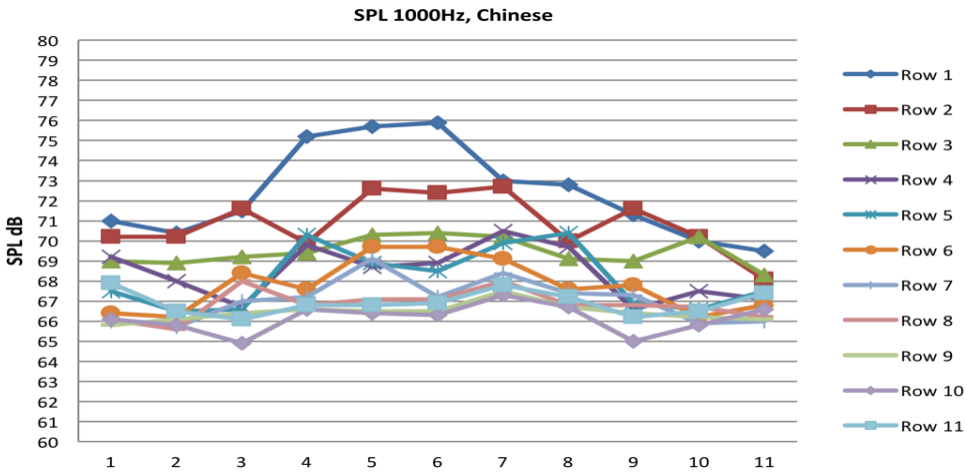


Figure 8 Chinese SPL at 1000Hz for mihrab all over floor rows.

3.4. SPL analysis for Almoravid's mihrab geometry

Almoravid mihrab has an Octagonal shape. As shown in Figure 9, Almoravid's mihrab has three strong sound diffusion and a low SPL values. This mihrab geometry provides SPL values ranging from 77dB to 62dB (Figures 9 and 10). The sound effect of this mihrab appears clearly at the center and the near sides of the mosque. The positive effect covers 43% of the mosque area. Generally, Almoravid's mihrab shape has a low sound effect on the mosque receiving points.

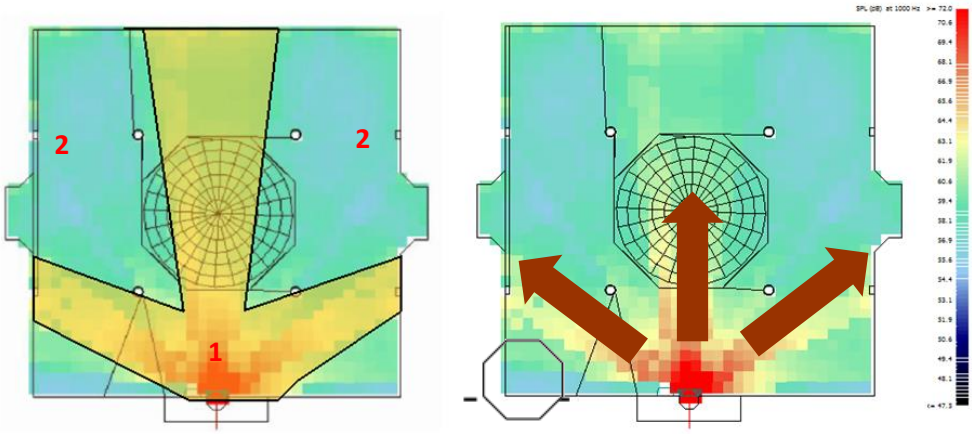


Figure 9 SPL contour values for Almoravid's mihrab at 1 kHz

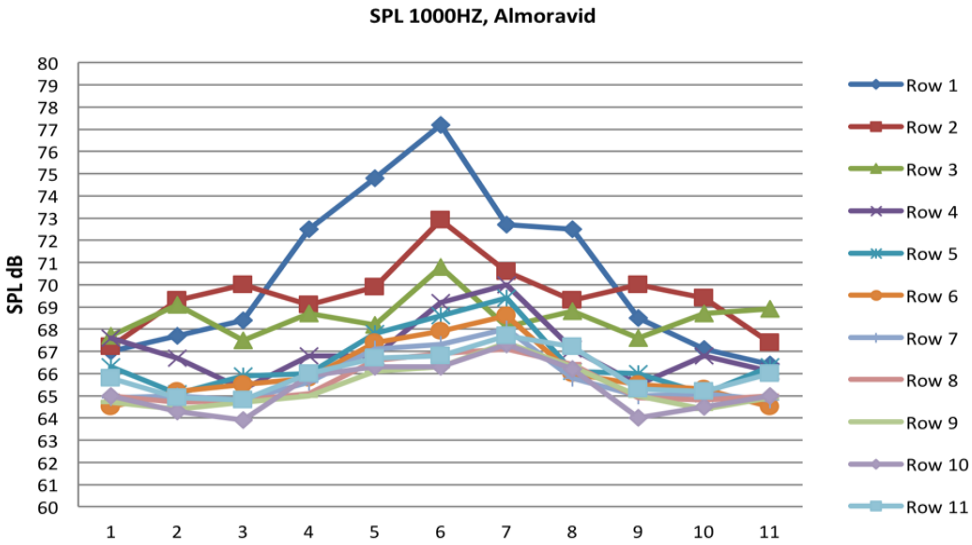


Figure 10 Almoravid's SPL at 1000Hz for mihrab all over floor rows.

3.5. SPL analysis for Safavids' mihrab geometry.

Safavids mihrab has a Decagonal shape. Figures 11 and 12 demonstrate the SPL values provided by this mihrab. We can notice that SPL values range from 79dB to 65dB at 1kHz. Generally, the sound effect of this mihrab appears clearly on 58% of the floor area. The maximum diffusion effect is located at the center and the 1st half area of the mosque.

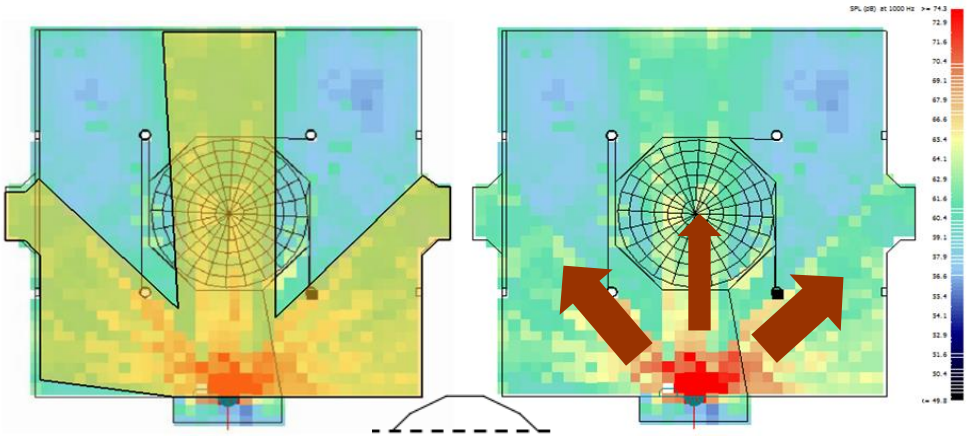


Figure 11 SPL contour values for Safavids Mihrab at 1 kHz.

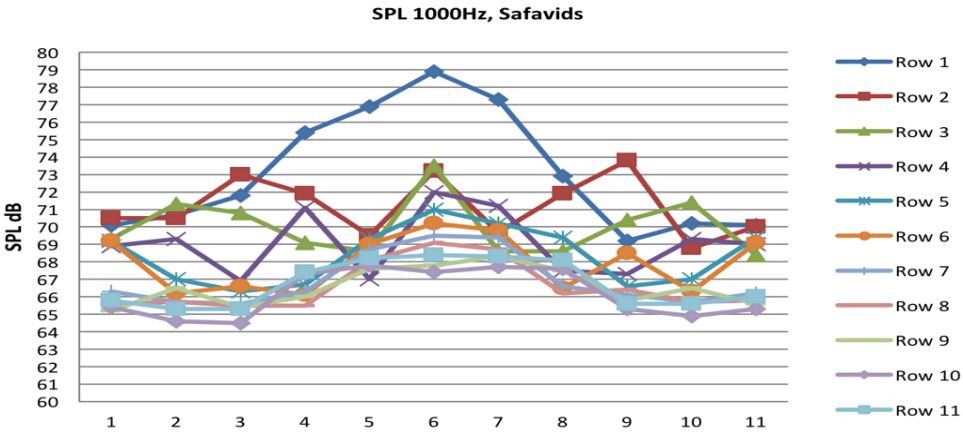


Figure 12 Safavids' SPL at 1000Hz for mihrab all over floor rows.

3.6. SPL analysis for Umayyad mihrab geometry.

Figures 13 and 14 show the SPL contours and SPL values for all proposed receiver points obtained by Umayyad mihrab geometry. This mihrab has a semi- circle form as the UOD mihrab. The main deference between the two mihrabs is the architectural decorations and the top end of the mihrab. For this reason, the results obtained by Umayyad mihrab geometry are completely different from that obtained by the UOD mihrab. Umayyed mihrab diffuses the sound energy in a semi-circular form, where SPL values range from 73dB to 65dB at 1kHz. Generally, we can say that this mihrab shape has a

homogeneous sound distribution on the floor. Moreover, sound distribution is good and suitable for square floor plan geometries.

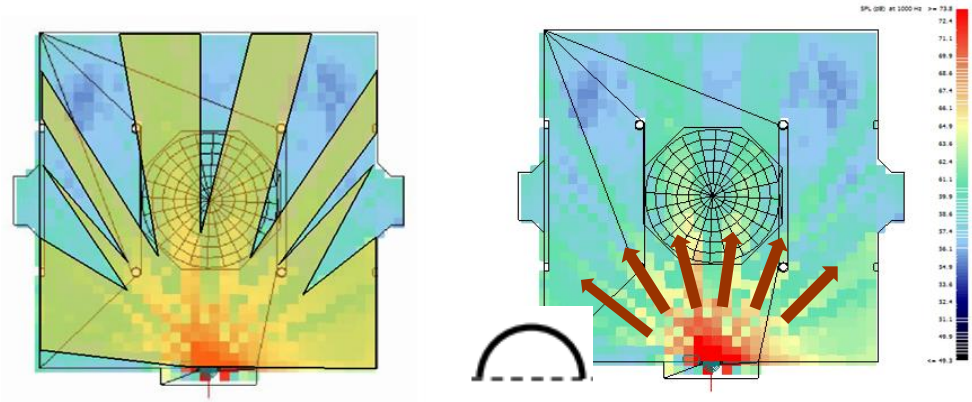


Figure 13 SPL value from 79 dB to 60 dB and sound main direction for Umayyad Mihrab

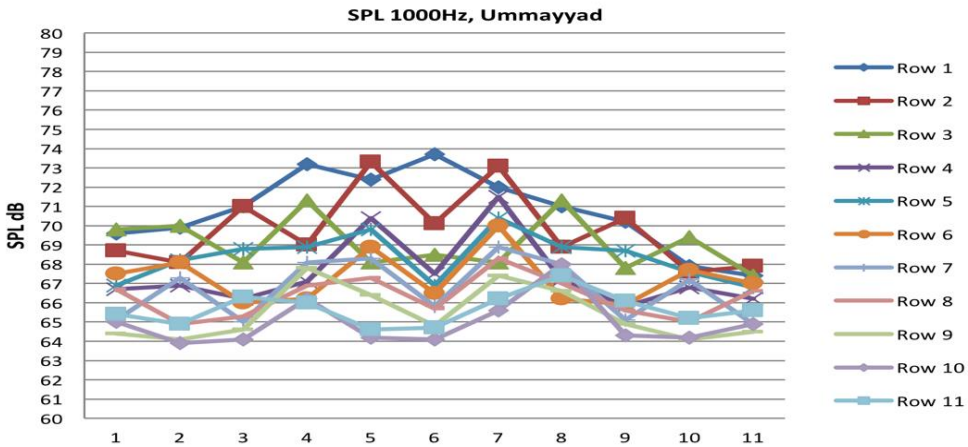


Figure 14 Umayyad SPL at 1000Hz for mihrab all over floor rows.

3.7. SPL analysis for Spanish Umayyad mihrab geometry

As Almoravid, Spanish Umayyad mihrab has an octagonal shape. The top end of this mihrab is different from that of Almoravid mihrab. This slight difference caused an increasing of sound energy especially on the left side of the mosque (Figure 15). We can notice that 58% of the mosque area is covered by acceptable SPL values. As demonstrated in Figure 16, SPL values obtained by this type of mihrabs range from 77dB to 64dB. Mihrab geometry diffuses sound energy in 3 directions, where we obtained the maximum values

of SPL. In addition, this mihrab shape has a homogenous sound distribution on mosque space.

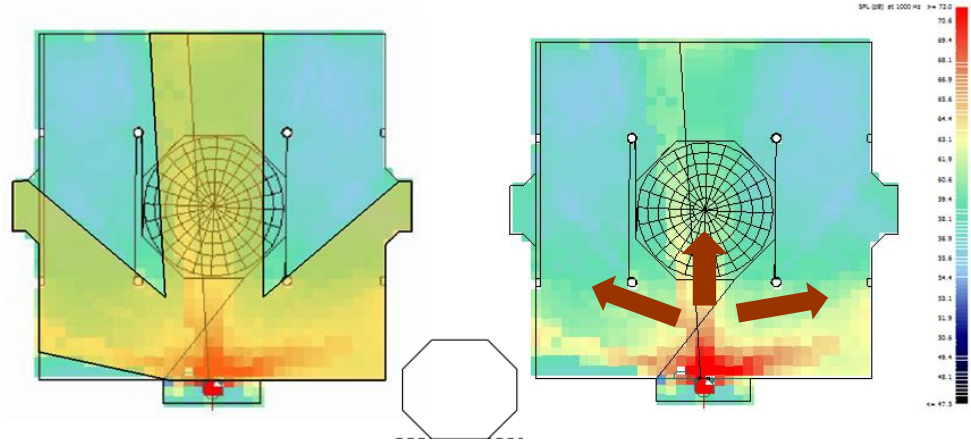


Figure 15 SPL contour values for Spanish Umayyad Mihrab at 1 kHz.

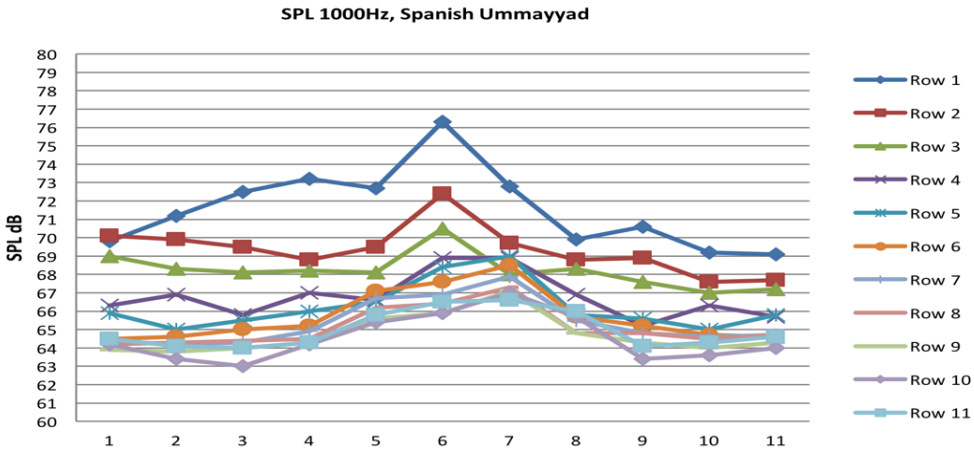


Figure 16 Umayyad Spain SPL at 1000Hz for mihrab all over floor rows.

3.8. SPL analysis for Mughal mihrab geometry.

Figure 17 shows the SPL contour for the Mughal mihrab. The yellow highlighted area presents the acceptable sound energy which covers 69% of the mosque floor area. Contrary to previous shapes, this shape covers most of floor plan area with high SPL values. Figure 18 illustrates the SPL values at 1kHz which ranges from 79dB to 65dB. The high acoustical performance of

this mihrab shape appears clearly on the left side of the mosque. In general, SPL values are homogeneous at the last rows.

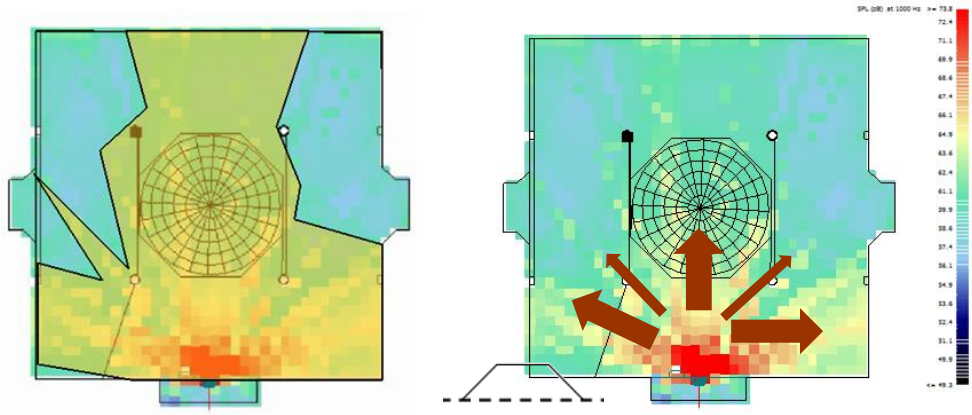


Figure 17 SPL contour values for Mughal Mihrab at 1 kHz.

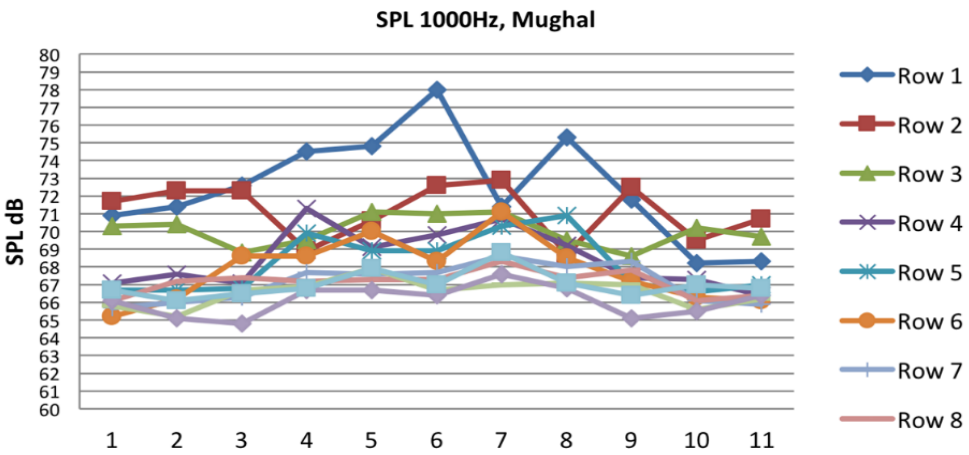


Figure 18 Mughal SPL at 1000Hz for mihrab all over floor rows.

3.9. SPL analysis for Abbasid mihrab geometry.

Figure 19 shows SPL contour obtained by the Abbasid mihrab. This mihrab provides very high SPL values on the entire mosque floor area. This geometry has the greatest acoustical impact on the mosque, and diffuses sound to all areas with high SPL value, which covers about 95% of the mosque area. Figure 20 shows high and low levels of SPL values from the 1st

to the 5th row. From 6th to 11th row, SPL values can be considered as homogenous.

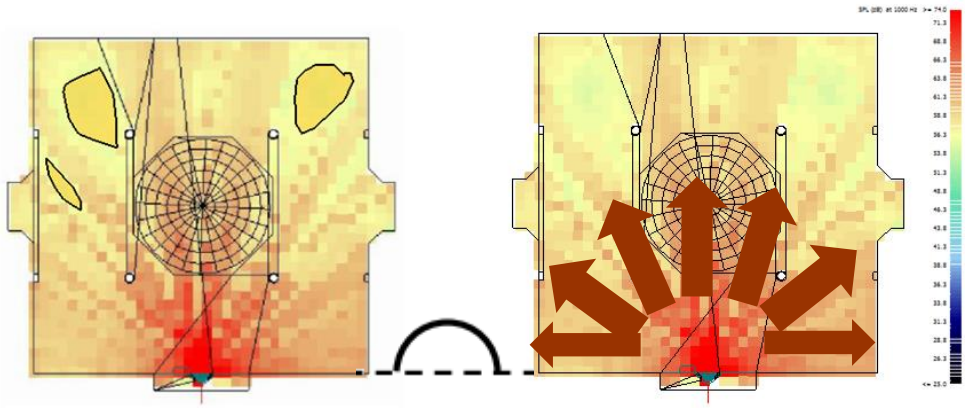


Figure 19 SPL contour values for Abbasid Mihrab at 1 kHz.

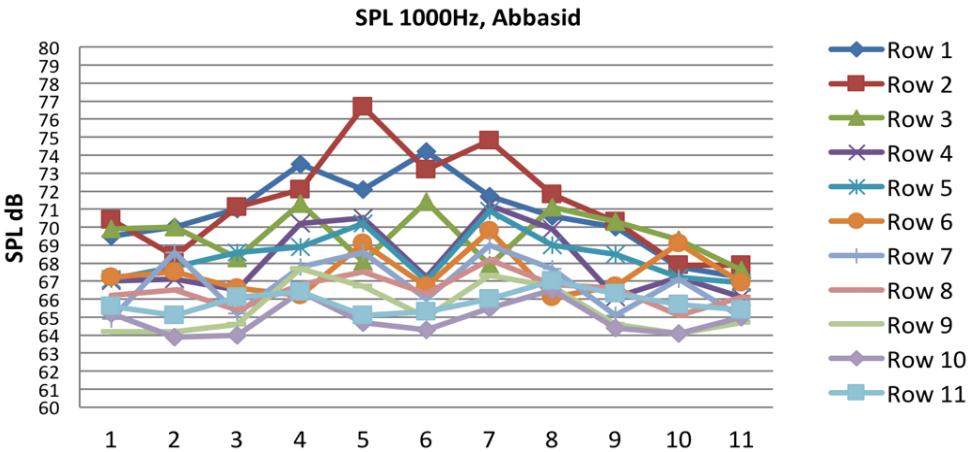


Figure 20 Abbasid SPL at 1000Hz for mihrab all over floor rows.

3.10. SPL analysis for Tulunid mihrab geometry.

Figure 21 shows the sound effect of the Tulunid mihrab in SPL. We found that Tulunid mihrab geometry diffuse the sound energy in semi-circle form, where 57% of mosque is covered by acceptable SPL. SPL values obtained by this type of mihrabs range from 77dB to 64dB (Figure 22). Furthermore, this mihrab provides a good sound diffusion on the mosque sides where we can obtain a homogeneous acoustical performance.

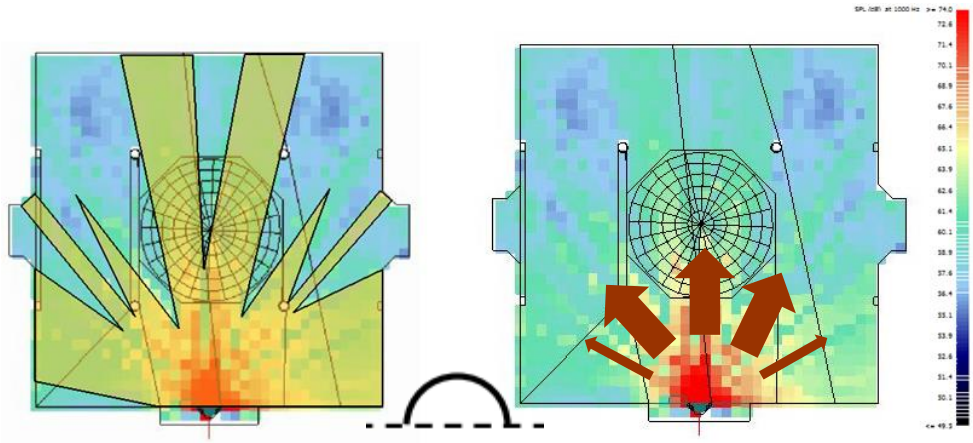


Figure 21 SPL contour values for Tulunid Mihrab at 1 kHz.

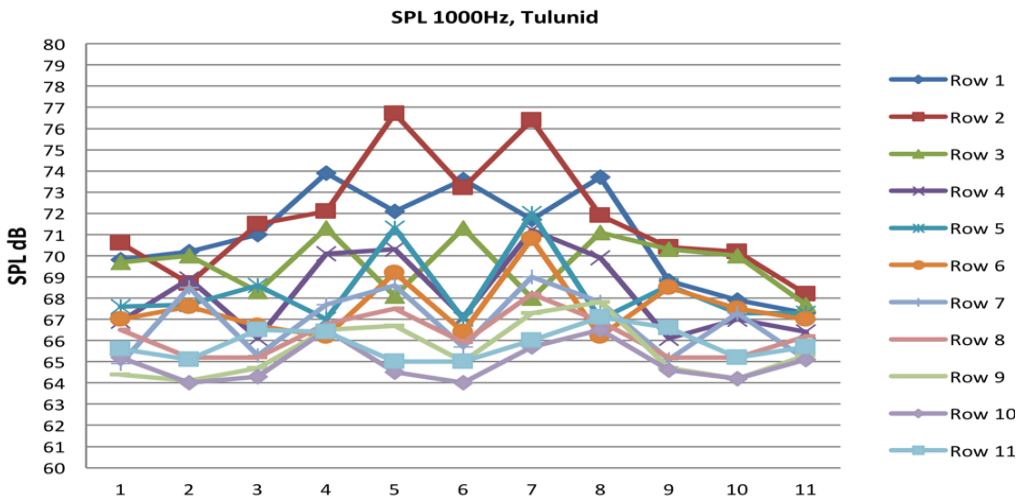


Figure 22 Tulunid SPL at 1000Hz for mihrab all over floor rows.

4. CONCLUSION

The mihrab has always been one of the major features in mosque's architecture that directly affect the sound quality inside the prayer hall. This sound quality has been tested and simulated in the university of Dammam mosque as case study by using ten principal mihrab shapes as a variable parameter in correlation with the fixed mosque shape and volume table 3. SPL parameter has been used to analyze the acoustical performance of each type of mihrab. In order to evaluate the acoustical performance of the proposed

types, five performance points were used. Each performance point has a grade of 20.

Table 3 Mihrab Geometries SPL Performance Summary

Mihrab	Good SPL area coverage	Average SPL value	Suitable for Square Floor Plan	Suitable for Rectangular Floor Plan	Overall Performance	Class
UOD	65%	69%	✓	✓	79.8%	B
Ottoman	59%	72.5%		✓	58.1%	C
Chinese	62%	70.5%	✓	✓	78.9%	B
Almoravid	43%	70.5%		✓	51.3%	C
Safavids	58%	72%	✓	✓	77.6%	B
Umayyad	67%	69%	✓		57%	C
Umayyad Spain	58%	69.5%		✓	57.1%	C
Mughal	69%	71.5%	✓	✓	81.9%	B
Abbasid	95%	70.5%	✓	✓	92.1%	A
Tulunid	57%	70.5%	✓		56.9%	C
Grade	40	20	20	20	100	

In general, we found that Abbasid mihrab geometry has the best acoustical performance, while Mughal, Safavids, Chinese and UOD have acceptable performances. The other geometries are acceptable for either square or rectangular floor plan geometry. According to the results it is quite obvious that mihrabs, as an Islamic architectural feature, mihrab can have a direct impact on the sound quality. This impact could be positive or negative.

The results reinforce the idea that good mihrab design in mosques is the key element of the acoustic performance inside the prayer hall.

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RESHAPING THE ARCHITECTURAL DESIGN & ICT CONSIDERATIONS OF MOSQUES FOR IMPROVING YOUTH PRESENCE

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Abstract

It is evidently noticeable especially in the recent years with the wide spread of social media that most of the youth are not commonly and regularly visiting mosques. However, they are fully engaged to the extent of addiction at sometimes to their digital and portable communication technologies by themselves or with their peers. By no means, digital communication technologies cannot be attributed as the cause for the lack of presence of youth at mosques. In fact, it should be made clear that the recent behavioral change of youth has not been given enough consideration in terms of specific architectural design and infrastructure of Information and Communication Technologies (ICT) for the design and operation of mosques. For instance, in order for the functional design consideration of mosques to attract youth to mosques such considerations should go beyond the basic common needs of offering only places for shoes, ablution, and prayer. These are considered as necessities for those who are already visiting and having presence at mosques, but cannot motivate youth who are not regularly visiting mosques in order to increase their level of presence.

This paper addresses the need to reshape architectural design and ICT considerations of mosques for improving the presence of today's youth at mosques. The paper proposes a conceptual approach and suggests a set of attraction features based on analyzing the current literature on behavioral patterns of youth for gathering and hanging together. Some of these attraction features include: open tech space adjacent or around the mosque for youth to hang out before and/or after prayers; quality landscape with decent sitting areas around the mosque to attract youth to spend quality time between or after prayers; deposit boxes with finger print access to keep mobile/smart phones outside the prayer area of the mosque to avoid disturbance; studying space outside the mosque with beverages service to attract youth to come together. These are in addition to integrating various youth functions in order to make the mosque as a hub of youth activities and at the same time preserving the sacred identity of the mosque as well as reverting its multiple functions as it were used to be at the time of the Prophet Mohammad (pbuh) while relating to the changing needs of today's youth. Accordingly, architectural designers and developers of mosques are required to carefully rethink the design of mosques by providing new facilities and intelligent ICT infrastructure to improve the presence of youth at mosques.

Keywords:

Mosques Typology, Youth Needs, Interactive ICT, Mosques Architecture, Social Role

تطوير الإعتبارات التصميمية وبنية تقنية المعلومات والاتصالات بالمساجد لتحسين مستوى تواجد الشباب

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المستخلص

لقد انتشرت الوسائل الرقمية للتواصل الاجتماعى بين معظم الشباب بشكل ملحوظ خاصة فى السنوات الاخيرة إلى الحد الذى ينهمك فيه كثير من الشباب بمستوى ربما يصل إلى حد الإدمان فى بعض الاحيان سواء بأنفسهم أومع أقرانهم فى إستخدام ادوات تقنية الاتصالات الرقمية المحمولة. ولكن لا يمكن أن يعزى إلى وسائل وتقنية الاتصال الرقمى أنها السبب فى عدم تواجد الشباب بإنتظام فى المساجد. وينبغى فى الواقع أن يكون واضحا أن التغيير السلوكى واهتمامات الشباب لم تحظى بالاهتمام الكافى من حيث ضرورة مراعاتها فى متطلبات التصميم المعمارى أوالبنية الأساسية لتقنية المعلومات والاتصالات عند تصميم وتشييد المساجد. وعلى سبيل المثال، لكى يساهم التصميم الوظيفى للمساجد فى جذب وتحسين تواجد الشباب فى المساجد فإنه ينبغى أن تتجاوز متطلبات التصميم الاحتياجات الأساسية المشتركة، والتي لا تساهم فى تحفيز تواجد الشباب.

وتقدم هذه الورقة البحثية منهجية فكرية لتطوير الإعتبارات التصميمية وبنية تقنية المعلومات والاتصالات والتى يمكن أن يستخدمها المطورين والمصممين المعماريين للمساجد وذلك من أجل إعادة التفكير فى متطلبات تصميم المساجد وذلك بتوفير فراغات لوظائف متعددة وجديدة مدعمة بالبنية الأساسية لتقنية المعلومات والاتصالات لإجتذاب تواجد الشباب فى المساجد بصورة أكثر انتظاماً. وتستند هذه المنهجية إلى تحليل الأنماط السلوكية الحالية لتجمعات الشباب والذى تم من خلاله تحديد عناصر الجذب المتميزة التى يمكن أن تساهم فى تحسين تواجد الشباب. ثم تم صياغة المنهجية والتى تتمثل عناصرها الأساسية فى: توفيرفضاء حول المسجد متعدد الوظائف مدعم بوسائل اتصال تقنية تدعم أنشطة تجمع وتواجد الشباب قبل أو بعد الصلاة، حزام أخضر وأماكن لائقة للجلوس حول المسجد لجذب الشباب لقضاء اوقات بين او بعد الصلاة، صناديق إيداع ذات بصمة الاصبع لحفظ الهواتف الذكية المتنقلة خارج منطقة الصلاة فى المسجد لتجنب حدوث ازعاج للمصلين، خدمات سريعة واماكن جلوس لجذب وتواجد الشباب. بالاضافة إلى دمج مختلف وظائف أنشطة الشباب على محور انشطة الشباب وحول محيط المسجد وبمعزل عن اماكن الصلاة مع الحفاظ على هوية وحرمة وقدسية المسجد ولكن فى ذات الوقت احياء دور المسجد متعدد المهام والوظائف وبدور اجتماعى أكثر تاثيراً كما كان فى عهد الرسول محمد (ص) وخاصة فى التفاعل الإيجابى مع الإحتياجات المتغيرة والمتجددة للشباب المعاصر.

الكلمات الدالة

الإعتبارات التصميمية والمتطلبات الوظيفية للمسجد، احتياجات الشباب المعاصر، تقنية المعلومات والاتصالات التفاعلية، الدور الاجتماعى للمسجد

1. INTRODUCTION

The role of the Mosque in the lives of Muslim youth is multifaceted and serves as the centerpiece from which the majority of socialization, across variety of formal and informal networks, occurs (Karimshah et al, 2014). Understanding of the role of mosques and their organizations are extremely important in order for issues concerning mosques to be identified and for effective changes whenever required to be introduced. Since the advent of Islam, mosques are always central to the Muslim community.

Allah Almighty says in the Glorious Qur'an: "In houses (mosques), which Allah has ordered to be raised, in them His name is glorified in the mornings, and in the evenings." [Al-Nur: 36]. The Mosque had a great significance in the life of the Prophet Muhammad (peace be upon him - pbuh). When the Prophet Muhammad (pbuh) migrated to Madinah in 622CE, one of his first actions was to build the mosque as the center of all Muslim activities. It is a sign from the Prophet (pbuh) that the mosque is a vital cornerstone in the appropriate establishment of any Muslim community.

The mosque at the time of the Prophet (pbuh) was used for the following purposes: center of learning and training, political platform; charity distribution center; shelter for the homeless; a place for social gatherings; inter-faith activities; civic engagement. An example of the multi-purpose use of the mosque at the time of the Prophet (pbuh) is that delegates from other states were received and accommodated in the Prophet's Mosque, such as the group of Christians who came from Najran. The Prophet's Mosque was therefore not just a place for ritual prayer and other Islamic rites, rather it was used as a center point for Muslims to conduct their affairs according to Islam. Throughout Muslim history the mosque has played a central role on the impact of Islam on a society.

For instance, there were a group of social and municipal service buildings that acted as a community center as well as the focal point of Friday prayers that included a kitchen to feed the needy or the traveler, a college, a hospital, a public fountain and a guest house for travelers. More recently there have been examples of drug rehabilitation clinics attached to mosques in Egypt such as the Abou El-Azayem mosque in Cairo. Mosques have always provided a variety of interconnected spiritual and civic services, and it is often the messages from mosques that significantly contribute to the revival of the Muslim community. The aim of Muslims has always been to make the

mosque a beacon of light and guidance for all who come across it (Asim, 2011).

The first Muslim community was generally established on youth. The first wave of Muslims traveled from Makkah to Madinah to give the first covenant was mostly youth. The Prophet Muhammad (pbuh) gave special care to youth throughout his life. The most famous scholar Ibn Abbas had not exceeded the age of 15 when Prophet Muhammad (pbuh) died.

Abdullah ibn Umar offered to fight in the Battle of Badr before the age of 14 but he was rejected admission for his young age. When he turned 14 he offered to fight in the Battle of Uhud, and he was admitted. He was very-well prepared mentally and spiritually to fight at the age of 14 due to the special care of the Prophet (pbuh) for youth. The first ambassador of Islam to Madinah appointed by the Prophet (pbuh) was very young famous man among his youth group, Mus'ab ibn `Umair.

Prophet Mohamad's (pbuh) directed specific teachings to the youth, regarding their marriage, education, health, and their special status on the Day of Judgment (among the seven categories of people that will be shadowed with the shadow of the throne of Almighty Allah is a young person who grew up and was nurtured in the obedience of Allah) (Slaves of Allah, 2009). The youth around the Prophet Muhammad (pbuh) grew up, trained, prepared and nurtured in the mosques wherein their level of presence was extremely high.

Today, there are more Muslims in the precious age group of 15 to 25years than in any other age group. This is true not only in Africa and Asia but also in the United States, England, France, and almost all of the Western countries (Fazaqa, 2009). However, with this group being the fastest growing, their presence in the mosques and participation in different Islamic activities is minimal. This conclusion is mostly based on observation. Every time one travels through the world, one finds a common theme in the mosques: the majority of the attendees are mostly old people.

By means of documented observations there could be various reasons for this phenomenon (Fazaqa, 2009):

- Lack of belonging and ownership to the mosques. Youth come in and feel they are guests because mosques are usually run by a small group of people with little room for participation. This may not be

true; however, this is the impression that the youth have about the mosque.

- Lack of activities that are age appropriate. A good number of activities revolve around such as lectures, speeches, seminars, conferences and similar activities; though they are needed, they cannot be the only activities held at the mosques, especially for the young ones.
- Lack of clear vision as to what is desired and expected. There is no clear idea as to what is supposed to take place with the presence of youth in the mosques.
- Limited facilities in the mosques have resulted in few activities that appeal to the youth and youngsters.
- Lack of understanding as what the challenges of the youth are. We cannot really address the needs of the youth if we do not know what their challenges are.

This phenomenon about the lack of youth presence in mosques has different and sophisticated dimensions in order to be fully and appropriately addressed and approached including the religious, social, economic and infrastructural perspectives. This paper focuses only on the perspective and provision of required facilities in terms of built and open spaces along with the Information and Communication Technology (ICT) infrastructure and equipment that can contribute to improving the level of presence of today's youth in the mosques.

2. YOUTH AND USE OF ICT

Youth are recognized as actors who experience intense emotions when using ICT and who learn skills to navigate and negotiate. Youth's experiences of ICT use include emergent from adolescent, societal and technological contexts and within continuous cultural change. Maczewski (2007) conducted an extensive study on the use of ICT by youth while he gathered the data through four interviews held with six youth aged 16-18 and two focus groups. The results of this study as shown in Figure 1 identified three themes of how ICT use matters to youth emerged: Fun, Convenience and Connections.

These themes illuminate how ICT have multiple ways of mattering for young people within their unique life contexts, such as providing continued

connections to peers after school and shifting spatial and temporal boundaries. Patterns of emotional experience emerged that encompassed simultaneous existence of contradictory emotions (e.g., stimulating and overwhelming) when engaged in a specific activity such as instant messaging. Examples of Self-ICT relations are: “We’re immersed” and “I feel empty without it.” These conceptualizations are linked to networked theories of self that constitute ICT as in relation to self.

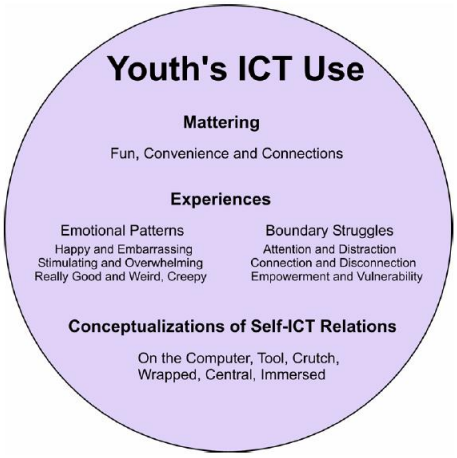


Figure 1. Youth's ICT Use: Emergent Themes of Mattering, Emotional Patterns and Self-ICT Conceptualizations
Source: (Maczewski, 2007)

The use of information and communication technology (ICT) and implications of such use on Middle Eastern youth were studied by Hashem (2008) who surveyed 225 youth wherein several key problems and great prospects were identified. Middle Eastern youth were found to be fond of their ICT use mostly because of their ability to access all sorts of information and

the ability to communicate with the outside world. ICT is helping those youths for building bridges between them and distant others, while at the same time building ever stronger walls between them and close individuals, including family members, relatives and neighbors. One of the negative impacts of ICT tools on youth is paying little attention to some of their own needs as well as the needs of others around them. Furthermore, they are fully aware that misuse of ICT tools and addiction are leading to destructive behaviors affecting them in major ways.

Religious institutions (such as mosques) should have a role on the deployment of ICT in order to enhance individuals and societal development, improve access and utility on the existing wealth created (Owan et al, 2016). The functions of mosque include offering knowledge as a place of learning and culture, acquiring moral and spiritual education, and practicing social and physical activities. Accordingly, the acceptance of ICTs into mosques is not that of mere tolerance but of mutual appreciation. In Malaysia, Dahlan et al (2015) proposed a conceptual program to develop the Islamic Transformation Center (ITC) through the Network-of-Mosques (NoM).

Harnessing on the NoM capabilities, mosques can be used as a center for transformation which provides value-added services to the society. These services will include community classes, marriage services, zakat collection and distribution, promoting halal center, sermons and Islamic learning and education hub. Also with NoM, Mosques can be used for medical clinic, home for the poor and the travelers, and eating place for the hungry and needy. This program introduces to improve the quality of service through strategic partnership between government, industry and society, which will result in enhancing the entrepreneurs and leading to their prosperity.

In Dubai, the Dubai Islamic Affairs and Charitable Activities Department launched the first phase of the smart mosques project as part of a plan to shift to the smart government initiative (Construction Online, 2014). The worshippers can access the 24/7 service on mobile phones and smart tablets through the Quick Response Code. E-services will include general information about the history, construction, capacity and category of the mosque, as well as donations, suggestions, complaints and faults reporting.

3. NEEDS OF TODAY'S YOUTH IN MOSQUES

There are various factors that influence the need for and willingness of youth to be a part of a greater good through involvement. These include: feelings of efficacy (Sherrod et al, 2002), the need to be valued and taken seriously by others in the community (Flanagan and Van Horn, 2001), increasing their own self-esteem, and having a responsibility toward society by performing a public duty (Independent Sector, 2001). Recognition by the community at large is part of feeling valued (Scales and Leffert, 1999).

In order to solicit the needs of today's youth in mosques, Asim (2011) conducted a session for youth in UK to discuss their idea of the "Ideal Mosque" and the types of facilities it would have, the events it would organize, and the services it would provide. Within this session, the participants were asked to discuss what they thought their local mosque was already doing well, and what more it could be doing to move it towards their perception of the "ideal mosque". The participants were asked open questions such as:

- What is the role of the mosque?
- What are the reasons for lack of engagement in mosques?
- What activities would an ideal mosque engage in?
- How many of these activities are already provided by your local mosque?
- What would attract more youth to be engaged with the mosque?
- Are there any challenges/obstacles in the way of youth being more involved with the mosque?
- Should the services provided by the mosque be focused purely on religious fulfillment or also deal with other issues affecting Muslims?

The main suggestions made by the youth when asked to consider reasons for lack of engagement in mosques. It was clear that it was not the lack of interest in religion that was the cause of lack of youth engagement in mosques; rather the main issue seemed to be the lack of extra-curricular activities organized by mosques for the youth as illustrated in Figure 2.

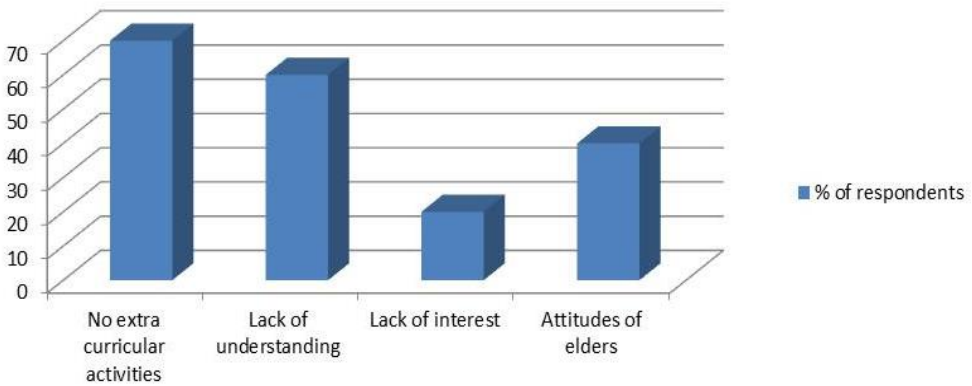


Figure 2: Reasons for lack of youth engagement in mosques
Source: (adopted from Asim, 2011)

When the youth were asked to consider what facilities mosques should offer, the main themes arising were; sports activities; sermons/lectures, and tackling contemporary issues affecting Muslims; library facilities; and computer equipment including internet access. These were cited as ideal facilities almost universally across each of the groups.

Other facilities which were mentioned by a number of groups were a relaxation area or a “chill-out room”/ “safe-space” for the exclusive use of youngsters in the mosque, organized excursions, and a gym. This shows that there is a real appetite amongst the youth to use the mosque for more than just the performance of ritual prayer.

They want to make the mosque a real “hub” of the community, a place where they can have social interaction with their peers in a spiritual setting. The main services that the youth would like to see being provided by mosques are outlined in the following sub-sections.

This is also supported by a set of focus groups and conducted interviews with youth by the author wherein the following four questions were raised and discussed and their outcomes were mostly in agreement with the findings from the extensive survey results conducted by Asim (2011).

- What are the activities (in addition to ritual worship) especially ICT related activities that you want to have available in the mosque that if provided will contribute to improving your presence at mosques with your youth colleagues?

- What are the concepts and the architectural design considerations, which you want to be embodied or included in the design of mosques so that it will contribute to the improvement of your presence at mosques with your youth colleagues?

- What are the functional spaces that wish to be included in the design of mosques so that it will contribute to the improvement of your presence at mosques with your youth colleagues?

- What are any other elements or factors to be included in the design of mosques so that it will contribute to the improvement of your presence at mosques with your youth colleagues?

3.1. Youth Club and Outdoor Activities

Mosques should organize sports activities in order to engage youth. Such sports could be either indoor or outdoor activities. Some of the mosques already have community halls adjacent to the mosque's building or owned by the mosque nearby. Those community centers could be used by the youth to 'chill-out' to play billiards, table tennis or such similar activities.

Spaces and facilities for young people's activities and meetings are required. In terms of outdoor facilities, sports activities could be organized around prayer times or study circles so that the youth attend the study circles or pray in the mosque as well as playing football or other sports. This practice will result on having some youngsters coming to the mosque more regularly and accordingly their level of presence at mosques will be improved.

3.2. Teaching Methods and Equipment

The teaching methods at mosques should be enhanced to make the content more attractive to the youth of the digital age, who expect more than simple paper and pens. Audio and visual equipment should be used where it can assist teachers and enhance the quality of youth education. Classrooms should have equipment such as: whiteboard, flipchart stand and paper, computers, TVs and video projectors, and books. The libraries of mosques should provide information in all formats i.e. books as well as videos, CDs, DVDs and rich online library.

3.3. Virtual Suggestion Box

Youth felt that in the digital age, mosques should have a website with an opportunity for the community to "communicate" with the management committee and the mosque leaders. It was suggested that there should be an "Ask" and "Suggestions" section on the website so that people can anonymously ask questions or post their suggestions.

The mosque could hold fortnightly, if not weekly, meetings to prioritize these suggestions. The "Ask" questions could be answered in the weekly circles for the youth. The website is also an ideal project for Muslim youth; young people could be asked to design the website, with the support and guidance of members of the management committee.

4. ANALYSIS OF ARCHITECTURAL FUNCTIONAL ELEEMNTS IN MOSQUES

The architecture of a mosque is composed of several elements developed over time and became symbols of religious buildings. There is, however, no sacred significance to any of these elements. The mosque is not defined by any architectural elements but by its orientation to the Kabah in Makkah, hygienic conditions, a kind of partition to contain the imam's or prayer leader's space and enough space for the worshippers to stand in rows and prostrate on a flat surface. Architectural elements such as gates, courtyards, water fountains, domes, Mihrab (niche), Minbar (pulpit) and the minaret are all nonessential elements in the constitution of the concept of the mosque.

The minaret, as an example, is not part of the worshippers' ritual sequence but rather part of the symbolic call of prayer, which was used for reaching out to a larger catchment area. There are various factors that influence the need for and willingness of youth to be a part of a greater good through involvement (Aazam, 2007).

Aazam (2007) conducted a study that consisted of 12 historical congregation mosques selected from diverse geographical regions of the Muslim world. These cases represented a particular prominence characterized by historical continuity and cultural diversity. The study assumes that these diverse 'living traditions' demonstrate little deviation from their original intent, and that this continuity is in itself an evidence of the society's continual investment in space.

The cases also represented the formal and regional building typology as classified by Frishman (1994) and Ardalan (1980; 1983). The mosques are referred to in the analysis by their abbreviations as follows: Damascus DAM, Sanaa SAN, Cairo CAI, Tunisia TUN, Fez, Djenne DJN, Istanbul IST, Isfahan ISF, Bukhara BUK, Shahjahanabad (Old Delhi) SHJ, Xian XIN and Malacca MAL as illustrated in Figure 3.

DAM SAN CAI

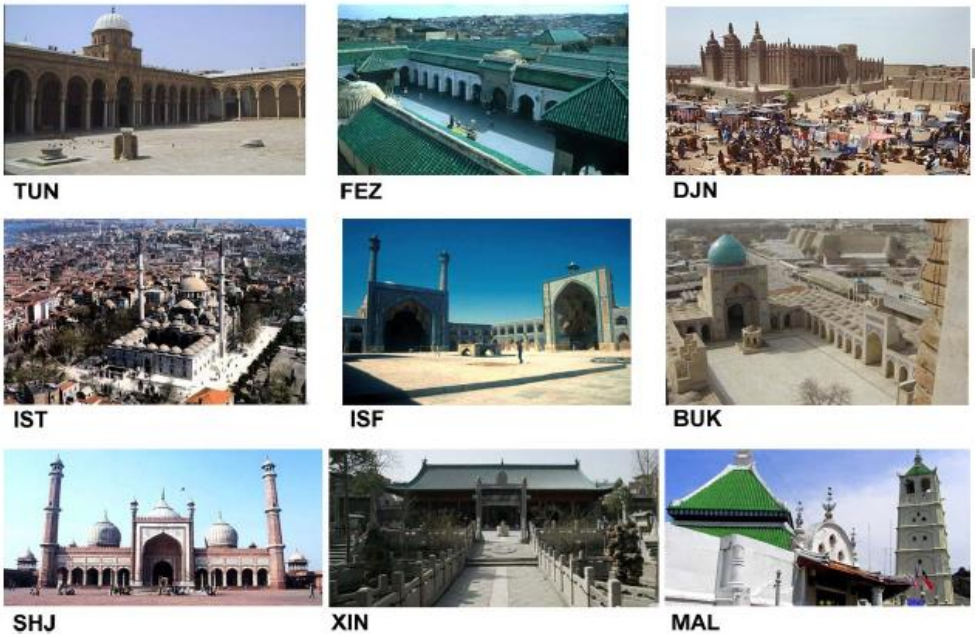


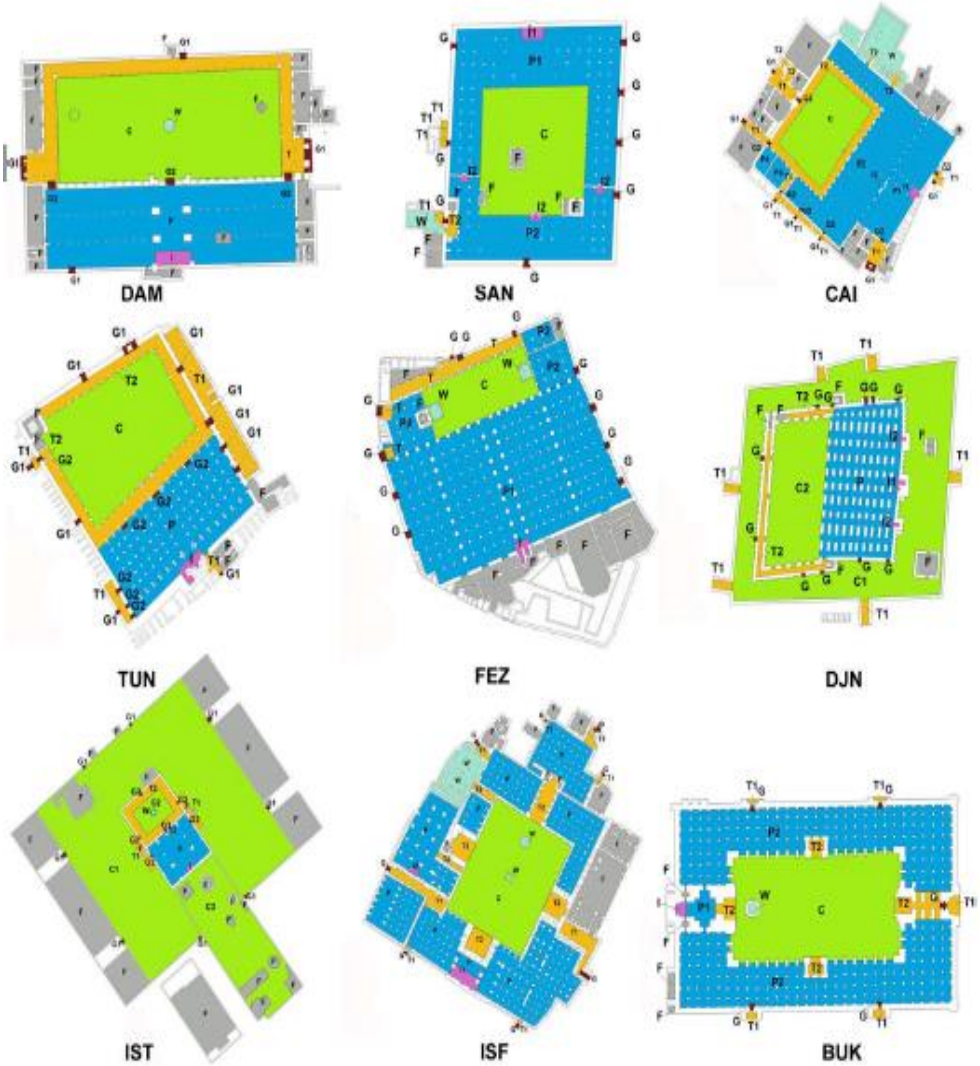
Figure 3: Mosques from representative cultural regions of the Muslim world
Source (Aazam, 2007)

Based on a general architectural analysis, seven spatial categories emerged as essential in these mosques. These spatial categories include: gate; transition space (transitional foyer, leading to either the court or the prayer area, and the transitional arcade around the courtyard); courtyard; ablution and hygienic (water fountains and lavatories); prayer area (with rows and central bay); Imam area (a group of objects found always in the proximity of one another forming the Imam's praying space such as Mihrab, Minbar); and functions (examples of these functions include minarets, libraries, treasuries, kitchens, storage spaces, bedrooms and other functions).

None of these spaces contribute directly to the ritual performance. Their presence, however, may suggest a degree at which the mosque contributes to social practices other than the rituals. This category is referred to in the analysis as 'F' as shown in Figure 4.

It is evidently noticeable from the space analysis shown in Figure 4 that the functional spaces (shown in grey color) vary considerably in their percentages to the total area of mosque spaces. However, the location of these

functional spaces is almost at the perimeter of mosques in order to be accessible to the public and not to interfere with the ritual spaces (Prayer area and Imam area). The variance in size of these functional spaces reflects the social role each of these mosques had on its neighboring community. This closely relates to the expectations and needs of today's youth from our modern mosques to provide more functional facilities that address their needs and to have a much stronger impact on the social life of people in its neighborhood.



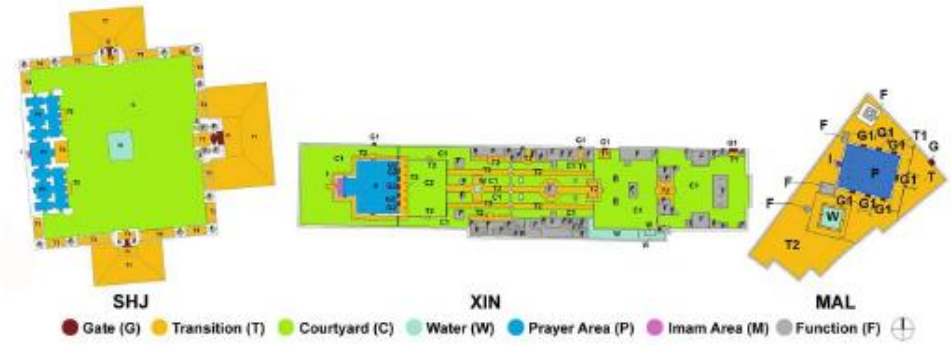


Figure 4: Analysis of architectural elements in the selected 12 Mosques
Source (Aazam, 2007)

5. A CONCEPTUAL APPROACH FOR RESHAPING ARCHITECTURAL DESIGN REQUIREMENTS AND ICT FACILITIES AT MOSQUES

Similar to the observation on the wide spread of social media especially in the recent years, it is also well noticed that most of youth are not commonly and regularly visiting mosques, and that they are fully engaged to the extent of addiction at sometimes to their digital and portable communication technologies by themselves or with their peers.

Based on the above analysis of youth's expectations and needs in mosques, there is a need to address the recent behavioral change of youth and to pay enough attention in terms of specific architectural design and ICT infrastructure for the design and operation of mosques. For instance, in order for the functional design consideration of mosques to attract youth to mosques such considerations should go beyond the basic common needs of offering only places for shoes, ablution and prayer. These are considered as necessities for the regular visitors, but cannot motivate youth who are not regularly visiting mosques.

This study introduces an approach as illustrated in Figure 5, to assist the architectural designers and developers to carefully rethink the design of mosques by providing new facilities and intelligent ICT infrastructure to attract the youth towards mosques. This approach is based on: (a) analyzing the current behavioral patterns of youth with regard to gathering and hanging out to the extent of not responding to the call for prayers; and (b) identifying

a set of attraction features based on the current literature of youth behavior and the set of focus groups, and on interviews with youth by the author.

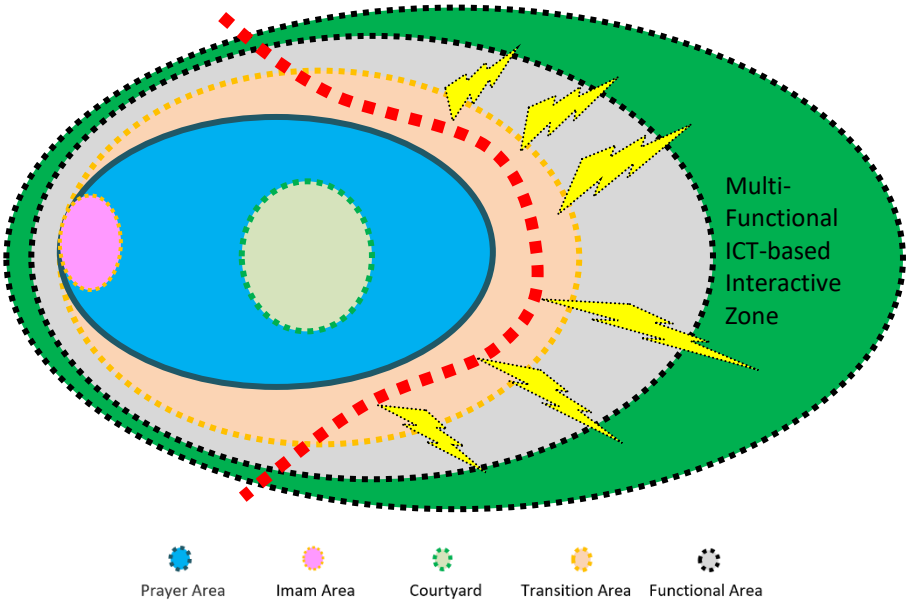


Figure 5: A conceptual approach for reshaping architectural design and ICT considerations of mosques for improving the presence of today's youth at mosques
Source (Author)

The proposed approach focuses on expanding the social role of mosques through expanding the areas allocated to functional spaces to be both flexible to multi-functional uses to youth and others and at the same time to be provided with ICT-based interactive infrastructure in a manner that does not negatively impact the prayer area. Also, the visionary approach is carefully considering the sustainability and environmental aspects by introducing greenery and around mosque as an interactive landscape and outdoor spaces to attract various sectors of the community including youth and to have the mosque as an attractive hub of activities including the usual worship.

Some of the attractive features of this approach include: open tech space adjacent or around the mosque for youth to hang out before and/or after prayers; quality landscape with decent sitting areas around the mosque to attract youth to spend quality time between or after prayers; deposit boxes with finger print access to keep mobile/smart phones outside the prayer area

of the mosque to avoid disturbance; study-zones outside the mosque with beverages service to attract youth to come together. These are in addition to integrating various youth functions in order to make the mosque as a hub of youth activities and at the same time preserving the sacredness of the mosque as well as realizing its multiple functions served during the time of the Prophet Mohammad (pbuh) while relating to the changing needs of today's youth.

6. CONCLUSION

Engagement of youth in the mosques is a duty that requires concerted effort of the entire Muslim community. To accomplish this change, all factors of change need to be taken into account. It is worth mentioning the beautiful reminder of Allah's beloved Prophet Muhammad (pbuh) about relationships among the people as well as the cardinal duty of mosques: “"He, who is not merciful to our youngsters and does not fulfil the rights of our elderly, is not one of us.

"[Hadith narrated by At-Tirmithi, Abu Daawood, Ahmad] (Islamweb, 2006). This paper has carefully investigated and analyzed most of the available literature on the uses of ICT by youth and their expectations and needs that should be considered while designing and constructing mosques that will potentially result in enhancing their level of presence in mosques. Some of the most recent initiatives for integrating some of the ICT features in mosques include the Network-of-Mosques in Malaysia and the Smart-Mosque in Dubai.

This paper introduced a conceptual approach associated with a set of attracting features in order to reshape architectural design and ICT considerations of mosques for improving the presence of today's youth in mosques. These features could be viewed as a startup tool kit that can be modified based on the target location, contextual conditions, and expectations and needs of potential users. The proposed approach will be best utilized at the early conceptual design stage especially at the time of formulating the requirements and design brief. The proposed approach is applicable not only to the new mosques to be designed and constructed but also in rehabilitating the existing mosques to meet the expectations and needs of surrounding neighborhoods in order to revert the role of mosques as interactive social hub for the community and most importantly for youth.

Accordingly, it is highly recommended for either the governmental authority or private investors to take the lead and implement a pilot implementation of the proposed approach to pursue the initiatives considered in both Malaysia and UAE. However, further research is required to identify the set of obstacles and barriers to rehabilitate the existing mosques and ways to overcome it to appropriately adopt the proposed approach. This is in addition to developing a set of criteria and measurable indicators for its successful implementation to both existing and new mosques.

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GREEN ROOF AND LOUVERS SHADING FOR SUSTAINABLE MOSQUE BUILDINGS IN RIYADH, SAUDI ARABIA

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Abstract

The number of mosque buildings is continuously increasing with the Muslim population, which is in fast growth around the world. In particular, the demand of new mosque buildings is high in the urban areas, due to increasing urban population growth in many parts of Muslim countries, as a result of economic growth and political instabilities in some parts of the Muslim world. Mosques are becoming more overcrowded and as a result a number of researches have been conducted to address the issue of thermal comfort of mosque users. Additionally, mosque building is unique because of its intermittent operation and user-diversity, which require unique heating or cooling strategies. On the other hand, due to environmental pressure to suppress global warming, more energy efficient and sustainable building design is one of the current issues.

This research aims to explore the sustainable techniques for mosque buildings in different climate zones. This research assesses a number of mosque buildings in different parts of the world with different climate, and investigates the strategies employed to cool or heat these buildings depending on the climate and season. The effectiveness of the building features in relation to each climate are carefully analyzed, and possibility of potential replication of these features elsewhere are examined. This paper examined two techniques, green roof and louver shading in hot arid climate. The eventual objectives are establishing a guideline for architects and mosques building designer at any climate in order to achieve sustainable mosque building. The study concludes that there is a potential saving of up to 10% in cooling loads when green roof and louvers shading are applied on the simulated mosque building in Riyadh, thus achieving the environmental feasibility in addition to economic and social benefits.

Keywords

Mosques, design, thermal performance, green roof, louver shading.

الأسطح الخضراء وسواتر التظليل لمباني مساجد مستدامة في مدينة الرياض بالمملكة العربية السعودية

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المستخلص

من الملاحظ عالمياً أن عدد المساجد في تزايد مستمر نظراً لتزايد تعداد المسلمين بنمو مطرد في جميع أنحاء العالم. على وجه الخصوص، الطلب على المساجد الجديدة يزداد في المناطق الحضرية بسبب زيادة النمو السكاني في أجزاء كثيرة من بلاد المسلمين، وذلك نتيجة للنمو الاقتصادي وأيضاً عدم الاستقرار السياسي في بعض الأجزاء من العالم الإسلامي. ونتيجة لإكتظاظ المساجد فقد تم إجراء عدد من البحوث لمعالجة مسألة الراحة الحرارية لمستخدمي المساجد. بالإضافة إلى ذلك، يعد مبنى المسجد فريداً من نوعه بسبب طبيعة استخدامه على فترات متقطعة من اليوم وتباين أعداد المستخدمين على الدوام وبالتالي يتطلب استراتيجيات تدفئة أو تبريد فريدة من نوعها. من ناحية أخرى وبسبب التوجهات العالمية البيئية للمساهمة بحل ظاهرة الاحتباس الحراري فإن تصميم المباني المستدامة، والتي هي أكثر كفاءة في استخدام الطاقة، هي واحدة من القضايا الراهنة والمحورية في صناعة البناء.

يهدف هذا البحث إلى استكشاف التقنيات المستدامة لمباني المساجد في مناطق مناخية مختلفة عبر دراسة عدد من مباني المساجد في أنحاء مختلفة من العالم في مناخات متباينة ومن ثم تقيم الاستراتيجيات المستخدمة لتبريد أو تسخين هذه المباني اعتمادا على المناخ مع فحص إمكانية تكرارها في مكان آخري. على وجه التحديد تتناول هذه الورقة اثنين من التقنيات، السطح النباتي وتظليل النوافذ بالسواتر في المناخ الجاف الحار مثل مدينة الرياض وذلك بهدف إنشاء معايير توجيهية للمهندسين المعماريين ومصممي المساجد لتحقيق بناء مساجد مستدامة في نهاية المطاف. تخلص الدراسة في نهايتها إلى أن هناك إمكانية توفير بنسبة ١٠٪ من أحمال التبريد عند استخدام الاسطح الخضراء وسواتر تظليل النوافذ على مبنى مسجد في مدينة الرياض تمت محاكاته حاسوبياً وهذا مما يحقق الجدوى البيئية مع وجود منافع أخرى اقتصادية وإجتماعية.

الكلمات الدالة

المساجد، التصميم، الأداء الحراري، الأسقف الخضراء، سواتر التظليل.

1. INTRODUCTION

The demand on the world energy market is increasing gradually and the expectations of future world energy consumption is significant which has led to strains on the depleting energy sources (Amer et al. 2015). For instance, the Middle East and North Africa region consumes a massive portion of the energy produced globally. By comparison, the Middle East countries have consumed approximately 40% more energy than Europe in 2010 while their population is only 53% of the European population (United Nations n.d.).

Arguably, Middle East countries such as Saudi Arabia, Qatar, Kuwait and United Arab Emirates (UAE) have become energy-draining, due to their extravagant energy usage. The Saudi Arabian energy consumption has increased by 75.26% for the period 2000-2011. Similarly, power consumptions of Qatar and UAE have risen sharply for the same period by 69.00% and 120.24% respectively. Figure1 shows the dramatic increase of the total energy consumption in Saudi Arabia for the period 2000 to 2012. (US Energy Information Administration 2012).

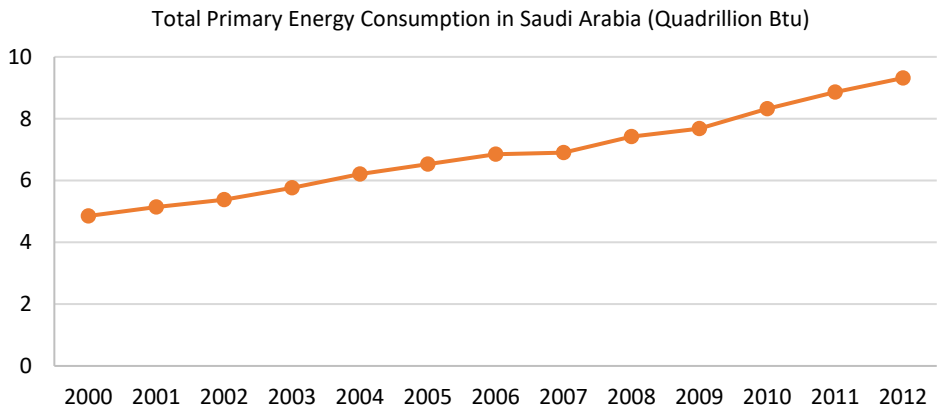


Figure 1 Total primary energy consumption in Saudi Arabia
Source: (US energy information administration 2012)

At least 40% (65% in some hot regions) of the energy consumption in buildings is used to assure user's thermal comfort by air conditioning the indoor space (Rosenlund 2000). The percentage varies based on the building type, climate zone and the microclimate of the building. Due to the harsh weather the percentage of electrical energy consumed by air conditioning is considerably higher in hot arid regions.

For example, only 22% of the energy consumption is used for providing comfortable indoor temperature in buildings in UK, whereas it is 65% in Saudi Arabia (Alajlan et al. 1998). Among a range of buildings, in particular, mosque buildings in Saudi Arabia are found to be one of the highest energy consumers. Figure 2 displays the energy consumption of mosque buildings in comparison to some other sectors in 2013 (Alsaeah 2013). The number of mosque building varies from country to country, and from city to city. For example in Saudi Arabia, Riyadh city is one of the popular cities in mosques' number, with more than 15 000 mosques (MOIA 2013), and it has a harsh hot dry weather.

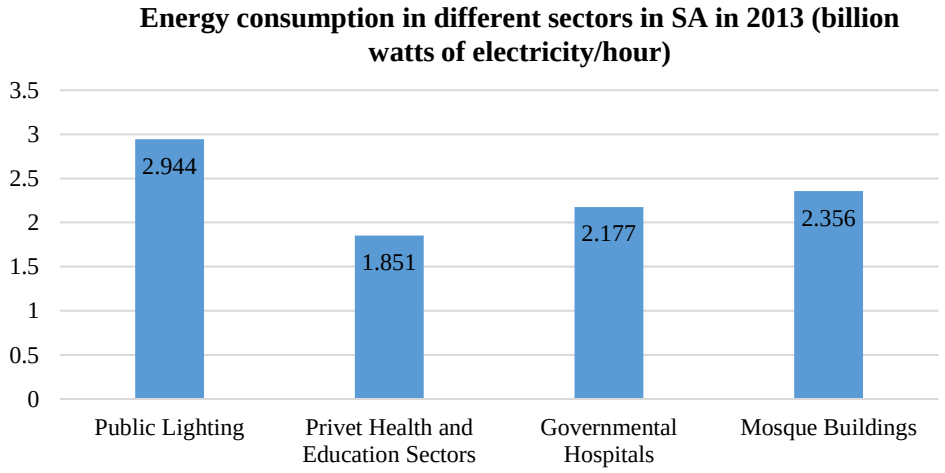


Figure 2 Mosque buildings consumed power more than hospitals in Saudi Arabia in 2013. Source: modified from (Alsaeah, 2013)

A mosque building is a worship place for Muslim to perform prayer and recite the holy book "the Quran". However, in the early stages of Islam, mosques were not only for worship but also for socializing, judicial and administrative purposes. Currently, mosques are used mainly for prayer and in some places for religion studies and Quran schools.

Moreover, the goal of sustainability could be achieved through different ways and under many names. For instance, low energy buildings, energy efficient buildings, passive houses, sustainable buildings, green buildings and so on. All of these are about providing comfortable indoor spaces without harming the environment.

Mosque buildings are unique among other religious buildings as they are used 5 times a day round the year by a varying number of occupants each time. Therefore, designing the cooling or heating systems for mosque building is also unique to meet the requirements of this varying occupancy and intermittent operation, in a sustainable way. Also, mosque buildings have unique specifications with regard to the internal space; usually it is large and has a high ceiling. Moreover, the prayer performance and nature of usage are dissimilar to other types of building. All these variables should be considered while studying the thermal performance in mosque buildings.

This study aims to investigate sustainable techniques for mosque buildings in order to reduce space cooling load, and assist designers and architects to make further sustainable decisions. The study assesses a number of mosque buildings in different climates, and investigates their features to achieve sustainability.

Figure 3 expounds the problem statement for this study and why mosques are different than other type of buildings. The main aim is to determine the most efficient sustainable features for mosque buildings in different climates, thereby providing a comfortable environment for worshipers and reduce the consumption of resources to obtain sustainable outcomes. The research focuses on green roof and louvers shading as means of reducing the cooling load, through computer simulation of mosque building in the climate of Riyadh city as a case study.

2. BACKGROUND AN REVIEW

2.1. Sustainability in Mosque Building

Mosque are called “Lord Houses” or “religious buildings” by Muslims, thus they are considered as Islamic symbols. Many verses in the Muslim Holy book (The Qur’an) state that the Almighty Lord (Allah) commanded all human beings against wasting and extravagant use of the resources of life, and urged all of us towards protecting the environment. Allah says in the Holy Qur’an: “O Children of Adam take your adornment at every place of prayer. Eat and drink, and do not waste.

He does not love the wasteful” (Holy Qur’an Chapter 8, Surat Al-‘Araaf, verse 31); these verses mention the mosque and the order of avoiding waste. Therefore, it is very essential for all mosque buildings to follow Allah’s commands including our responsibilities towards the preservation of the

resources and the environment in the first place. So if the concept of sustainability should be added as a value to all types of buildings, the religious buildings, particularly mosques, should be in top priority.

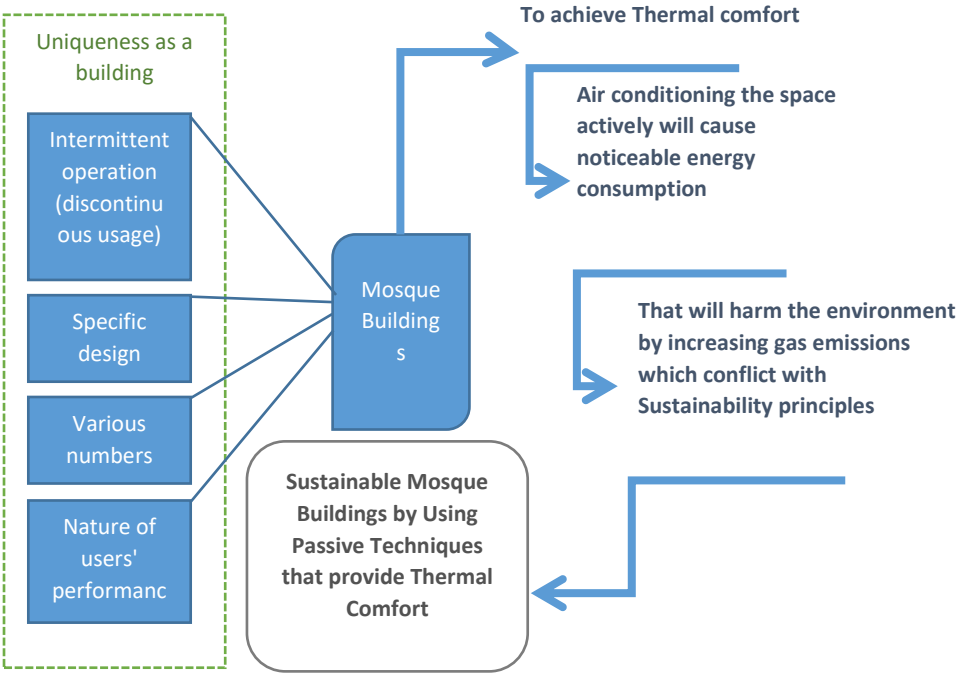


Figure 3 Illustration of the problem addressed in this research project.
Source: Authors

2.2. Previous Studies on Mosque Buildings and Energy

The research on mosque buildings in terms of thermal performance and energy conservation is new compared to other types of buildings; only in the last 20 years that some research has done on mosque buildings. Among many of the researches on mosque buildings, some of the critical issues included thermal comfort, thermal performance, low energy and passive strategies.

There is a large volume of literature on sustainable mosque buildings, and Figure 4 summarizes some of the investigations and the key outcomes. A group of researchers from Malaysia have proposed a system that recycles used ablution water within a close-loop system for toilet flushing, general washing, green roof, plantation and flowerbed cultivation (Suratkon et al. 2014). Another group of researchers have proposed a social sustainable assessment model for mosque development in Malaysia (Ahmad et al. 2012).

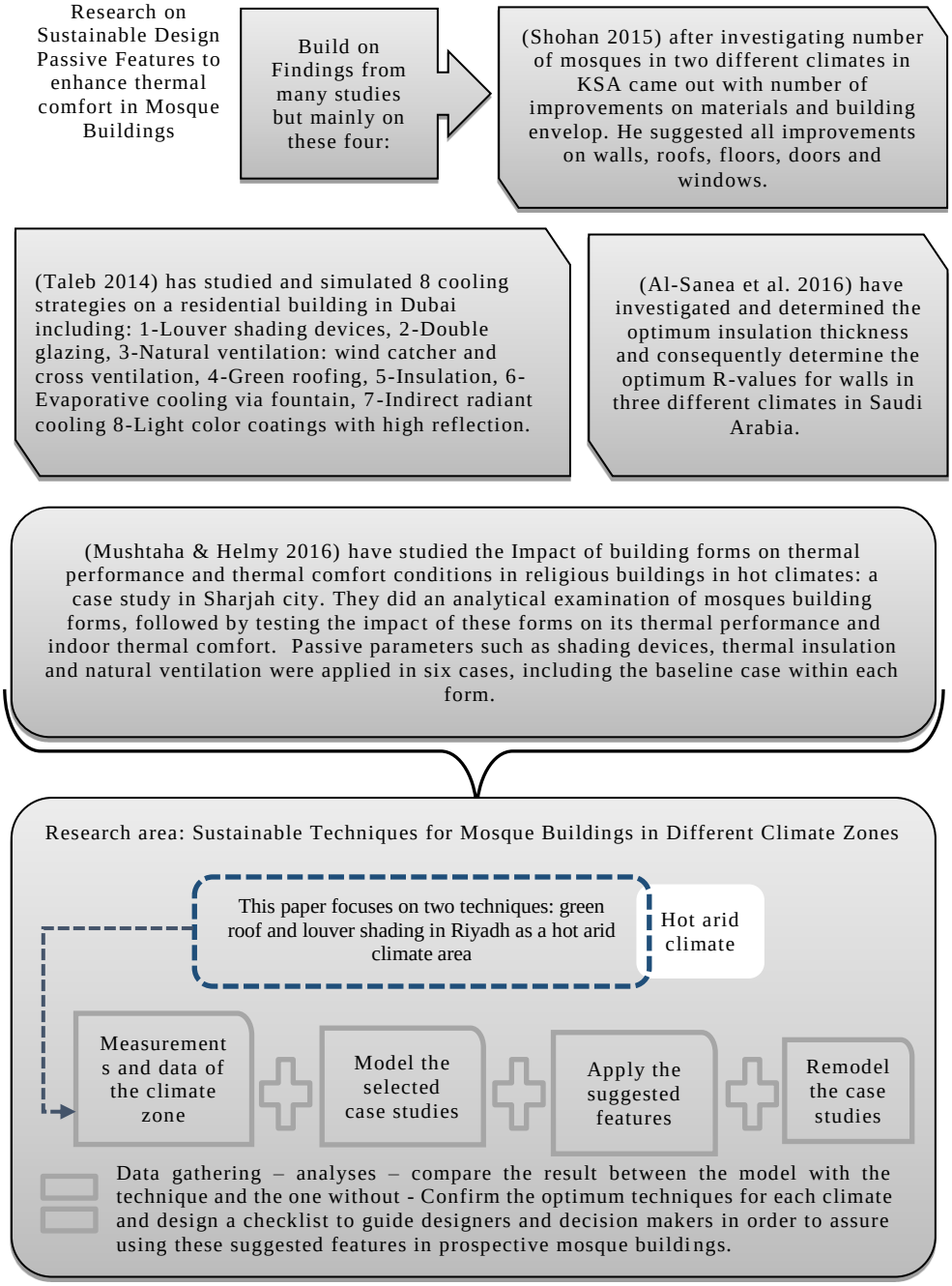


Figure 4 A simplified diagrams of the major outcomes of the key investigations on sustainable mosque buildings.
Source: Authors

2.1.Causes of Irrational Use of Electricity in Mosque Buildings

Mosque buildings are considered as the most frequently and temporally used buildings compared to other public buildings (Alsaeah 2013), and for this reason they are adequately investigated in terms of their energy performance.

Many mosque buildings are built based on the traditional Islamic architectural design, which in some occasions are well designed based on the climate. In many other cases this was not the case, as architects copied designs blindly. The power wastage in mosque building could be attributed many factors. For instance, mosque buildings are usually built by using donations, and their operational costs are covered by local donations or by governments (as in many Islamic countries). As a result, the comfort of the occupants was the most important issue when so heavy air-conditioning systems and extravagant lighting are employed. Moreover, the energy systems are operated without considering the varying number of occupants, which results in wastage of energy.

Most are normally full during Friday prayers, and the number declines in dawn and other periods of the week. Therefore, the energy use per a user is very intensive in most occasions. In order to rationalize the energy consumption, Mosque buildings have to be designed in a flexible way to allow expanding upon need (Umran 2009). Other factors include, negligence to the adoption of rationalized solutions in building, low prices of air conditioning devices compared to the monthly operation cost and lack of awareness on the impact of mosque buildings on the energy bill and the environment. Therefore, it was necessary to pause and reflect on how mosque building are designed and operated, in order to highlight the pros and cons of mosque buildings features in relation to energy use and the resulting environmental impact that they cause (Rosenlund 2000).

3. MOSQUE BUILDINGS FEATURES

3.1. Comparison of Mosques Buildings in Different Regions

In order to correlate mosque building features with the climate for the sustainability point of view, a number of mosque buildings have been selected randomly from around the world, and are then filtered to ten buildings with unique features related to the climate zone. An extended analysis has been carried out to investigate and assess the sustainable features that have been

employed in these buildings with regards to the climate zone. The purpose is to assess the relevance of the feature to the climate zone. Each case has been investigated and presented in a specific order. A summary of the mosque's sustainable features including the architectural and geometrical arrangement are highlighted in Tables 1 and 2. Analysis is made of the heating, ventilating and air conditioning functions and lighting systems. Finally, the mosque facilities and serves are noted, highlighting their sustainability.

Table 1 Comparison of mosque buildings in different regions
Source: Authors

	Mosque's name	Location	Year of built	Notes on sustainable features	Weather				
					Climate zone	Classification	Average Temperatures (weatherbase)	Average Humidity	
1	Great Mosque of Djenné	Djenné, Mali	1307	1- Assuring Security by building it on a 3 m high platform. 2- Using local materials of mud bricks, palm wood and mud plaster. 3- It has a courtyard. 4- Very good insulated muddy walls that is up to 1m thickness. 5- Basic but effective solutions for natural lighting (diffuse light) and ventilating.	Tropical	Tropical Savanna	Annual: 29°C Highest: 45°C Lowest: 6°C	Morning:62% Evening:35%
2	The Great Mosque of Touba	Touba, Senegal	1963	1- Using some local materials for textures but it is a concrete building as a structure. 2- It has a courtyard mostly shaded and a water fountain in the centre. 3- It depends on the natural ventilation plus ceiling fans.	Tropical	Mid-Latitude Steppe and Desert	Annual: 28°C Highest: 33°C Lowest: 20°C	Morning:56% Evening:32%
3	Great Mosque of Dakar	Dakar, Senegal	1964	1- Using local materials from Moroccan style since it's partly funded by Moroccan price. 2- It has a courtyard with a water fountains. 3- The mosque small windows to limit heat gain from the sun.	Hot Arid	Mid-Latitude Steppe Humid and Desert	Annual: 24°C Highest: 38°C Lowest: 11°C	Morning:85% Evening:65%
4	London Central Mosque	London, UK	1977	1- Even if the main material for the mosque is concrete, the designer used some natural materials such as: Derbyshire spar aggregate on wall's decoration and copper on the dome. 2- High monumental ceiling that help in ventilation. 3- Good use of daylight from skylight, vents at the base of the dome and the large windows in two parallel walls.	Temperate	Marine West Coast	Annual: 10°C Highest: 35°C Lowest: -13°C	Morning:91% Evening:68%
5	Sultan Salahuddin Abdul Aziz Mosque	Shah Alam, Malaysia	1988	1- It provides windows glasses solution of grills and coloured glaze. 2- The site overlooks the Garden of Islamic Arts which gave a unique surrounding and offered a clean and desirable environment. 3- It has a courtyard with a water fountains. 3- The mosque has small windows to limit heat gain from the sun.	Tropical	Rainforest	Annual: 27°C Highest: 39°C Lowest: 16°C	Morning:96% Evening:70%
6	Masjid Alabbas	Riyadh, Saudi Arabia	2003	1- The concept behind this mosque is saving energy by using expanded pray area in 3 halls to be used as needed. 2- This solution decrease maintenance cost as well. 3- Skylights have been used to get natural daylight.	Hot Arid	Subtropical and Desert	Annual: 26°C Highest: 47°C Lowest: +1°C	Morning:36% Evening:19%
7	The Shaikh Zayed Grand Mosque	Abu Dhabi, UAE	2007	1- water pools around the arcade of the building. 2- It unites the cultural diversity of Islamic world by its complex design from different Islamic styles. 3- It has a separate prayer hall for daily use; the whole mosque is used weekly for Jumaa pray on Friday and for two Eid prayers.	Hot Arid	Subtropical Desert/ Costal Humid	Annual: 27°C Highest: 47°C Lowest: 3°C	Morning:75% Evening:43%
8	Sancaklar Mosque	Istanbul, Turkey	2013	1- The mosque highly respected the site and it harmonies with the location. 2- Using natural stone from local sources. 3- Using water elements. 4- Using natural daylight and skylight perfectly.	Temperate	Mediterranean	Annual: 14°C Highest: 37°C Lowest: -8°C	Morning:82% Evening:51%
9	Khalifa Altajer	Dubai, UAE	2014	1- This mosque got accepted from USGBC and awarded the silver certificate. 2- The first sustainable mosque in Islamic world. 3- All external lights are powered by solar PV. 4- Other solar panels to heat water for ablution and imam house (no electrical heater). 5- All lights inside and outside are LED lights. 6- It uses a Light operation system during prayer times on need base. 7- Water reusing system from ablution to flush toilets and gardening. 8- Insulated materials for building and double glazing windows.	Hot Arid	Subtropical Desert/ Costal Humid	Annual: 27°C Highest: 48°C Lowest: 7°C	Morning:71% Evening:49%
10	Nilüfer Trade Centre Mosque	Bursa , Turkey	Under constr uction	1- This mosque has been designed to be a sustainable mosque. It featured some great ideas in using renewable energy such as: solar panel, vertical wind turbine and reusing grey water from rain and after ablution.	Temperate	Mediterranean	Annual: 14°C Highest: 41°C Lowest: -15°C	Morning:86% Evening:57%

Table 2 Analysis of mosque features
Source: Author

		Lighting			HVAC			Sustainable Building Features						
	Mosque's name	Skylight	Double Glazing	Reflictive film	Electrical fans	Mechanical air conditioning		Courtyard	Photovoltic	light color coating	Shading	Green Roofing	Evaporative cooling	Thermal Mass
						Heat	Cool							
1	Great Mosque of Djenné													
2	The Great Mosque of Touba													
3	Great Mosque of Dakar													
4	London Central Mosque													
5	Sultan Salahuddin Abdul Aziz Mosque													
6	Masjid Alabbas													
7	The Shaikh Zayed Grand Mosque													
8	Sancaklar Mosque													
9	Khalifa Altajer													
10	Nilüfer Trade Centre Mosque													

3.2. Mosque Building Climate Zones Classification

Following critical analysis of the selected ten case studies, the features that enhanced their sustainability are summarized. The objective here is to demonstrate the ability of these features to sustain the building operation, in particular, its accessibility, energy consumption for both lighting and HVAC (heating, ventilation and air-conditioning) under the relevant climate. Pacheco et al. (2012) mentioned that even there are many factors affecting climate based building design; the most important are energy-efficient design methods. A building design based on energy-saving criteria reduces economic costs throughout the useful life of the building, and this compensates for the greater initial investment. Since there are also less CO2 emissions into the atmosphere throughout the building's life cycle, this benefits the society through ecological and environmental sustainability (Pacheco et al. 2012).

Likewise, suitable heating and cooling designs are paramount in energy efficient building designs (Omer 2008). Accordingly, the factors considered for the present study are: shape and orientation of the building with respect to solar geometry and wind flow, building envelope materials, shading and

green roof. Most of these features and parameters govern the building energy requirements (Bektas Ekici & Aksoy 2011), and hence should be carefully considered when designing a mosque building under any given climate or region. The climate zones could vary considerably; however in this study the main three zones widely recognized in previous case studies (Gut & Ackerknecht 1993; Rosenlund 2000)will be considered, such as tropical, hot arid, and temperate climate.

The climatic conditions are sensitive and may vary even within the same country, so general outlines are sufficient to understand how buildings performance are affected by a given climate. Climate dictates what passive design strategies are most suitable for a given building site. There are many parameters that contribute to the climate definition such as temperature, altitude, humidity, solar position, precipitation, topography and wind; but for practical reasons, this paper focuses on most effective factors that play a key role in building features and indoor comfort.

Review of the ten cases of mosque buildings from various climates and investigation of the climate design features, have led to the understanding of the relationship between each climate and the potential passive cooling/heating and ventilation features. Further search has been carried out on the building standards and green building codes in a number of countries, which has recognized building regulations and codes. The top sources, in addition to recently published papers, were from the United Nation documentations, USA, United Kingdom and Australia. Some of these countries such as USA and Australia have the capacity of involving almost all climate zones in their codes due to the size of these countries, covering a range of climate zones. Figure 5 illustrates the links between climate zones and the most relevant passive features.

3.3. Discussion of Sustainable Buildings' Features for Different Climate Zone

Across the history, people built and housed themselves in enclosures that had strong consideration to the local climate (Olgyay 1982). The buildings in most cases have some special features to overcome the harsh weather conditions; for example, compact well insulated and airtight form in cold climate versus a wider form with courtyards, heavy construction materials, shading devices and small windows in hot climate (Mofidi 2007; Liu et al. 2006). Hot and dry climatic zones generally occur at latitude between 150 and

300 on both the hemispheres. Maximum day time summer temperature goes as high as 480C and relative humidity as low as 20 %. This type of climate is experienced in areas far from sea coasts and do not receive heavy rainfall. Thus, the humidity is very low. In this climate air flow is paramount to ventilate the enclosure. Similarly, the hot humid climate has the same feature of hot-dry climate except for the level of humidity. The temperature range is relatively high at around 30 - 35°C(Gut, P., & Ackerknecht 1993) and is fairly even during the day and throughout the year.

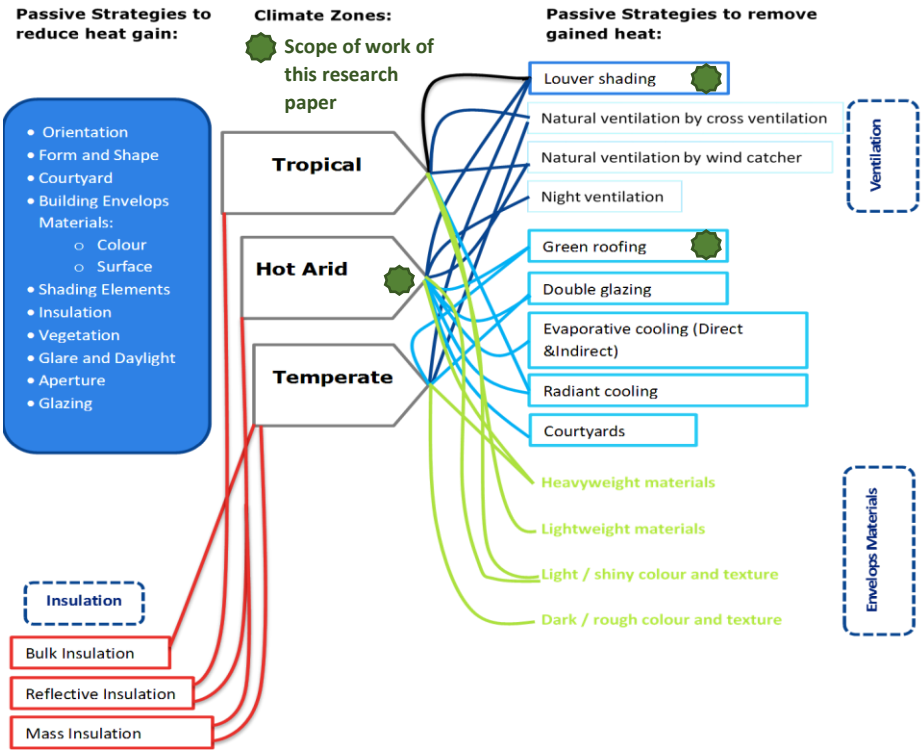


Figure 5 Correlation of Mosque buildings' features with climate
Source: Author

Winds are light or even nil for longer times because of slight temperature differences; however, heavy precipitation and storms happen commonly. The indoor temperature can barely be kept much below the outdoor temperature, but with an effective design the indoor temperature can abstain from surpassing the outdoor temperature and internal surfaces can remain generally cool. Comfort conditions can be obtained by a legitimate ventilation. The

followings are some of the features that are key and should be carefully considered for building design for most of the climate zones.

3.3.1. Shape and Orientation:

The shape of the building plays a key role on the external surface area, which consequently determines its energy balance and hence the cooling or heating load. As a general rule, the square and rectangular shapes with 1:2 percentages of width and depth are most suitable choices. Use of courtyards is a means of meeting this requirements for hot climate (Olgyay 1982). A number of studies have shown that courtyards can contribute greatly to energy efficiency in hot arid climate (Aldawoud 2008; Almhafdy et al. 2013), owing to the extra external surface area that aids heat removal.

Building orientation can reduce cooling loads through minimizing solar heat gain through windows, minimizing or increasing solar heat gain through walls and roofs based on the climate. Choosing an appropriate orientation relative to the wind direction can also help to maximize cross ventilation, which mostly suits building in hot arid areas (St. Clair 2009). It is generally agreed that a southern orientation is optimal for gaining heat in the winter and for controlling solar radiation in the summer. As a general rule, the longest wall sections should be oriented towards the south especially if the shape is not a cube which is generally the most efficient shape (Mingfang 2002;Olgyay 1982).

For any architect, the problem for orientating the mosque building is its requirement to be toward Qibla (the direction to Kaba, inside the Holy Mosque in Mecca). However, there is a possibility to change the orientation of the whole building except the prayer hall, as in the eighth case – Masjid Alabbas in Riyadh, KSA (case number 6 in table 1and 2). Most designers or architects tend to orient the whole building based on the direction of "Qibla"; this is not necessary because the prayer rows could be adjusted, while the building could be appropriately oriented according to the energy saving strategy for the climate zone.

For example in hot climate, to reduce solar penetration in the afternoon, the glazing on the west facade should be minimized, and the building may be oriented along east-west direction for minimum solar heat gain by the building envelope (Ahsan & Tekniska 2009). In cold climate, the emphasis is to enhance solar heat gain, and the building should be orientated with larger glazing facing south, east and west.

3.3.2. Building Envelops Materials

The building envelope materials play a major role in the overall energy performance of any building, by controlling heat transfer, solar radiation, air flow and moisture penetration. All these have impact on the building energy requirement. A study conducted by Al-Sanea et al. (2016) has concluded that, the optimum R-values of buildings walls for Riyadh city, which is classified as hot and dry, are from 2 to 2.9 m2. K/W. The most suitable color for external surfaces is a light color for roofs and walls in order to reflect heat.

The comfort of people inside the buildings depends largely on the thermal properties of the outer and inner walls and the roof. Although not very much investigated or considered in many mosque buildings, the internal thermal storage capacity (thermal mass) is one of the most important elements of sustainable building features, as this helps to decrease the diurnal temperature variations and also may be employed to utilize the night ventilation potential by "storing the coolness of the night for use during the day time. There is a range of materials which could be considered based on the climate characters (Gut & Ackerknecht 1993).

3.3.3. Blinds and Shading:

As a general rule for extremely sunny areas, it is recommended to avoid overuse of glazing in buildings; glazing of low U-value and double-glazing are essential in all cases. Australian government selected the passive shading for north-facing windows in their sustainable housing guide (Reardon 2013). On the other hand, the opposite is selected for the northern hemisphere.

Figure 6 shows some example types of shading arrangements, which have been studied by varies researchers. The use of adjustable shading devices is recommended to allow variable solar access in different seasons based on the climate variation. The type and arrangement of the shading elements may vary depending on the climate zone.

However, it was widely suggested to have vertical shading elements for northern and southern facades in southern and northern hemisphere respectively, while the horizontal ones are suggested for western and eastern (St. Clair 2009). Also, these shading devices are recommended to be operable since they are most effective in hot and arid climates where they can reduce solar heat gain through windows by 85%- 90%, while still permitting day-lighting (Givoni 1998).

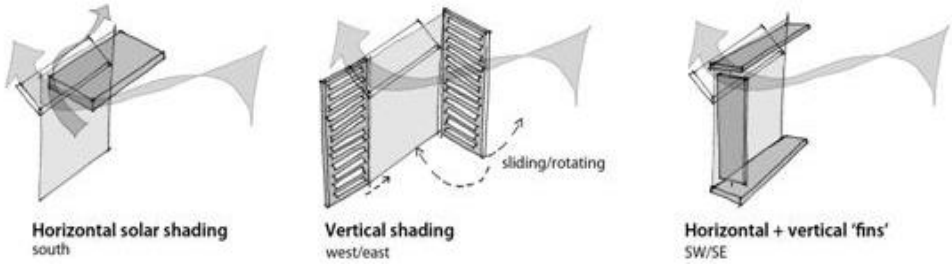


Figure 6 shows different types of shading devices, the middle one is the movable louvers. Source: (McGregor 2013)

3.3.4. Other Sustainable Systems:

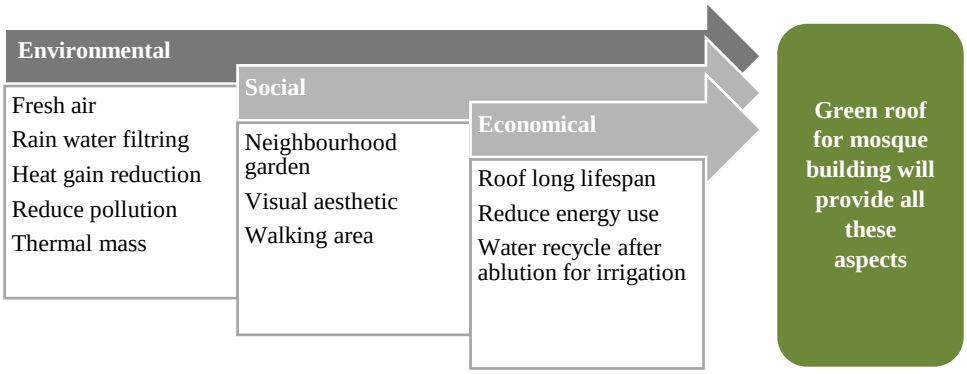
A range of sustainable techniques including passive techniques for control of indoor temperature and humidity were employed for long time and in many parts of the world in ancient times, and with the widespread use of electrical energy, these methods gradually became obsolete (Sanjay & Chand 2008). A passive system refers to any technical solution or design feature implemented to reduce the temperature of buildings without the need of mechanical device or with minimum power consumption. Taleb (2014) has performed a study in hot arid climate (Dubai city as a case) by testing eight passive cooling strategies. It has found that the total annual energy consumption of a residential building could be reduced by up to 23.6% with passive cooling strategies (Taleb 2014).

3.3.5. Green Roofs

In this paper, the strategy used by Taleb (2014) has been assessed further. The green cover on outer walls and roof has many advantages. It protects the walls against heavy rain and reduces the wind velocity on the surface. Also, green cover eliminates glare and offers visual aesthetic value. In particular, green roof system has many advantages not only for environmental reason but also for economic and aesthetic reasons.

For the environment, green roof helps lowering gas emissions, improving air quality, water management and heat gain reduction. Aesthetically, it provides open spaces, visual value, acoustic absorption and vegetables production. On the other hand, green roof aids in increasing life for the roof, insulating building and energy efficiency (Aziz & Ismail 2011). Table 3 explains the motive of this paper by using green roof for mosque buildings.

Table 3 The motive of using green roof for mosque buildings
Source: Author



The green roof is a building's top surface, which could be flat or pitched, either planted completely or partially. It could be planted with eatable or non-eatable vegetation on a growing medium, soil as an example. The main objective of any green roof is to enhance building's thermal performance through two ways: decreasing direct heat gain from the sun and reducing energy consumption. Figure 7 shows the basic layers of green roof system; green roof is also known as living roof, planted roof and vegetated rooftop (Sailor 2008). There are many types of green roofs around the world and because of the growing demand there is new invention from time to time in the green roof field. However, the main three types such as extensive, semi-extensive and intensive are compared in Table 4.

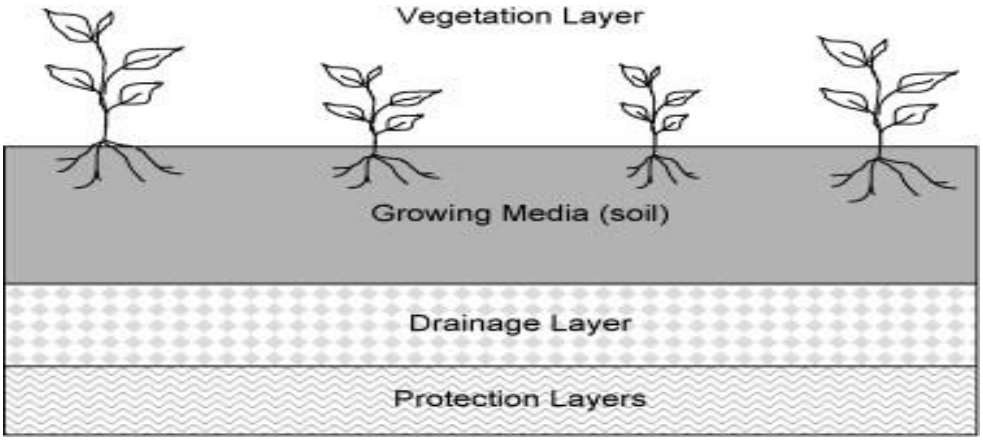


Figure 7 the basic layers of green roof
Source: (Sailor 2008)

Table 2 comparison table of major types of green roofs and their characteristics
Source: (Hui 2011)

Characteristics	Extensive	Semi-intensive	Intensive
Depth of material	150 mm or less	Above and below 150 mm	More than 150 mm
Accessibility	Often inaccessible	May be partially accessible	Usually accessible
Fully saturated weight	Low (70–170 kg/m^2)	Varies (170–290 kg/m^2)	High (290–970 kg/m^2)
Plant diversity	Low	Greater	Greatest
Plant communities	Moss-sedum-herbs and grasses	Grass-herbs and shrubs	Lawn or perennials, shrubs and trees
Use	Ecological protection layer	Designed green roof	Park-like garden
Cost	Low	Varies	Highest
Maintenance	Minimal	Varies	Highest

3.4. The Proposed Building Model

Despite many interesting features, the green roof is employed only in Sancaklar mosque in Istanbul, Turkey (see Table 2). This mosque is located in a temperate climate and has neither active heating nor cooling systems. The green roof was able to provide a sustainable environment by maintaining indoor thermal comfort year round. This successful example is an inspiration to investigate the applicability of green roof for mosque buildings in different climates, which is the aim of this paper. In order to obtain a more valid results, a real case has been chosen to simulate the applicability of the green roof. Shohan (2015) selected some cases in Riyadh city to investigate the thermal comfort for mosque buildings and then he has selected one case to apply the suggested improvements on the envelope. These improvements will be referred to as (Ref.1).

The building is Prince Sultan mosque in Almoroj district in northern part of Riyadh city. He used field studies and simulation by using the Thermal Analysis Simulation (TAS) program of Environmental Design Solutions Limited (EDSL). In addition to services zone, this mosque has a main prayer hall of 480 m2 Shohan (2015), which is the main space for this study. Figure 8, 9 and 10 respectively show the mosque's 3D model, real image by Google Earth and some photos showing the building elevation.

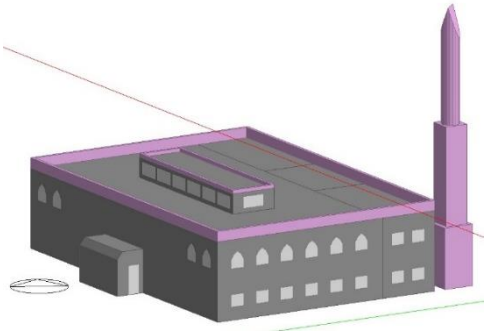
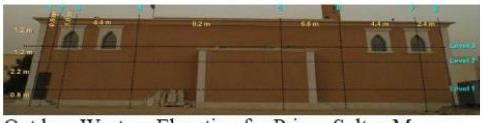


Figure 8 the 3D model of the mosque for energy study
Source: Authors

Figure 9 Prince Sultan mosque
Source: Google Earth

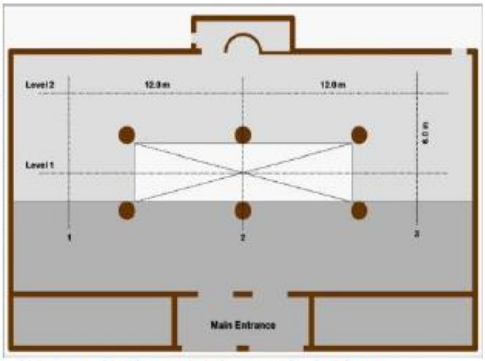
Indoor Western Elevation for Prince Sultan Mosque



Outdoor Western Elevation for Prince Sultan Mosque

Indoor Northern Elevation for Prince Sultan Mosque

Outdoor Northern Elevation Prince Sultan Mosque



Prine Sultan Mosque's Plan

Figure 10 the selected case mosque
Source: (Shohan 2015)

3.4.1. Mosque Building Model's Setting:

The building configuration setting for Riyadh city was developed in Design Builder software and has been used in conjunction with data from Climate Consultant v4, a software that analyses the weather data for a given site based on the climate. Figure 11 shows the Psychometric chart for Riyadh site from Climate Consultant v4. The model was simulated by using Energy Plus v8.3 computer simulation. The results were analyzed and compared. The

model setting for the building template and specifications was selected based on ASHRAE Standard 90.1 and 62.1 (Stanke 2006) where the selected building type was Public Assembly Spaces - Place of religious worship.

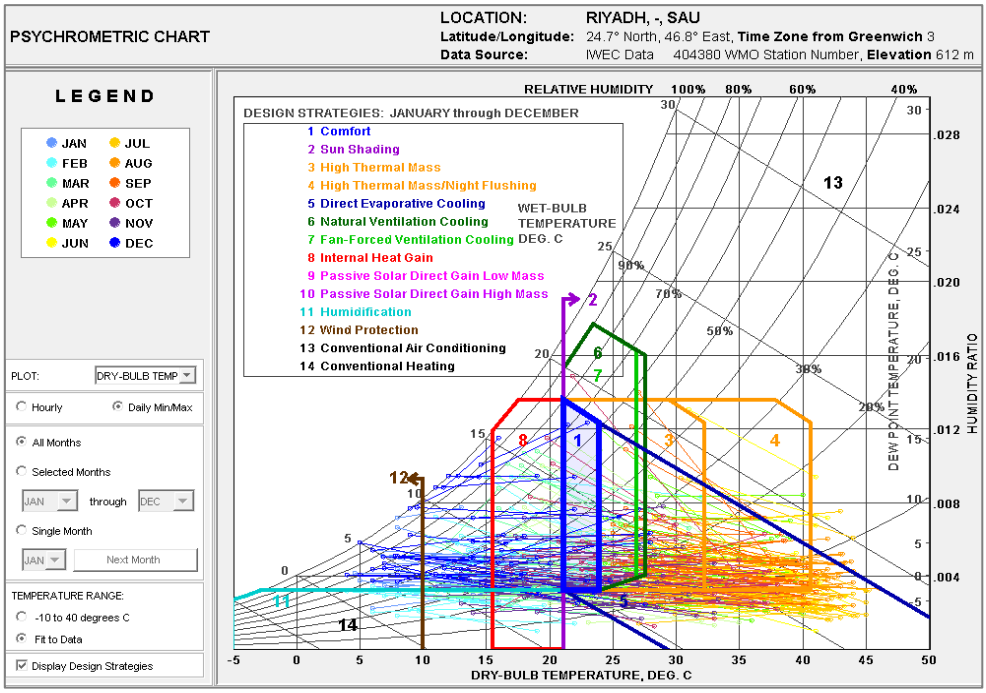


Figure 11 Psychometric chart for Riyadh from Climate Consultant
Source: modified from Climate Consultant

Clothing set for winter was at 1.25 clo and for summer was 0.75 clo according to a study carried out by Al-ajmi (Al-ajmi 2010) which took into account the Arabic style of clothing. Regarding the occupancy density, from observation it varies according to day and prayer time in most mosque buildings. In this model it was assumed as percentages for each prayer for five daily prayer times, as shown in Figure 12.

The green roof itself was set as semi-intensive green roof of 30cm depth built by10cm grass layer on soil, filter, root barrier and waterproof layers arranged sequentially, on the top of the roof structure. On the other hand, the shading louvers are assumed to be made of aluminium material with 6mm thickness of 5 blades in 15° angle. Each blade is 20cm in depth and with a width similar to that of the relevant window i.e.; 120cm.

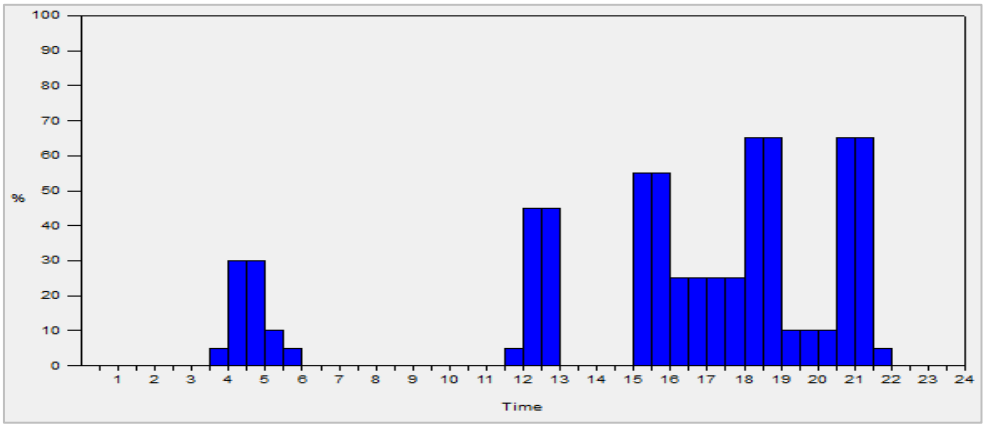


Figure 12 Average daily occupancy for each prayer time
Source: Author

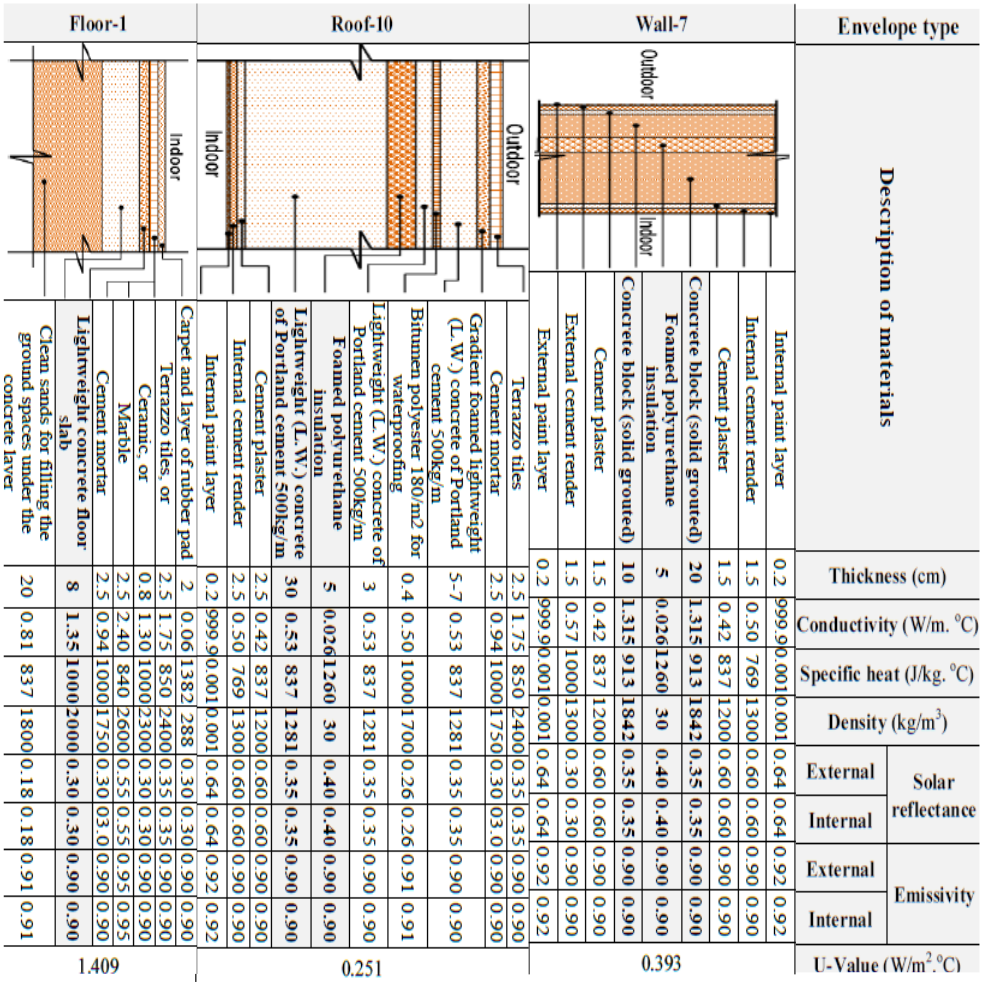
3.4.2. Material Properties:

Shohan (2015) has examined a number of alternatives for building materials for selected case envelops, following actual measurements and energy simulation using TAS software. He came up with an arrangement for a number of materials for Riyadh climate to assure higher insulation in walls, roof and floor, which could provide the most suitable annual thermal comfort. Figure 13 illustrates each element of the materials and their descriptions.

3.4.3. Assessment Procedure:

After obtaining the dimensions of the real case mosque, the building material specifications have been drawn. Then all the settings and weather configuration were set as mentioned above. Four different scenarios were established; the first scenario was the base case which is the current condition of the mosque building where model specifications were entered based on the actual building materials specifications.

The second scenario involved the base case integrated with a green roof. The third scenario was the base case with an addition of basic louver shading elements on all windows. The fourth scenario involved scenarios 2 and 3 integrated with the improvement suggested by Ref.1(Shohan 2015), which included improvement of the building envelope and the addition of louver shadings. Figure 14 shows the rendered model with Riyadh sun-path with and without the green roof. Moreover, to obtain accurate result the minaret was built as a component block, so it did not affect the thermal performance of the mosque.



Envelope type	Description of materials	Thickness (cm)	Conductivity (W/m. °C)	Specific heat (J/kg. °C)	Density (kg/m³)	Solar reflectance External	Solar reflectance Internal	Emissivity External	Emissivity Internal	U-Value (W/m².°C)
Wall-7	Internal paint layer	0.2	999.90	0.001	0.001	0.64	0.64	0.92	0.92	0.393
	Internal cement render	1.5	0.50	769	1300	0.60	0.60	0.90	0.90	
	Cement plaster	1.5	0.42	837	1200	0.60	0.60	0.90	0.90	
	Concrete block (solid grouted)	20	1.315	913	1842	0.35	0.35	0.90	0.90	
	Foamed polyurethane insulation	5	0.026	1260	30	0.40	0.40	0.90	0.90	
	Concrete block (solid grouted)	10	1.315	913	1842	0.35	0.35	0.90	0.90	
	Cement plaster	1.5	0.42	837	1200	0.60	0.60	0.90	0.90	
	External cement render	1.5	0.57	1000	1300	0.30	0.30	0.90	0.90	
	External paint layer	0.2	999.90	0.001	0.001	0.64	0.64	0.92	0.92	
Roof-10	Terrazzo tiles	2.5	1.75	850	2400	0.35	0.35	0.90	0.90	0.251
	Cement mortar	2.5	0.94	1000	1750	0.30	03.0	0.90	0.90	
	Gradient foamed lightweight (L.W.) concrete of Portland cement 500kg/m	5-7	0.53	837	1281	0.35	0.35	0.90	0.90	
	Bitumen polyester 180/m2 for waterproofing	0.4	0.50	1000	1700	0.26	0.26	0.91	0.91	
	Lightweight (L.W.) concrete of Portland cement 500kg/m	3	0.53	837	1281	0.35	0.35	0.90	0.90	
	Foamed polyurethane insulation	5	0.026	1260	30	0.40	0.40	0.90	0.90	
	Lightweight (L.W.) concrete of Portland cement 500kg/m	30	0.53	837	1281	0.35	0.35	0.90	0.90	
	Cement plaster	2.5	0.42	837	1200	0.60	0.60	0.90	0.90	
	Internal cement render	2.5	0.50	769	1300	0.60	0.60	0.90	0.90	
	Internal paint layer	0.2	999.90	0.001	0.001	0.64	0.64	0.92	0.92	
Floor-1	Carpet and layer of rubber pad	2	0.06	1382	288	0.30	0.30	0.90	0.90	1.409
	Terrazzo tiles, or	2.5	1.75	850	2400	0.35	0.35	0.90	0.90	
	Ceramic, or	0.8	1.30	1000	2300	0.30	0.30	0.90	0.90	
	Marble	2.5	2.40	840	2600	0.55	0.55	0.95	0.95	
	Cement mortar	2.5	0.94	1000	1750	0.30	03.0	0.90	0.90	
	Lightweight concrete floor slab	8	1.35	1000	2000	0.30	0.30	0.90	0.90	
	Clean sands for filling the ground spaces under the concrete layer	20	0.81	837	1800	0.18	0.18	0.91	0.91	

Figure 13 the arrangement material for Riyadh with description
Source: (Shohan 2015)

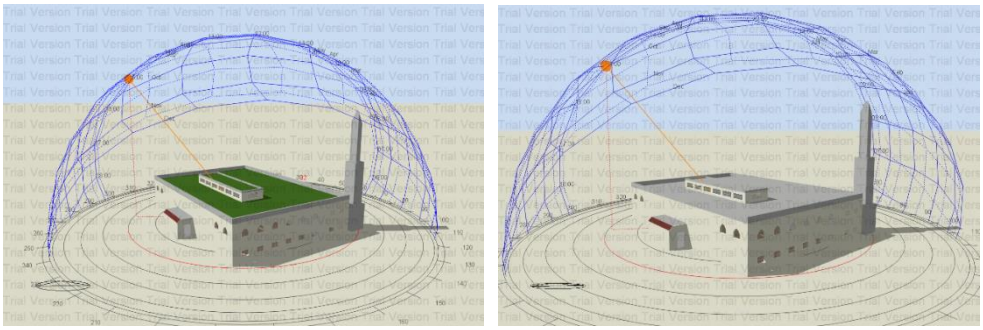


Figure 14 the model showing the sun path, left is with green roof and without it on right
Source: Author

3.4.4. Simulation Results and Findings:

Provision of the required thermal comfort of any building is possible, but might consume huge power by active systems such as air conditioning system. The present simulation was an attempt to assess the annual building cooling load for different scenarios to provide indoor thermal comfort by passive techniques. Results show that generally a reduction in indoor air temperature could be achieved by applying both green roof and louver shading. Figure 15 shows a possible reduction by an average of 10C in the hottest day (summer day) of the year i.e.; 21st of July according to Weather and Climate Consultant. This simulation was run while no active air conditioning system was operated.

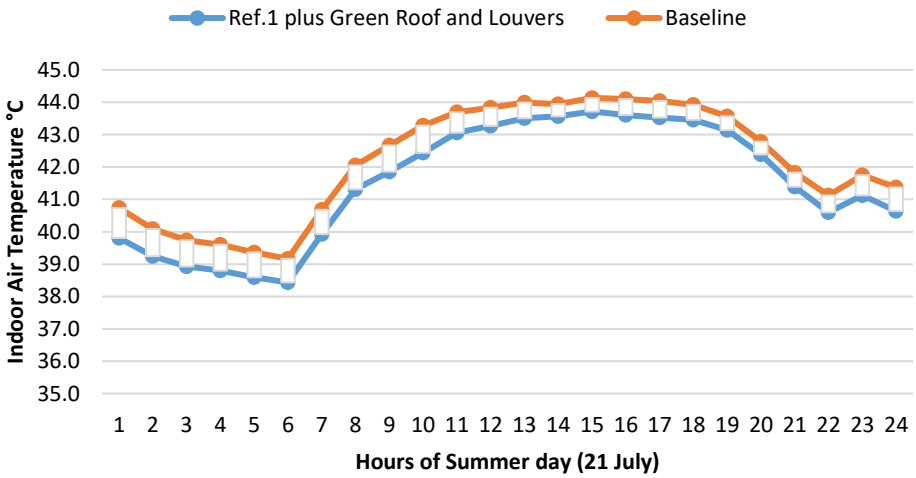


Figure 8 Reduction in Air Temperature of summer day (21st of July)
Source: Author

Equally important is how the cooling load responds to the applications of the proposed technologies and the potential energy saving of the mosque building. Figure 16 shows the monthly variation in summer months for the cooling load of the mosque building under the tested scenarios. The results show that there is a promising reduction in the cooling load when a green roof is applied to the mosque building without introducing any improvement to the building fabric. Of course there are further improvements when both the green roof and shading louvers are applied. Because the effectiveness of the

blind varies with the sun geometry, the benefits of the shading louvers also vary with the months, as shown in Figure 16.

The green chart shows the cooling load, when all improvement to the building design are included i.e.; improved fabric, green roof and shading louvers. Moreover, an annual saving by 4% of cooling load could be achieved in mosque building in Riyadh by using the green roof; however, this percentage could be raised up to 10% if shading louvers were added to windows while keeping the green roof. Figure 17 below shows the annual cooling load.

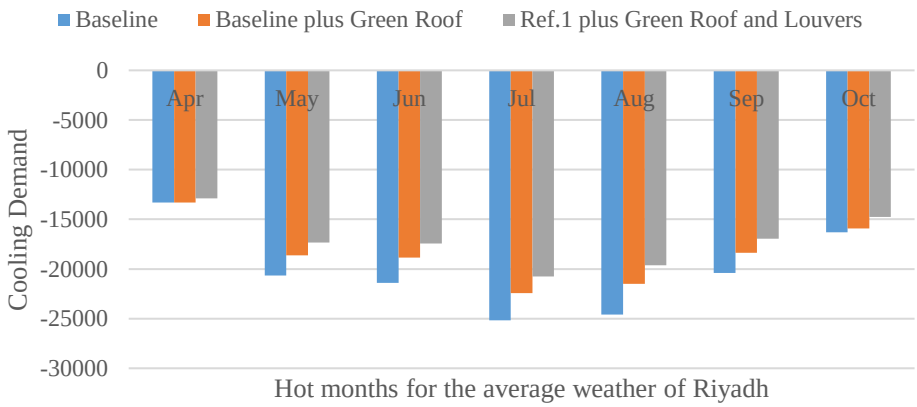


Figure 16 Monthly cooling demand reduction when apply both green roof and louvers shading particularly in not-cold months of Riyadh
Source: Author

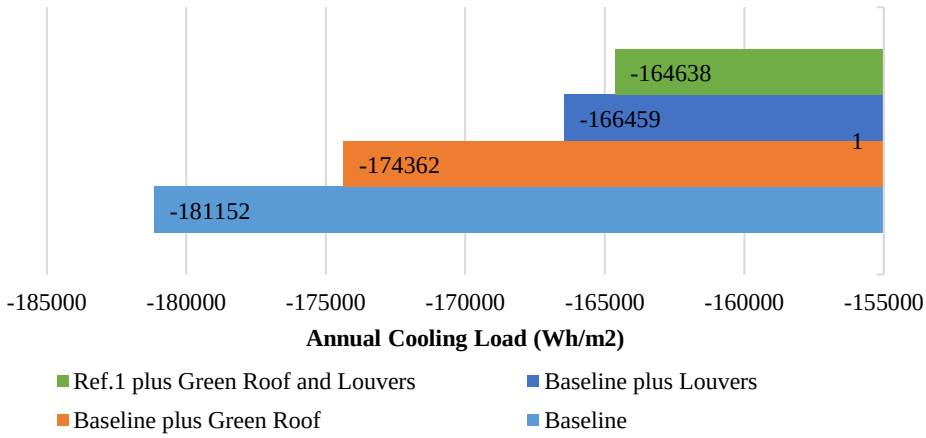


Figure 17 Annual cooling load per square meter could be reduce by 10%
Source: Author

4. CONCLUSIONS

With the increasing number of Muslims and the ongoing demand of new mosque buildings, it is important to give attention to the thermal performance of mosque buildings and to use appropriate sustainable technologies based on the climate zone. This paper is part of an ongoing research that aims to determine the most appropriate sustainable features for sustainable mosque buildings in different climates, thereby providing a comfortable environment for worshipers and reducing the consumption of resources. A number of mosque building are explored to acknowledge their sustainable features, and classify them according to the climate zone.

The purpose is to draw attention to these technologies when considering mosque building in any climate. The investigation found that most of the research work on mosque building focused only on the building envelope, without suggestions of applying appropriate sustainable techniques and technologies to enhance building performance and its energy consumption. This research aims to fill this gap by considering the most appropriate sustainable techniques for mosque buildings in different climate zones. Application of green roof and shading devices in hot - arid climate are examined alongside the fabric improvement, and the results illustrate the potential of these techniques in improving the building performance and reducing building energy consumption. Further investigations are required to relate these techniques and other potential sustainable technologies to particular climate zone.

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COOL MINARET: A FUNCTIONAL ELEMENT OF PASSIVE COOLING FOR MOSQUES IN HOT-ARID CLIMATES

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Abstract

Energy efficiency and conservation in building is becoming the focus in many countries. In countries with hot climatic conditions, space cooling in buildings consumes large amount of fossil fuel-derived energy with a negative environment impact. To reduce energy consumption for space cooling in buildings and provide thermal comfort, evaporative cooling technologies have been applied in many regions of the world using different design techniques and materials. For example, the application of porous ceramics materials as wet media material in evaporative coolers has gained renewed interest with novel idea in the field. In this paper, a study has been conducted into building integrated evaporative cooling with the aim of adapting the minaret in a mosque building as a passive air cooler by using an integrated wind catcher /evaporative cooling as additional functional significance. Hence, a new configuration of porous ceramic materials integrated with a wind catcher in a minaret is considered. The cooling system is intended to operate on the principle of sub-wet bulb temperature in which the air is cooled and supplied into the occupied space without increasing its moisture. This can be performed by arranging the supply cool air and wet humid air in two separate channels with wind pressure from the wind catcher used as the driving force. This design is of particular interest in locations with a hot and dry climate. The preliminary investigation identified a number of structures that can be implemented as well as the effectiveness of such cooling method.

Keywords

A Minaret - wind catcher – Passive cooling - evaporative cooling - porous ceramic.

المئذنة الباردة : عنصر وظيفي للتبريد السلبي للمساجد في الأقاليم المناخية الحارة والجافة

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المستخلص

أصبحت كفاءة الطاقة والحفاظ عليها في المباني هي الهاجس الرئيسي في كثير من البلدان وخاصة في المناطق ذات الظروف المناخية الحارة حيث يعتبر التبريد في المباني هي النسبة الاكبر في الاستهلاك وذو التأثير السلبي على البيئة.

التقليل والحد من استهلاك الطاقة لأجل التبريد في المباني ولتوفير الراحة الحرارية، تم تطبيق واستخدام تقنيات التبريد بالتبخير في عدة مناطق في العالم باستخدام مواد وتقنيات وتصاميم مختلفة. على سبيل المثال، تطبيقات مواد السيراميك التي يسهل اختراقها (مادة مسامية مبلله) ضمن نظام التبريد التبخيري والتي أكتسبت هذا الاهتمام مجدداً كما تعتبر فكره حديثة في هذا المجال.

في هذه الورقة، تم دراسة تكامل نظام التبريد بالتبخير والاهتمام بملائمة هذا النظام مع المئدنة في المساجد، حيث يعتبر تبريد سلبي باستخدام ابراج التبريد (ملاقف) والتبريد التبخيري كأهمية وظيفيه إضافية. بالتالي التصميم والتشكيل الجديد المكون من السيراميك يعتبر متكامل مع الملقف في المئذنة. الهدف من هذا النظام في التبريد ليعمل على مبدأ درجة حرارة الهواء الشبه رطبة بحيث يتم تبريد الهواء وتوصيله الى الحيز المراد تبريدة من دون اي زيادة بمعدل الرطوبة، تتم من خلال تنظيم إمدادات الهواء البارد والهواء الرطب في قناتين منفصلتين تعمل بضغط الرياح من ابراج التبريد كقوة دافعة. حيث روعي في هذا التصميم المقترح ان يكون مخصص للمساجد التي تقع في المناطق ذات المناخ الحار والجاف. من خلال التحقيق الأولي تم تحديد عدداً من الهياكل والتصاميم التي يمكن تنفيذها بالإضافة الى فعالية وتأثير هذه الطريقة في التبريد.

الكلمات الدالة

مئذنة – ابراج التبريد - التبريد السلبي - التبريد التبخيري - السيراميك المسامي.

1. BACKGROUND

A large proportion of primary energy consumption in the Kingdom of Saudi Arabia (KSA) is for providing thermal comfort for building occupants. The recent available data on energy consumption (SEC, 2014) shows that over 77% of total electrical energy generated in the country is consumed by buildings. This is particularly influenced by the prevailing hot climate for most of the year, which in turn lead to huge use of energy intensive air conditioning systems. This eventually results in increased investment on power generation infrastructure, higher cost of power generation and environmental pollution. To address the energy sustainability in buildings, the KSA, through King Abdul-Aziz City for Science and Technology (KACST), is initiating a number of measures to improve construction standards and energy efficiency, and to raise public awareness about energy consumption. This research focuses on investigating mainly energy use in worship buildings (mosques) and the different techniques for reducing energy demand.

The architectural design of mosques has been the subject of many published studies. However, there has been little work on thermal comfort and sustainable environmental design. Interest in energy use in mosques was studied by Al-Homoud (2009) and Al-Hemiddi (2004), favorable indoor temperature by Al-ajmi (2010), and usage of water by Manan et al. (2006). Similarly, Abideen (1996) showed that various passive techniques could be employed to considerably decrease the cooling capacity of air-conditioned mosques located in Jeddah city. It was found that the suggested passive cooling plans could conserve 82% of air conditioning energy, 50% of financial costs, 28% of CO2 emission, and 80% of CFCs emission in the city. Al-Homoud et al. (2005) studied the energy consumption rates of different mosques sited in the Eastern Province of Saudi Arabia. The analysis examined the utility bills and evaluated the usage of energy.

The study showed that air-conditioning systems are deployed throughout the year to maintain comfortable indoor temperature resulting in consumption of considerable amounts of energy. Furthermore, Al-Hemiddi (2004) conducted a comparative analysis of electrical energy consumption in mosques located in Riyadh and in Skaka (Al-Rahmanyah Juma), as shown in Figure 1. It can be seen that the two locations have very different climatic

conditions where in Skaka most of the energy used is in wintertime for heating whereas in Riyadh the energy is used during summer for space cooling.

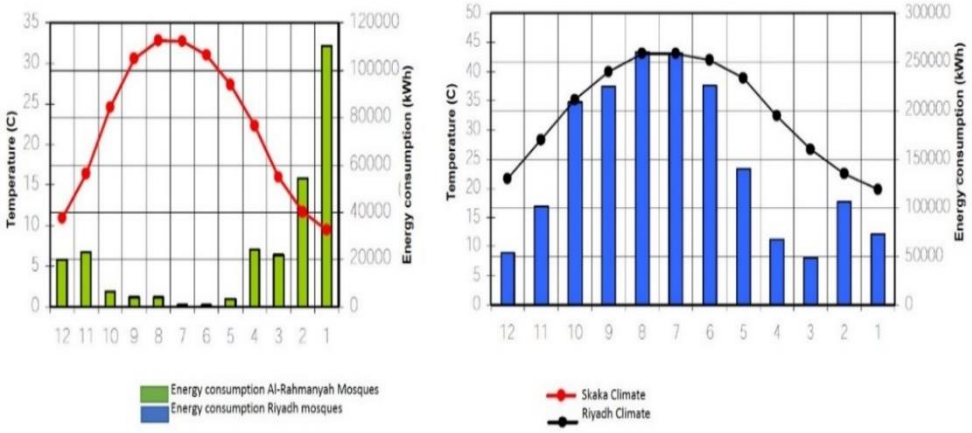

Figure 1: Energy consumption in mosques and outdoor temperature in Riyadh and Skaka

In hot and dry climate as prevailing in most parts of Saudi Arabia and Middle East, an effective alternative to the conventional air conditioning systems is the adoption of evaporative cooling systems. In its simplest form, evaporative cooling has been used for many centuries in Middle East and lends itself well for integration into building elements. Direct evaporative coolers, also known as desert coolers, are confined to dry conditions, and they are extensively used for cooling in pilgrims' accommodations in the Holy sites in Mekkah (Alharbi et al., 2014).

The authors conducted a comparative study of thermal performance and environmental effect of various evaporative coolers. They found that the evaporative cooling systems employed for cooling in larger spaces such as those to accommodate pilgrims and in railway stations may conserve over 70% of the energy costs and decrease the CO2 emissions by 78% compared to the mechanical vapor compression system, as shown in Figure 2. Moreover, the evaporative cooling tends to maintain favorable comfort level by employing 100% fresh air. In addition, a significant reduction in peak electricity demand is achieved.

Further work on monitoring energy consumption in mosques was also carried out as part of the current research project. Ten mosques buildings were monitored in Saudi Arabia and the energy data use is illustrated in Figure 3. The data shows large seasonal variation in energy consumption with summer

months being the highest, as vapor compression air conditioning system are used for periods of day.

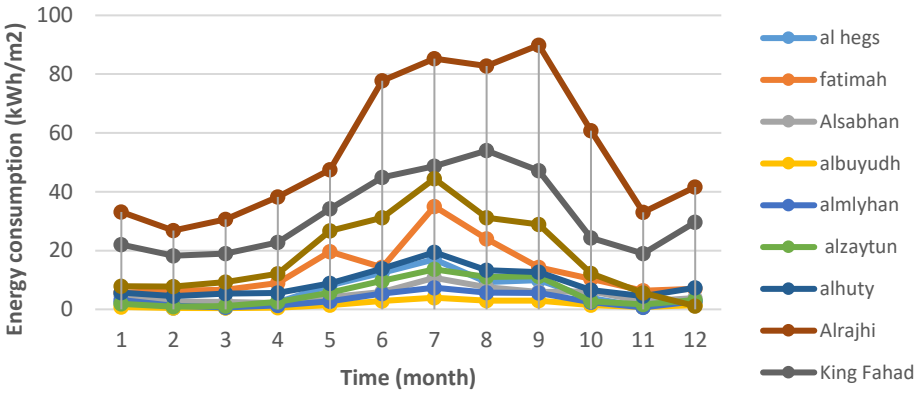

Figure 2: Electricity consumption comparison between evaporative coolers and vapor compression

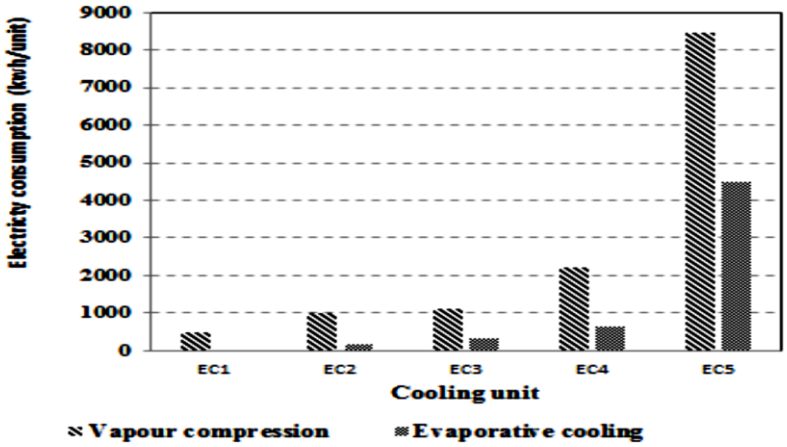

Figure 3: monitored electrical energy consumption in mosques in Saudi Arabia

2. THERMAL COMFORT IN MOSQUES

Thermal comfort in general is perceived as affecting the state of mind of an individual. Thermal comfort depends mainly on the surrounding environmental conditions (temperature, relative humidity, radiation and air velocity), the level and type of activity (metabolic rate and clothe insulation) as well as other indirect parameters such as state of health, age, etc. CIBSE (2006) refers to thermal comfort standards in places of worship and the

recommended comfort ranges is given in Table 1. The standards suggest a temperature range of 19 to 21oC for wintertime and 22 to 24oC for summer time. It also indicates that adequate ventilation should be maintained at 10 Air Changes per Hour (ACH).

Table 1 Recommended Comfort ranges for religious buildings

Building Type	**Winter Operative Temperature Range for stated Activity and Clothing Levels**			**Summer Operative Temperature Range (Air Conditioned Buildings) for stated Activity and Clothing Levels**			**Suggested Air Supply Rate (L/s)**
	Temp. (ºC)	Activity (met)	Clothing (clo)	Temp. (ºC)	Activity (met)	Clothing (clo)	
Religious Buildings	19-21	1.3	1.15	22-24	1.3	0.65	10 ACH or 0.1 m/s

The above guidelines are general indoor climatic conditions in buildings, however, to maintain those conditions in mosque buildings will vary depending on the building structure, design, materials, orientation and users clothing, activities, etc. The occupancy density is also an important factor in ensuring healthy and comfort conditions, particularly during period of high usage such as in Ramadan. As a space for worshiping, the mosque buildings should also offer a serene and calm environment to worshippers (Ibrahim et al., 2014).

3. INTEGRATED PASSIVE COOLING TECHNIQUES IN MOSQUE BUILDINGS

Mosques are public buildings that have specific structures and elements such a dome, Minaret, courtyard, etc. The dome serves as structural roof for the prayer hall to reduce the number of supporting columns as well as facilitate cross airflow and natural lighting to the central section of hall. The curved surfaces of the dome also allows a natural flow of air around it and traps less heat (Asfour, 2006). The minaret, a vertically tall component is utilized to call for prayers. Spiritually, the dome signifies the arch of heaven, while the minaret represents the assertion of faith. In modern mosques' designs, and with the help of advancement in construction materials, the building elements can be integrated as part of the environmental services. According to Mushtaha and Helmy (2016), the minarets can be incorporated

within the prayer halls so to serve as wind catchers to facilitate passive cooling in severe climate conditions.

3.1. The Minaret as a Wind Catcher

In this traditional system, the wind catchers pass the air entering into a space through wet mats, water containing permeable jars or underground storage to achieve evaporative cooling. The air before entering a room is channeled over porous pots so that evaporation can be carried out and the air prior to entering the space experiences a reduction in temperature. This technique of cooling was reported by Fathy (1986) in Egypt and applied it to housing projects and schools for ventilation, as shows in Figure 4. The traditional techniques like downdraught

for the purpose of cooling and ventilation are also being adopted in contemporary buildings to reduce the impact of the built environment (Ford et al., 2010).

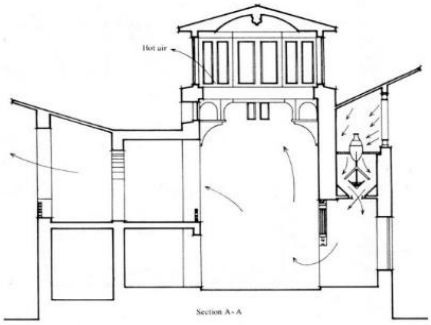

Figure 4: Wind-catcher and Maziara water jar in Egypt (1970-80s)

Imam (2003) also looked at the way a minaret can be employed to enhance the natural ventilation in a mosque, especially in the warm-humid climate. Figure 5 shows various arrangements of the minaret to exploit prevailing wind directions and enhance airflow through the occupied space.

Al-Tassan and Bahobail (2006) studied the Al Ruhmaniah mosque located in Al-Jouf, KSA as shows in Figure 6. The building is equipped with twelve cooling towers, which enables smooth flow of cold air through the building. Perforated evaporating pads were used in the towers for evaporative cooling. The mosque, a rectangular structure, is covered with a dome above the Mehrab area and has a courtyard (surhaa) at the front façade.

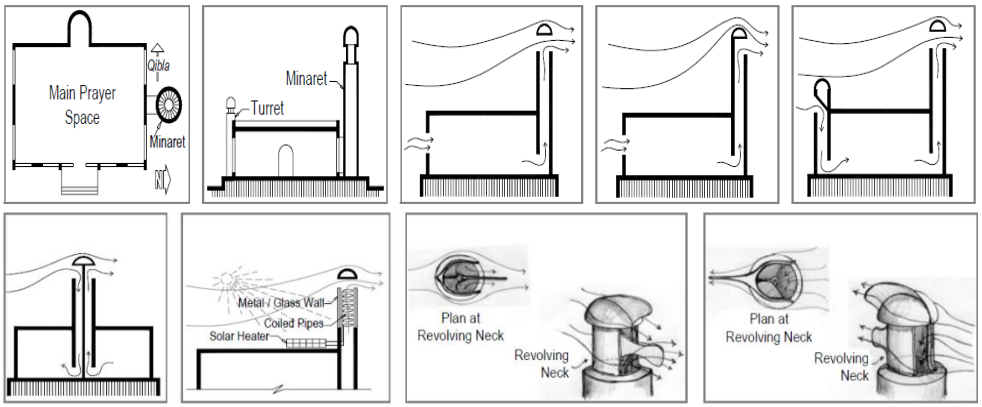

Figure 5: Different concepts of Minaret for ventilation a) wind tower / wind scoop / 'badgir' - as a solar chimney/ Revolving neck for wind tower
Source: (Imam)2003)

Figure 6: Al-Ruhmaniah mosque
Source: (Al-Hemiddi, 2004)

3.2. Types of Wind Catcher

The use of wind catcher (tower) has evolved from a simple one-sided opening to shapes that are more complex. The following are examples of wind catcher found today in most buildings and parts of the world:

a. <u>One-sided wind towers:</u> These types of wind towers are designed to have the air openings facing prevailing seasonal wind direction (Figure 7a). When the wind direction changes, this type of wind catchers has limited effect.

b. <u>Two-sided wind towers:</u> These are small in size and fairly simple from architectural perspective. Performance of the two-sided towers is reportedly high and they are found more efficient for circulating

airflow as compared to the one-sided wind towers in (Figure 7b). This type of wind catchers allows air circulation both into and out of the building.

c. Four, six, eight-sided wind towers: These are usually of larger structure and more complex. The height, number of openings and their size depends on prevailing climatic conditions. (Figure 7c) shows a two-story wind catcher with multiple openings.

d. Cylindrical wind towers: The structure of a cylindrical wind catcher allows air scoping from all wind direction. This offers better performance compared to other types of wind catchers. In (Figure 7d), shows an example of a circular wind catcher(Dehghani-sanij et al., 2015).

(a) one-sided wind tower (b) Two-sided wind towers (c) A two story wind tower (d) A cylindrical wind tower

Figure 7: Types of wind catchers

3.3. Wind Catcher Integrated Passive Cooling

The design of wind catchers (towers) for passive cooling in buildings depends on location, functionality and appearance. Schiano-Phan (2010) studied different designs and found that these vary according to the desired airflow, heat transfer area, sensible heat storage capacity and evaporative cooling surfaces which in turn determine the height of the tower, openings and different cross-sections of airflow passages. Cooling in buildings using wind catchers mainly takes the form of passive downdraught evaporative cooled air, including the following (Ford et al., 2010):

a. Shower Towers: The type of wind catcher incorporates a water spraying mechanism whereby the air stream into the building is sprayed with water droplets. A showerhead in the form of water

nozzles is located at the top of the tower through which high pressure pumped water is sprayed into fine droplets that mixes with incoming air. In Figure 8, shows an earlier example of this system used by Fathy by flowing water on charcoal in an Egyptian 'Malgaf'.

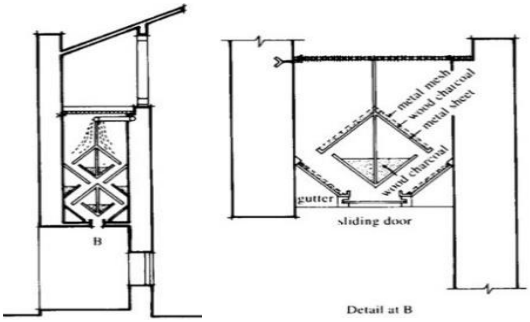

Figure 8. Example of a shower Tower 'Malgaf', Egypt

b. Misting Towers: Similar to shower towers, incoming air into the building is spraying with a water mist. Water misting using water nozzles has also been used in food processing, botanical gardens and chemical industries. This takes advantage or produces very fine water particulates (mist) which improves evaporative cooling when mixed with air. An example of this system can be seen in Stanford ecology centre, USA where the downdraught tower is installed with misting nozzles to cool the reception area using evaporative cooling as shows in Figure 9.

Figure 9: The Stanford Ecology Centre

c. Wet media: Evaporative cooling can be enhanced by using porous media to increase surface area contact between the saturated media and air flow. This could take the form of dampened porous ceramic bricks in the tower for developing cool downdraught, clay water jars placed on windows or at the bottom of wind towers (Schiano-Phan, 2010). Wet media such as construction materials are a good example where

passive evaporative cooling systems are integrated into building elements. In Figure 10, shows an example of using a clay water jar in wind catcher in a courtyard house (Iraq) with a series of wind catchers placed on the roof to provide natural ventilation for the building basement rooms. The incoming air is then through direct heat transfer when it comes into contact with the cold inner surfaces of the duct walls, whereas it absolute humidity is increased as it collects water moisture from the wet porous water jars before being discharged into the basement. Similar evaporative cooling techniques can be found in the Sind region (Pakistan).

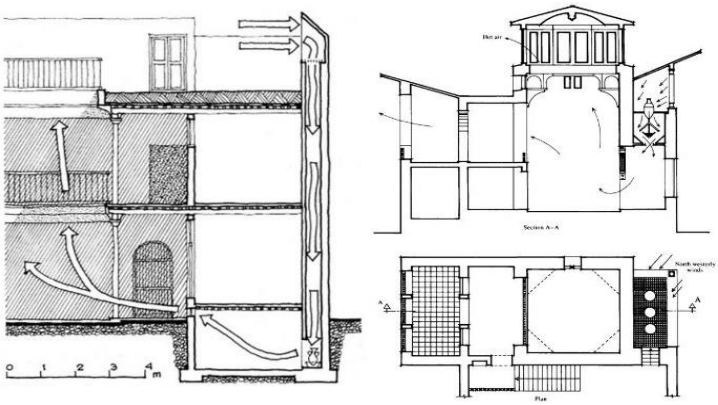

Figure 10: integrated wind catcher evaporative cooling using water jars

The adoption of traditional water jars into modern buildings use a modular clay bricks dividing the tower into a multitude of wet conduits by uniformly spraying water as depicted in Figure11, sump located at the bottom of the tower collects excess flowing water which is recirculated over the wet clay material (Bahadori, 2014).

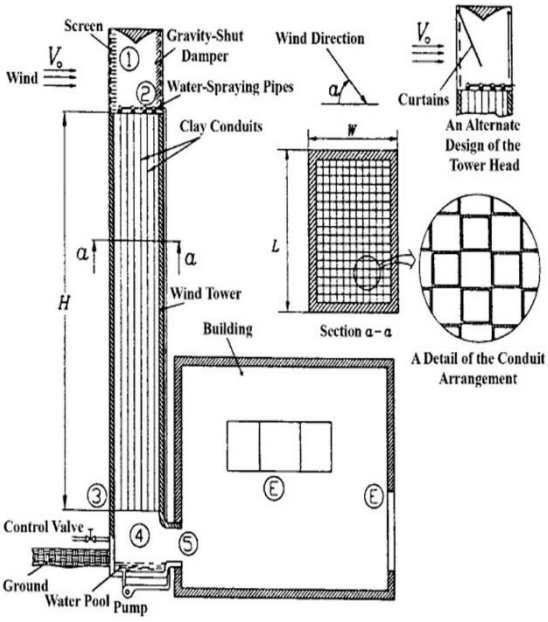

Figure 11: Cross section of baudgeer with wetted column

4. DESCRIPTION OF THE PROPOSED SYSTEM

This work focuses on adapting the design of a minaret to encompass the function of delivering thermal comfort in mosque buildings. The structure of a minaret lends itself well to playing an important role in providing energy efficient and passive cooling. Previous research showed that evaporative cooling integrated as part of a building element has been practiced over centuries in the Middle East region. However, traditional direct evaporative cooling has the disadvantage of adding moist air into the building living space and has low cooling performance with temperature limited to prevailing outdoor wet bulb temperature.

In this work, a structure of cooling air indirectly below wet bulb (sub-wet bulb) temperature without adding moisture into the supply air has been investigated. It was also proposed to use porous ceramic material in the form of wet panels as it also can be easily incorporated as a stable and moldable construction material. Figure 12 shows simplified diagram of a minaret integrated sub-wet evaporative cooling arrangement.

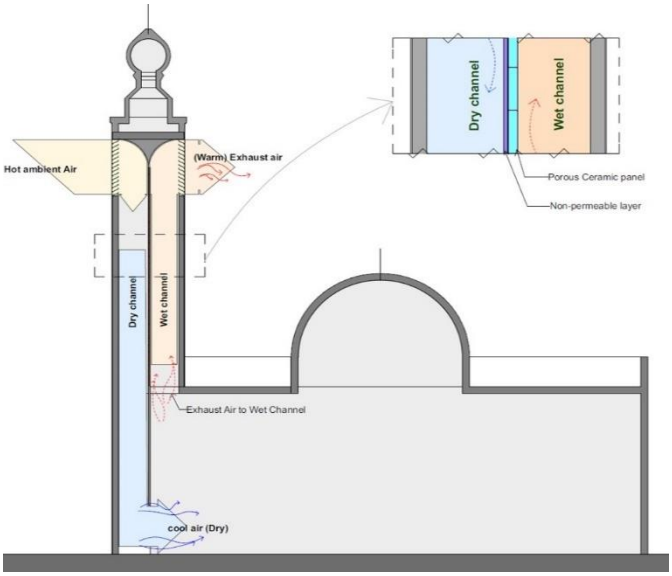

Figure 12: proposed arrangement of a cool minaret

In a sub-wet bulb temperature evaporative cooling arrangement, the air streams are separated into dry channel for supply air and wet channel for rejecting spent working air. The supply air in the dry channel is cooled indirectly by transferring its heat to the working air in the wet channel through a thin non-permeable channel wall. To achieve sub-wet bulb temperature, part of the cool air in the dry channel is diverted to accomplish the evaporation

process in the wet channel, as shown in Figure 13. The type and structure of the porous ceramic panels can be

made into hollow structures to hold water and be interconnected. The wet side of the panel constituting the wet channel will be water permeable with controlled porosity while the side forming the dry channel will be water proof. An example of a ceramic panel is shown in Figure 14. In this design, the wet and dry air channels can be arranged in many configurations that can maximize the evaporation and cooling effectiveness of the minaret tower cooling system.

The wet and dry channels formed by the porous ceramic block can be in the form of rectangular, square, triangular or more complex structures. The ultimate aim is to maximize direct contact surface area between the dry and wet channel for heat transfer on one hand and between air and wet surface in the wet channel on the other hand. Figure 15, shows some of the proposed configuration of interposing the ceramic panels within the minaret.

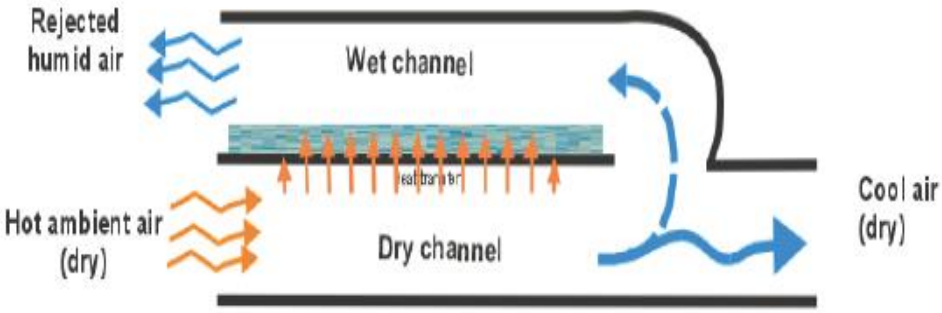

Figure 13: Sub-wet bulb temperature evaporative cooling arrangement
Source: (Boukhanouf et al., 2013)

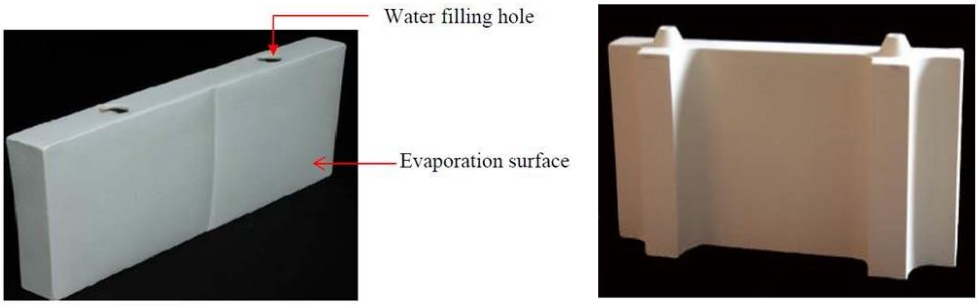

Figure 14: Porous ceramic panels

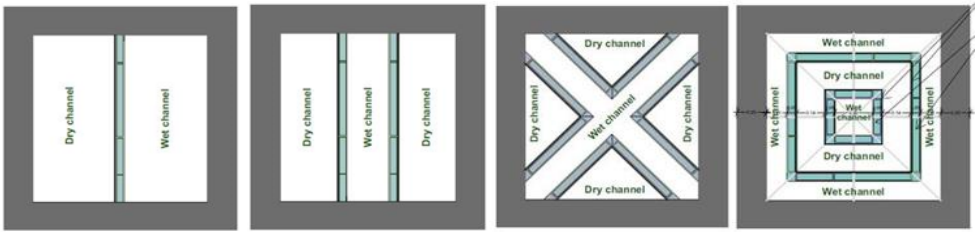

Figure 15: Section plan of dry and wet channels configuration

To maximize the thermal performance of the whole structure, other arrangements with more elaborate designs have also been considered. Figure 16 shows an exploded view of the main parts of cylindrical shaped minaret structure as a wind catcher and cooler. This made of the following components:

1. **Head:** when the wind blows through the external louvered grill at high level from different sides, the star shaped dampers orientate the air only to the dry channel while the wet channel is being closed. Rejected air assisted extraction fan would pull away exhausted air outside the building.

2. **Evaporation cooling panels:** the minaret void is divided into separate air ducts to form dry and wet columns within. The porous ceramic panels are mounted in the form of a wall and filled with water which is supplied from the top, to flow from one panel to the other and to permeate in the outer surface of the ceramic wall. The porous ceramic wall is sandwiched between two channels with two narrow air gaps on its front and back (the dry channel and the wet channel).

    - Dry Channels: The inlet air can be pulled into the building through the opening grid and the dry side of the ceramic material, and the air is cooled by transferring its heat to the ceramic panel without increasing its moisture content. The cool air is delivered to the building by chilled ceiling as well as through radiation directly into the occupied space.

    - Wet Channels: the evaporation of water from the porous ceramic panel surface in the wet channels carries away the heat added to the ceramic panels from the building space, which is rejected to outside by an assisted fan.

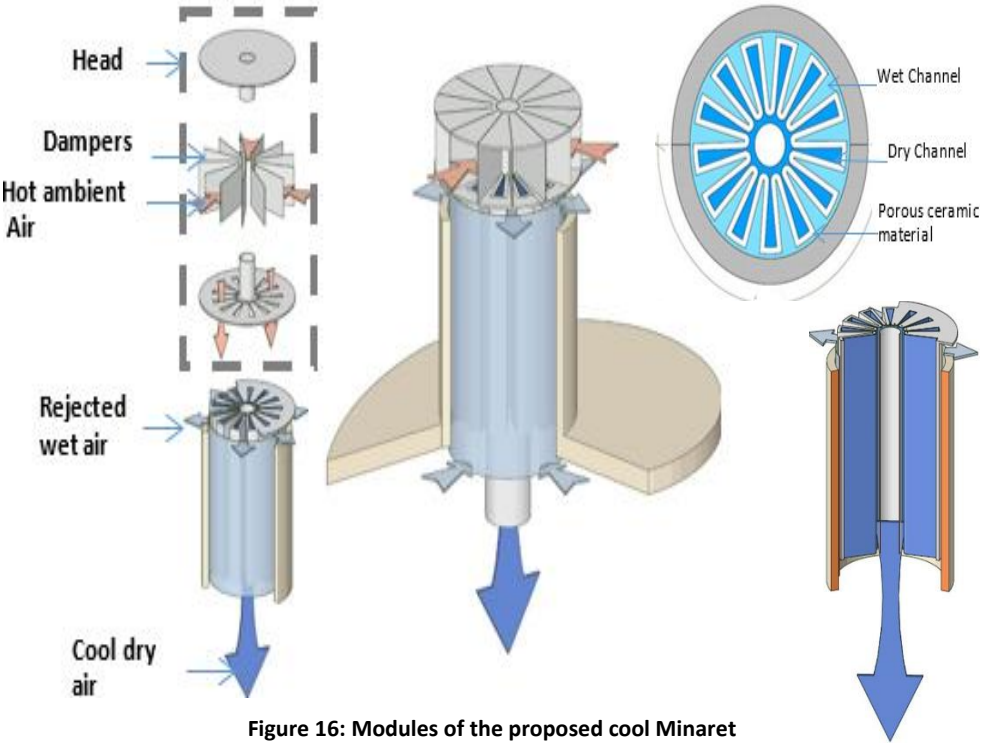

Figure 16: Modules of the proposed cool Minaret

It was also envisaged in this design that cool air could be supplied into the occupied space in the mosque through direct circulation, using overhead delivery diffusers or chilled ceiling type cooling methods. Figure 17 shows example of cooling air distribution using air diffusers.

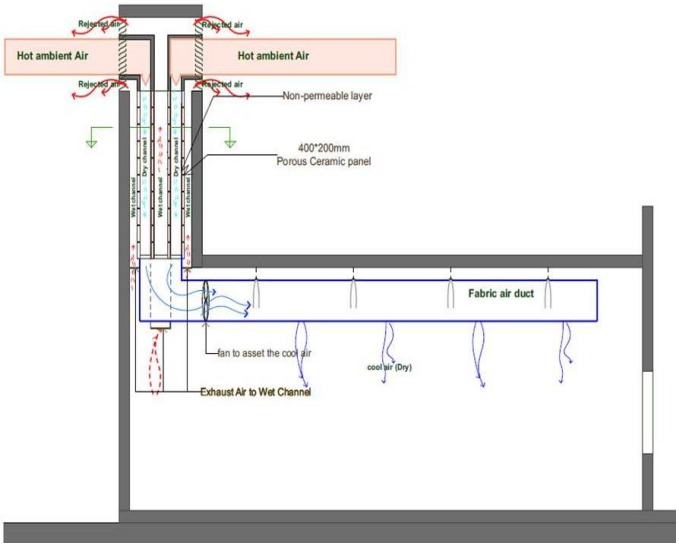

Figure 17: The proposed system componants

5. PREVIOUS RESEARCH RESULTS

Previous research by Boukhanouf et al. (2013) showed that evaporative cooling is effective in hot arid climates. Experimental results using the porous ceramic as wet media materials for evaporative cooling showed that the ambient temperature could be depressed by as much as 12.50C at low relative humidity (Figure 18).

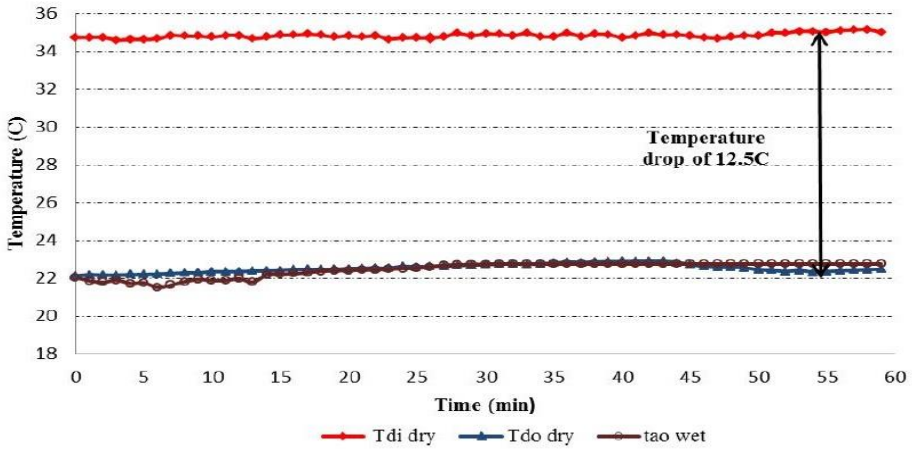

Figure 18: Recorded temperature profile in the wet and dry channel
Source: (Boukhanouf et al., 2013)

Similarly, the cooling capacity as a function of the exposed porous ceramic panels' evaporation surface was very high at low air moisture content. Figure 19 shows that the cooling capacity is over 200W/m2 for ambient air relative humidity lower than 40%. Therefore, the total cooling capacity that could be achieved is scalable with the size of the porous ceramic panels.

6. CONCLUSION

Evaporative cooling is a native technology that has been used as part of Middle East architectural heritage for many centuries. It provides thermal comfort in buildings for occupants in the harshest of weather conditions with minimum impact on the natural environment. This work has attempted to apply the principle of evaporative cooling into the mosque minaret to extend its functionality to provide cooling, by incorporating wind catcher and porous ceramic materials. Both sub-wet bulb evaporative cooling and the use of optimized porous ceramic structures within a minaret have the potential to

enhance thermal comfort in mosques in hot and dry climates, while minimizing the energy consumption.

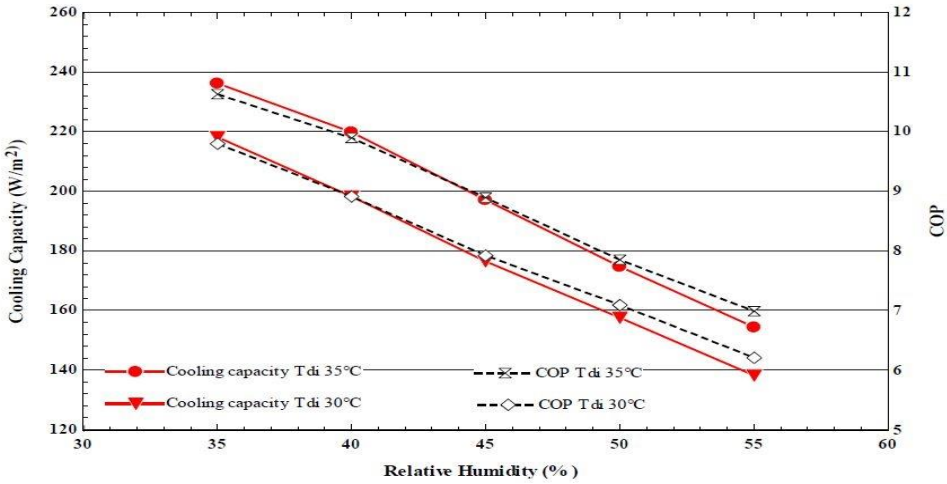

Figure 19: Effect of relative humidity on cooling capacity and COP
Source: (Alharbi, 2014)

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MORPHO-LIGHT IN THE FIRST GREAT MOSQUES OF TUNISIA, THE RESEARCH OF IDENTITY THROUGH THE LIGHT'S FORM

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Abstract

In this paper, we propose a Morpho-light study applied to a corpus of the first great mosques in Tunisia. The natural light is at the moment at the core of several studies focusing on religious architecture. Its sensitive and symbolic dimensions have significantly marked all the cultures and particularly the Islamic one. Besides, the natural light is also a spatial immaterial phenomenon but measurable. This study aims at qualifying the morphology and understanding how it is used and spatialized in the architecture of the first Tunisian great mosques. The distribution of the natural light inside mosques gives place to forms, which deserve to be studied and characterized. They help to define the identity of places and the specificity of a particular architecture. The way light is propagated and spread up by the architectural devices of the first mosques feeds our current concerns of sustainable development.

The corpus includes the first five great mosques built in Tunisia: the mosques of Kairouan (670), Sfax (849), Sousse (851), Tunis (864) and Mahdia (916). These mosques have the particularity to belong to the hypostyle style widely defined by the historians and the specialists of the Islamic architecture. We propose to characterize their Morpho-light identity.

We provide a form study of the daylight distribution in these great mosques, using an innovative methodology of daylight simulation and morphometry (shape measurement). For that purpose, we use the Radiance software under Ecotect for the natural light simulation and the Morgine program implemented under Matlab for the morphometric analysis. The cartography of the daylight factor distribution and the morphometric analysis of the natural light report Morpho-light characteristics of these first Tunisia's great mosques. Morphometry allows to identify the morphological structure underlying of the natural light distribution forms inside the mosques under study and to acquire knowledge in terms of identity and diversity, which we present in this article and submit for discussion.

Keywords

Morphometry, Daylight Factor, Radiance, Great mosques of Tunisia.

دراسة مورفوضوئية لأقدم المساجد الجامعة في تونس البحث عن الهوية من خلال شكل الضوء

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المستخلص

نقترح في ورقة البحث هذه دراسة مورفوضوئية لأقدم المساجد الجامعة التي أنشئت في البلاد التونسية. الضوء الطبيعي هو في صميم العديد من الدراسات المتخصصة في هندسة المنشآت الدينية ويشهد له بأبعاده الحساسة والرمزية في جميع الثقافات وخاصة الإسلامية منها . الضوء الطبيعي هو أيضا ظاهرة هندسية غير ملموسة و قابلة للقياس . يقترح هذا البحث تحديد خصائصها المورفولوجية و فهم كيفية استخدامها في هندسة المساجد الجامعة في تونس . يأخذ توزيع الضوء الطبيعي داخل المساجد أشكالا متميزة تستحق أن تدرس لتساهم في تعريف هوية الأماكن وخصوصياتها المعمارية . كيفية انتشار الضوء داخل المساجد الاولى تتماشى مع الاهتمامات الحالية للتنمية المستدامة.

يتضمن البحث خمسة مساجد جامعة هي الاولى التي شيدت في تونس : مساجد القيروان (٦٧٠) وصفاقس (٨٤٩) وسوسة (٨٥١) و تونس (٨٦٤) و المهدية (٩١٦) . هذه المساجد لها خصوصية انتمائها إلى النمط المغربي المعروف من قبل المؤرخين والمختصين في العمارة الإسلامية أ ن أهم ملامحه صحن محاط بأروقة وبيت صلاة مقامة على أعمدة. يطرح البحث توصيف هويتها المورفوضوئية.

نقدم دراسة مورفولوجية لتوزيع الضوء الطبيعي في هذه المساجد عن طريق منهجية مبتكرة لمحاكاة الضوء الطبيعى وقياس الأشكال (morphometry). لهذا الغرض، نحن نستخدم البرنامج راديانس Radiance تحت اكوتاك Ecotect لمحاكاة الضوء الطبيعي وبرنامج مورجين Morgine تحت الماتلاب Matlab للتحليل المورفومتري . نستخدم خرائط توزيع عامل الضوء الطبيعي Daylight factor والتحليل المورفومتري للضوء الطبيعي لنتبين الخصائص المورفوضوئية لهذه المساجد الجامعة. الدراسة المورفومترية تمكن من تحديد الهيكل المورفولوجي الكامن وراء أشكال توزيع الضوء الطبيعي داخل المساجد قيد الدراسة واكتساب المعرفة المتعلقة بالهوية و التنوع ، وهو ما نقترح تقديمه في هذه المقالة و إخضاعه للمناقشة.

الكلمات الدالة

قياس الأشكال ، عامل ضوء النهار ، Radiance Ecotect ، المساجد الجامعة في تونس

1. INTRODUCTION

This article questions the place of the light in the conception of the first mosques built in Tunisia. Indeed, most of the related studies deal with the Ottoman and Persian mosques. The main natural light source in mosques is the window, which can be side in walls or zenithal in domes. In several examples of the Ottoman architecture, the central dome, which unifies the space of the prayer, guarantees the natural illumination, (Antonakaki, 2007) (Belakehal et al. 2015). The light enters through the central dome to illuminate the central space and “gives reason to the believers to gather under the dome” (Antonakaki, 2007). In mosques, the main concern is to create a space of great unity and serenity (Antonakaki, 2007).

The goal of using light should not be the creation of a "mystic atmosphere", but to draw clearly the form of the prayer hall (Kreuz, 2008). In the Ottoman mosque’s design, the orientation and the centrality are two closely linked concepts. One of the particularities of the architecture of the first Ottoman mosques is the non-directional aspect which would be achieved by the form, but which would not be possible without light (Antonakaki, 2007). The symbolism of the light strengthens the feeling of union in the believers and revives the sense of space communion. In the architecture of the first Ottoman mosques, there was no clear relationship between daylight design and liturgy. « The Muslim architecture transforms the stone into light, which in turn, is transformed into crystals» (Burckhardt, 1985).

In their entitled article "Light, shadow and spiritual evolution of Iranian architecture soul after islam in Iranian mosques", Sobouti and Rajabioun explain the symbolism of the light in the architecture of Iranian mosques : “Light is the most characteristic symbol of architecture in Iran, and not only as a physical element, but also as a symbol of divine wisdom that penetrate into the elements and turn it to something great and appropriate that is suitable habitat for human soul, that has an origin in the light world” (Sobouti & Rajabioun , 2014). Belakehal et al. (2015) propose to go through the daylighting design in the architecture of the Ottoman mosques built in Algeria and in Tunisia. «From the daylighting point of view, the Ottoman architects, with Sinan in particular, created a different innovative and specific manner to catch, guide and diffuse the natural light inside the mosque» (Belakehal et al., 2015). But what about first mosques built in Tunisia before Ottoman period in the Maghreb?

Nowadays, the mosque architecture is evolved. The forms released themselves from prototypes and classic models, and the light became a mastered tool of conception. We propose two examples, the first one is the Sancaklar mosque designed by Emre Arolat Architects in Turkey. The project, with its uncluttered drawings, is a light staging a form. "The internal space of the building similar to a cellar, is characterized by its sobriety, materiality and the quality of its light".

The Qibla wall contains cracks and splits underlining the directivity of the prayer room, while allowing the permeability of the material in front of the natural light and its transmission into the mosque. The second project is the Said Naum mosque, built in Jakarta in Indonesia. The project is the result of a competition organized by Jakarta's municipality in 1975.

The prize-winner, the Enam Architects workshop and Planners, knew how to answer the constraints imposed by the sponsors of the project, which included the respect for the traditional character and the integration with the environment by the use of local materials. The project was designed according to a square and symmetric plan. Each wall is provided with five arched openings; the central opening of the Qibla wall gives its place to the mihrab. The hipped roof is elevated above the main roof to create a space for ventilation and lighting. Two types of illumination sources were proposed. On one hand, the lateral allows to promote an atmosphere of meditation.

On the other hand, the zenithal coming from the center of the roof accentuates the unity and the geometry by the space illumination. According to Burckhardt, 'the artist who seeks to express the idea of the Unity of Existence has three means at his disposal …geometry, rhythm, light'. Geometry translates the unity in the spatial order. Rhythm reveals it in the temporal order, and "there is no more perfect symbol of the Divine Unity than light." (Burckhardt, 1985). The light is a physical quantity, which has the greatest "silent power" that man can hold and hope to maintain.

It cannot be claimed that its main function is limited "to make visible the phenomena of the material world", but it seems that, above all, light as a mysterious force, symbolizes the human desire to reach light (Sobouti & Rajabioun, 2014). The first attempt to study the light form goes back to Ibn Al Haytham (1968) who explains, in his speech of the light, the necessity of combining mathematics and physics to understand the light. "Enunciating light essence belongs to physics, but to deal with its distribution requires an appeal to mathematics because of the lines according to which the lights

propagate. Also, the study of the essence of the ray is a part of physics whereas that of its form and its face sends back to the mathematics" (Rached, 1968).

In this paper, we propose to consider the natural light as a measurable and spatial phenomenon. Moreover, we qualify the daylight morphology and try to understand how it is used and spatialized in the architecture of the first Tunisians great mosques. The daylight distribution inside mosques gives rise to forms, which deserve to be studied and characterized. They help to define the identity of the places and the specificities of cultural architecture.

2. MATERIALS

We consider a corpus formed by the first Tunisian great mosques: those of Kairouan, Sfax, Sousse, Tunis and Mahdia (Table 1).

Table 1 Samples presentation
Source: Kammoun S. (2016)

Code	Mosque's name	Location	Date	Dynasty
M1	Great mosque of Kairouan	Kairouan	862-875	Aghlabide
M2	Great mosque of Sfax	Sfax	849-988	Ziride
M3	Great mosque of Sousse	Sousse	851	Aghlabide
M4	Great mosque of Tunis	Tunis	864	Aghlabide
M5	Great mosque of Mahdia	Mahdia	916	Fatimide

This corpus presents diversity and unity at the same time. It is one of the lines standing out with the Islamic architecture, which contributes to the development of modern architecture combining authenticity and opening. Indeed, the fidelity "to models, which religion does not actually prescribe but which the consensus of believers, has in a sense consecrated, has earned for Islamic art, the stigma of being a victim of "stagnation", as if its stability over the centuries had been the result of inertia or lack of awareness" (Burckhardt, 1985).

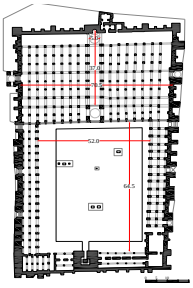
Tunisia had a specific type of mosque called "hypostyle" mosque. This style is characterized by a prayer-hall supported by arches and preceded by a courtyard, with porticoes. Hypostyle mosque finds its origins in the prophet house (622) and in the great mosque of Damascus built in Iraq in 706 (Ettinghausen et al., 2001; Burckhardt, 1985).

2.1. Great Mosque of Kairouan

Built in 670 by Uqba ibn Nafi, the great mosque of Kairouan is a masterpiece, which testifies the progress of Muslim world in the VIIth century. It acquired its essential features under the Aghlabides (9th century), with successive enlargements and renovations. The mosque has an irregular rectangular plan measuring 125 m of length and 78 m of width. It covers about 9750 m² of surface. The rectangular prayer-hall has a T-shaped plan. It is made of seventeen naves that run perpendicular to the Qibla wall, crossed by three transverse arcades of semicircular arches. The Mihrab is covered by a dome with foliate scrolls and five-lobed leaves.

The latter is supported by an octagonal drum with concave faces, pierced by eight windows and resting on a square base. The length and the width of rectangular courtyard are about 64.5 m and 52 m respectively. It is surrounded by galleries on the four sides. The square-based minaret was flanking the center of the northern facade. It consists of three overlapping volumes with 31.5 m of height (Table 2).

Table 2 Sample M1 Presentation
Source: Kammoun S. (2016)

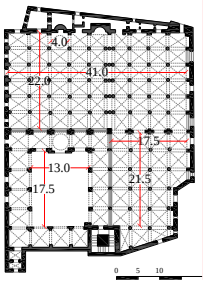
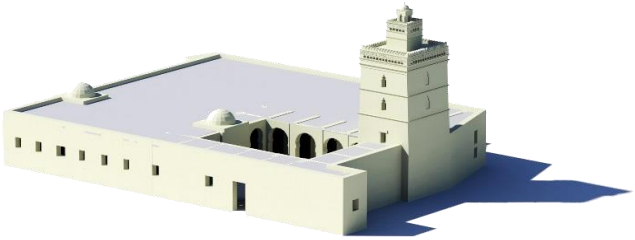
M1	Kairouan Great Mosque		
Construction date	670 – 836		
Dynasty	Aghlabide		
Rite	Malikite		
Location information	Latitude	35.40	
	Longitude	10.06	
	North orientation	219°	
Plan characteristics	Dimensions (m)	78 X 125	
	Prayer-hall area (m²)	2608	
	Courtyard area (m²)	3354	
			
Plan	**3d model**		

2.2. Great mosque of Sfax

Situated at the heart of the Sfax's Medina, the great mosque was built in 849 by the cadi Ali Jbenyani, a pupil of the great jurist Sahnoun. The original building was half ruined during the XIIth century. The Turks restored it. Then it was enlarged and reestablished several times. The current mosque presents morphology very close to the work built under the Zirid reign (Marçais & Golvin, 1960).

The mosque plan is a deformed rectangle with 53 m length and 43 m width. The prayer-hall is covered with the cross vaults resting on Moorish arches supported by antique recovered columns. Rows of columns bound nine naves running perpendicular to the Qibla wall and six parallel aisles. A row of pillars crosses the building in all its width (Marçais & Golvin, 1960). Two parts of quasi-equal surfaces extend in front of these pillars (Table 3).

Table 3 Sample M2 presentation
Source: Kammoun S. (2016)

M2	Great mosque of Sfax		
Construction date	849 - 988		
Dynasty	Ziride		
Rite	Malikite		
Location information	Latitude	34,44	
	Longitude	10,45	
	North orientation	213°	
Plan characteristics	Dimensions (m)	43 X 53	
	Prayer-hall area (m²)	1376	
	Courtyard area (m²)	227.5	
			
Plan	**3d model**		

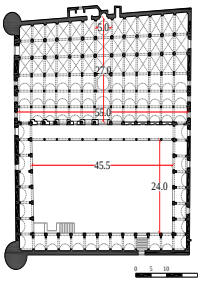
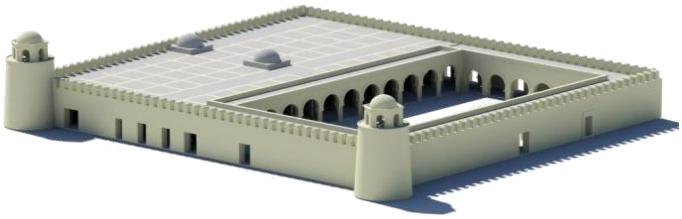
The west part is occupied by the continuation of the prayer-hall, with its lines of columns and its cross vaults. The courtyard extends in the eastern

part, with a size of about 17.50 m × 13 m, surrounded by galleries on its four sides (Marçais & Golvin, 1960). The northwest minaret consists of three superimposed towers reminding the silhouette of Kairouan Minaret.

2.3. Great Mosque of Sousse

Built near the Ribat, the great mosque of Sousse had a defensive function, which could well explain its eccentric situation and its massive and sober architecture (Al Ansari, 1996). The mosque's construction goes back to the Aghlabid reign of Abi Abbes Abdallah ibn Ibrahim ibn Al Aghlab in 851. The actual mosque belongs to the Xth century, its last enlargement dates. The plan has rectangular form measuring 64 m length and 58 m width (Table 4).

Table 4 Sample M3 presentation
Source: Kammoun S. (2016)

M3	Great Mosque of Sousse		
Construction date	851		
Dynasty	Aghlabide		
Rite	Malikite		
Location information	Latitude	35.83	
	Longitude	10.63	
	North orientation	219°	
Plan characteristics	Dimensions (m)	58 X 64	
	Prayer-hall area (m²)	1220	
	Courtyard area (m²)	1092	
			
Plan	**3d model**		

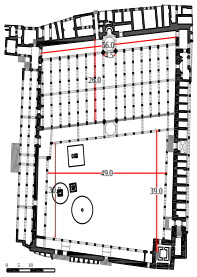
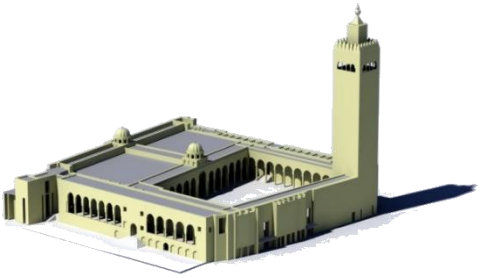
The rectangular courtyard covers a surface of 1092 m² and it is surrounded on four sides by galleries. The prayer-hall is constituted by thirteen naves perpendicular to the Qibla wall crossed by six parallel aisles. The central nave is wider and punctuated with two domes. The first one is raised in front of the mihrab, and the second surmounts the crossing of the

central nave with the fourth aisle counted from the Qibla wall. The mosque presents two circular towers situated in the northwest and southwest corners, with heights reaching the mosque's terrace. The northwest tower serves for the call to prayer. Both the towers have dome at the top.

2.4. Great mosque of Tunis

Built at the heart of the medina of Tunis, the great mosque of Tunis, also called Zytouna mosque, is the first religious building of Tunis (Al Ansari, 1996). The first construction was built under the aegis of Hassan ibn Enn' men in 700. The mosque was reconstructed however in 734 at the time of the Caiid Omeyyade Obeyd Allah ibn Al Habhab. In the Aghlabide time, the mosque was reconstructed (836) according to the model of the Kairouan mosque (Al Ansari, 1996). The Zytouna mosque played undoubtedly a defensive role in its early stages (Ammar, 2010). It underwent modifications in the IXth century and embellishments in the Turkish times of husseinite. The hypostyle prayer-hall is formed by fifteen naves perpendicular to the Qibla wall crossed by seven aisles parallel to this wall (Table 5).

Table 5 Sample M4 presentation
Source: Kammoun S. (2016)

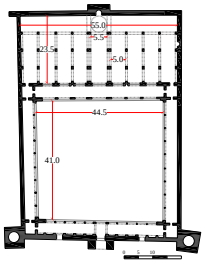
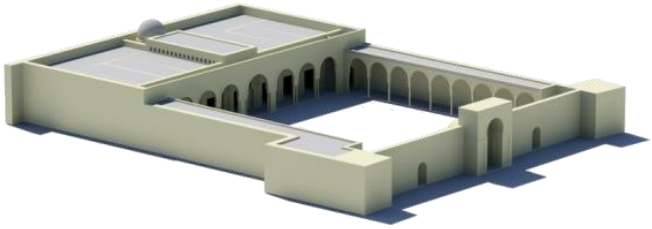
M4	Great Mosque of Tunis		
Construction date	734		
Dynasty	Aghlabide		
Rite	Malikite		
Location information	Latitude	36,47	
	Longitude	10,10	
	North orientation	215°	
Plan characteristics	Dimensions (m)	78 X 84	
	Prayer-hall area (m²)	1470	
	Courtyard area (m²)	1676	
			
Plan	**3d model**		

The median nave and the aisle following the Qibla wall are wider and form a T-shape, their crossing is punctuated by a dome with grooves and with octagonal drum on square base, which rises over the mihrab. The mosque takes a deformed rectangle shape measuring 78×84 m. The courtyard also takes a deformed rectangular shape measuring 49×39 m, lined by galleries on four sides. The current minaret, which resumes the principle of the Almohade, dates the XIXth century (Ammar, 2010).

2.5. Great mosque of Mahdia

Built in the South of the peninsula, by the sea, on a hill of the Mahdia city, the great mosque of Mahdia is the work of the caliph al Mahdi. Totally reconstructed in 1961 according to the plans of the Xth century due to the architect Alexandre Lézine, it is the early Fatimid mosques, and was inspired by Fatimid's mosques of Egypt (Ammar, 2010). It is consisting of a large rectangular enclosure of 58×80 m (prayer-hall 55×23.5 m). It is formed by nine naves perpendicular to the Qibla wall. Where the axial nave is slightly wider and form with the transverse aisle parallel to the Qibla wall a T-shape (Table 6).

Table 6 Sample M5 presentation
Source: Kammoun S. (2016)

M5	Great Mosque of Mahdia		
Construction date	916		
Dynasty	Fatimide		
Rite	Chi'ite		
Location information	Latitude	35,30	
	Longitude	11,04	
	North orientation	213°	
Plan characteristics	Dimensions (m)	58 X 80	
	Prayer-hall area (m²)	1292.5	
	Courtyard area (m²)	1824.5	
			
Plan	**3d model**		

The mihrab was decorated with splines and the walls of the niche were accentuated by vertical grooves. The courtyard is of almost square shape, about 41 m × 44.5 m lined by galleries with unique nave surrounding the courtyard on four sides, interconnected in every angle by square rooms. The mosque presents architectural innovations compared with the previous mosques. A monumental entrance, door of honor intended for the caliph and for the dignitaries, the monumental hall followed by a portico on courtyard appears to it. This hall presents an arch with a slight horseshoe shape and niches in the mihrab form (Ammar, 2010). On the wall opposite to Qibla are flanked two towers of angle, which serve recycling water and call to prayer.

3. METHOD

3.1. Presentation

To report the natural light inside mosques, we chose the daylight factor (DF). This notion allows to estimate the internal illumination of spaces. It is defined by the international commission on Illumination (CIE) as a ratio of the internal natural illumination received in a point of a plan of reference to the simultaneous illumination on a horizontal surface in perfectly cleared site, under the CIE overcast sky condition. To validate the choice of the simulation software, we conducted a comparative study between in situ daylight measure and digital simulations. We have established a protocol of experiment, which allows to compare measurements taken in situ with two luxmeters, with the results of the DF simulations by six software's such as 3ds Max Design, Radiance under Ecotect, Ecotect, Solene, Daysim and Dialux, tested in identical conditions (date, type of sky, etc.). Radiance in Ecotect analysis is the most accurate tool for daylighting lighting analysis. As confirmed by Marsh (Marsh, 2007) the Radiance software is among the most reliable tools for the light simulation. "It uses a two-pass, hybrid, backwards-raytracing algorithm that can handle complex geometry and sophisticated material definitions".

We then studied the distribution form of the illumination through the morphometric approach. The morphometry is a tool that allows to measure the form and to reveal its invisible structure. It is an operation of spatial forms conversion into quantitative representation (Ben Saci, 2000). The objective of the morphometric analysis is to understand the form defined in epistemological terms, by an objective understanding of forms and, in pragmatic terms, by a systematic characterization tool of morphological information allowing to compare and to categories forms, and to disclose

invisible morphological structures from visible forms (Ben Saci, 2000). We performed morphometric calculation by using Morgine implemented to Matlab software. This tool characterizes forms by generating a descriptor representing an information distributing profile of DF in the mosque. The Morpho-frequency description outlines the topological and configurational form determination. The unidimensional representation allows to compare the equivalent parts (morphological and Morphic homology). It is possible to provide the space of metric forms and to automate the classification of the forms (Ben Saci, 2000).

3.2. Daylight simulation and morphometric approaches

The first step in the proposed approach was the collection and organization of different type of data: text, image, graphic and iconographic document. Then we proceeded to the plan modelling with the AutoCAD software. We drew facades using On-Site Photo software, which uses photogrammetric procedure to redraw views on digital photos. Then we created numerical models by using both AutoCAD and 3ds Max software. We created the three-dimensional models of the five studied great mosques by setting up a very elaborate methodology to assure reliability of spatial information, which could guarantee a better quality and an accuracy of the later calculations. In fact, we collected and rectified drawing plan and facades in situ, and we took photos of each detail to create the 3d model. We chose to assimilate openings with holes; it is about the case of maximum penetration of daylight entering the mosque.

For the daylight simulation, we began by importing the 3d model under 3Ds format for the Ecotect Analysis software; we specified the drawing scale, the objects textures, date and hour chosen for the analysis as well as the characteristics of the site (latitude, longitude and North position). We chose an analysis grid with a square cell of 1 cm to have an optimized precision and to be able to compare the studied specimens.

We exported to the radiance analysis by specifying that the DF simulation is performed with the model of CIE overcast sky and that the parameters of materials are defined according to Ecotect. Finally, we exported the calculated values to the csv format for the morphometric analysis. We used the Morgine software implemented in Matlab. We used the lines of commands presented in Table 7 to generate a morphometric signature of the DF distribution in the mosque. We obtained two types of results: graphic (energetic curve) and photographic (DF distribution cartography) (Figure 1).

Table 7 Morgine command lines
Source: Kammoun S. (2016)

Commands	Functions
>> A=1:128;	Define work space
>> [Tn,TTn]=tableau;	Import DF table (csv file format)
>> a1=Morgine(Tn,1,128,0,0);	Apply Morgine to emoted table
>> ec_excel('Results',[an]);	Record morphometric signature to csv file format
>> figure, plot(A, an);	Generate morphometric graph

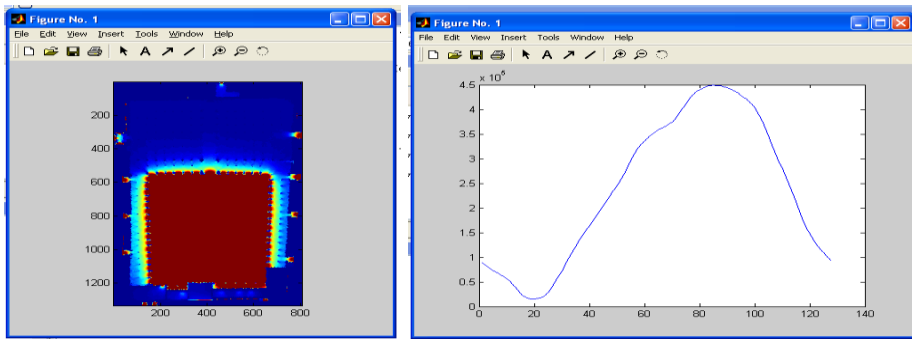


Figure 1 Morphometric Transcriptions of DF table (Kairouan example)
Source: Kammoun S. (2016)

4. RESULTS

We applied the explained approach to the five mosques and we obtained the following results: the average DF varies between 8.66 % for M2 and 39.51 for M5. These values are directly related to the courtyard dimensions. Indeed, M2 possesses a small courtyard of surface 227.5 m² while the other specimens present large courtyards with surfaces going of 1092 m² for M3 to 3354 m² for M1. All the graphs, that represent morphometric DF distribution, have sinusoidal form (Figure 2) with a hollow, which corresponds to the projection of the prayer-hall and a peak, which inform about the courtyard form.

The Morpho-light graph of M1 (Table 8) shows a slight shrug in every extremity caused by the light that passes through the lateral doors. The central position of the courtyard causes a peak. It is about a specimen, which represents the largest mosque of the corpus with the largest courtyard. The main natural light source is the courtyard. The second source is eight lateral doors. The prayer-hall daylighting is provided by two side doors and thirteen

doors giving into the gallery, which separates the prayer-hall of the courtyard and the dome over the Mihrab allowing the zenithal light introduction.

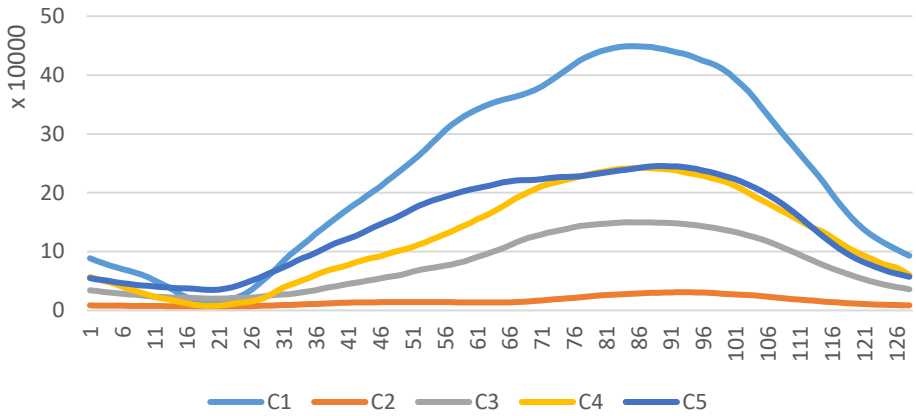
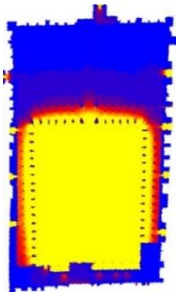
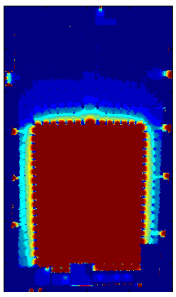
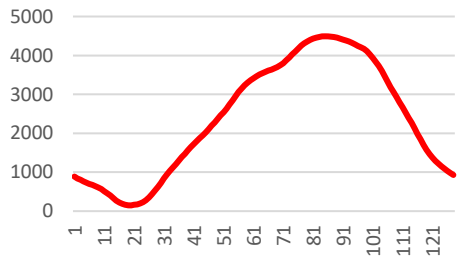


Figure 2 : Energetic graphs of samples Morpho-light.
Source: Kammoun S. (2016)

Table 8 - M1 morpho-light results
Source: Kammoun S. (2016)

M1 : Great mosque of Kairouan		**Average DF = 33.85%**
		
DF Cartographie	**Morphometric fig.**	**Morphometric graph**

The central nave, parallel to the Qibla wall, marks the decrease of the DF values. We can conclude that the orientation of naves plays a key role in the distribution of the light inside the mosque. Perpendicular orientation promotes the introduction in-depth of the light by effect of reflection while parallel orientation plays the role of light obstruction. In M2 Morpho-light graph (Table 9), the gallery arches are projected in the center of the morphometric graph and mark the pause of the descent of the curve (at point 65). M2 a specimen with a small courtyard bordered with gallery in a row on four side have lateral doors to assure the illumination of the prayer-hall.

Table 9 - M2 morpho-light results
Source: Kammoun S. (2016)

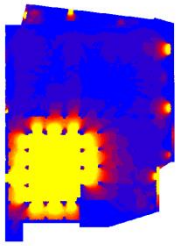
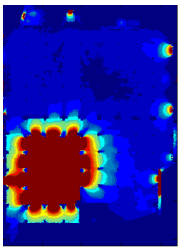
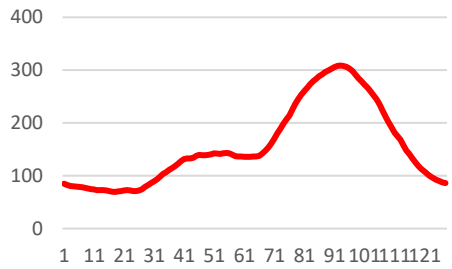
M2 : Great mosque of Sfax		Average DF = 8,66 %
		
DF Cartographie	**Morphometric fig.**	**Morphometric graph**

Table 10 - M3 morpho-light results
Source: Kammoun S. (2016)

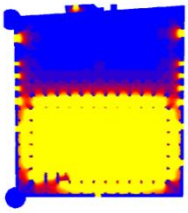
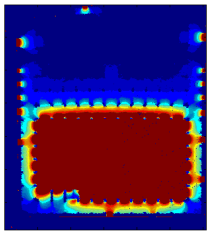
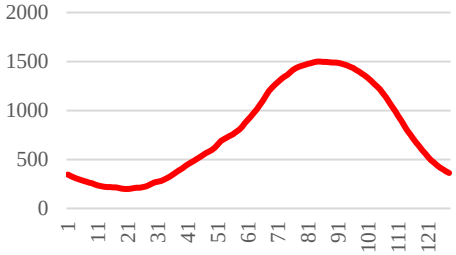
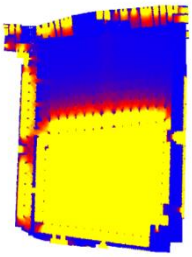
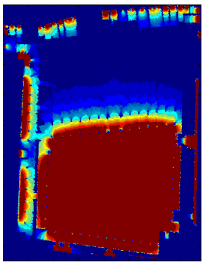
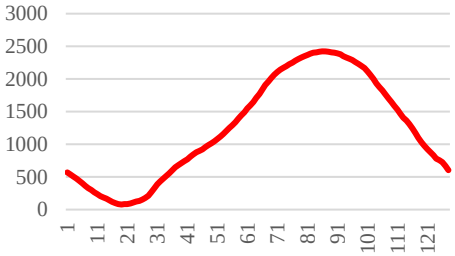
M3 : Great mosque of Sousse		Average DF = 27,68 %
		
DF Cartographie	**Morphometric fig.**	**Morphometric graph**

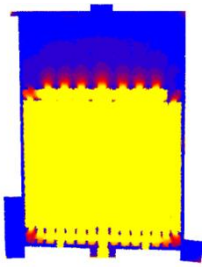
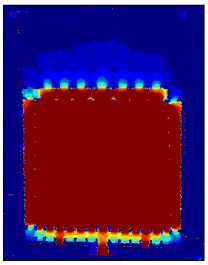
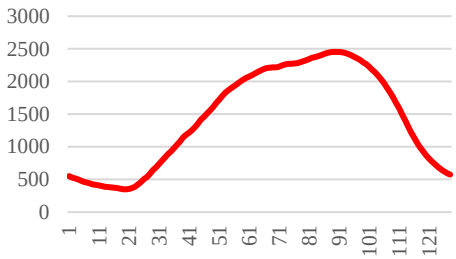
Table 11 - M4 morpho-light results
Source: Kammoun S. (2016)

M4 : Great mosque of Tunis		Average DF = 28,12 %
		
DF Cartographie	**DF Cartographie**	**Morphometric graph**

This specimen presents naves raised in both directions, and this configuration can explain the lowest DF value recorded compared to the other

studied specimens and confirms the assumption of the direct relation between the orientation of naves and the daylight distribution. Three specimen M3 (Table 10), M4 (Table 11) and M5 (Table 12) correspond to mosques with large courtyards. The prayer-hall is mainly enlightened by the doors open into a gallery in a single row of arches, which separates the courtyard of the prayer-hall. Specimens M3 and M4 present besides the side doors, which enlighten the prayer-hall. The prayer-hall of the specimen M5 is enlightened more by a series of zenithal windows placed on the axial nave.

Table 12 - M5 morpho-light results
Source: Kammoun S. (2016)

M5 : Great mosque of Mahdia		**Average DF = 39,51 %**
		
DF Cartographie	**DF Cartographie**	**Morphometric graph**

The analysis of the DF distribution cartography and the study of the Morpho-light of the first mosques of Tunisia show the importance of the architectural form and particularly, the naves orientation, the position of the devices of illumination. The zenithal lighting represents a better device than a side lighting (M5 represents the biggest average DF) and the vertical orientation of naves optimizes the distribution of the natural light inside the prayer hall (Table 13).

Table 13 Form and light data
Source: Kammoun S. (2016)

Specimen	**Courtyard**	**Naves orientation**	**Light source**			**DF Average**
			Lateral Opening	**Frontalal Opening**	**Zenithal Opening**	
M1	Large	Perpendicular	2	17 opening	Cupola	33.85 %
M2	Small	2 sens	9	5 opening	0	8.66 %
M3	Large	2 sens	8	13 opening	0	27.68 %
M4	Large	Perpendicular	7	15 opening	Cupola	28.12 %
M5	Large	Perpendicular	0	9 opening	axial nave	39.51 %

5. DISCUSSION

The obtained results confirm that daylight is a measurable morphological phenomenon. We were able to transform the sensitive into tangible by the scientific approach that combines the daylight simulation and the morphometric analysis. We have demonstrated that the daylight distribution and mosques morphology are closely connected. We proved that the daylight distribution in the studied mosque is directly related to the shape of mosques and particularly, the courtyard shape, the presence of galleries, the architectural devices used to favor the introduction of the natural light and the naves orientation. The light is an important component in mosques design. We studied and compared the Tunisian first great mosques and we can conclude that in spite of the adherence to the hypostyle style, every mosque has its own Morpho-light specificity.

On the other hand, Morpho-light study of the first mosques helps the designers in the morphological choices to optimize the daylight exploitation. This article provides knowledge, which addresses the current concerns of sustainable energy. Besides, the Morpho-light approach helps to take particular account of the heritage, and at the same time as building mirror of the identity and as knowledge rooted in space. It offers a reference design tool for the architects, which allows them to introduce and to test the daylight form in their conceptions and a tool for understanding and analyzing Morpho-light in old and new mosques.

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REUSING OF TREATED MOSQUE ABLUTION GREY WATER: A SUSTAINABLE WATER MANAGEMENT STRATEGY INTEGRATED INTO MOSQUE DESIGN

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Abstract

Globally, Kingdom of Saudi Arabia (KSA) is one of the countries possessing the highest number of medium to mega mosques. In KSA, public ablution ritual using tap water consumes very large amount of water from majority of such mosques. Meanwhile, the tap water supply comes from expensive desalination plants mixed with priceless groundwater resources that are barely, renewable. Unfortunately, significant portion of taps are usually left running during ablution leading to wastage of huge amounts of clean water.

The enormous volume of very low polluted grey water generated is then unnecessarily allowed to freely drain away, eventually, ending up in public wastewater treatment plants (WWTP). This increases the pressure on the WWTP units as well as their operating costs. Considering this tradition of wastage during ablution, the need to adopt a sustainable approach to salvage huge volume of precious and costly water resource, while achieving significant reduction in wastewater that goes to domestic WWTP, cannot be overemphasized. This paper presents a proposed project which suggests carefully, redesigning of ablution and toilet area of a mosque via introducing a recycling system for treating collected ablution grey water for reuse within mosques premises.

The proposed close-loop system would be used for non-portable toilet flushing usage by worshippers attending the mosques services and also for landscaping for mosques beautification. Unlike other similar projects conducted elsewhere, the project would investigate into developing a robust solution that would integrate low cost and sustainable engineering solutions in the overall management of mosque water system. The project would identify the best way to redefine the engineering design of mosque toilet and ablution area architecture for contribution towards meeting KSA sustainable development target goal as enshrined in Vision 2030 and the SDGs of United Nations.

Keywords

Mosque, ablution grey water reuse, sustainable water management, toilet flushing and landscaping, engineering and architectural redesign, Vision 2030, SDGs

إعادة استخدام المياه الرمادية المعالجة الناتجة من الوضوء بالمسجد: الاستراتيجية المتكاملة للإدارة المستدامة للمياه عند تصميم المساجد

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المستخلص

على الصعيد العالمي تعد المملكة العربية السعوديةواحدة من الدول التي تمتلك أكبر عدد من المساجد المتوسطة إلى الضخمة. إن التعاليم العامة للوضوء تستخدم ماء الصنبور في المملكة العربية السعودية، ومن ثم تستهلك كمية كبيرة جدا من المياه من معظم هذه المساجد. وفي ذات الوقت فإن إمدادات مياه الحنفية تأتي من محطات تحلية المياه المكلفة، مختلطة مع موارد المياه الجوفية التي لا تقدر بثمن.

وبعد ذلك يسمح لهذا الحجم الهائل المنتج من المياه الرمادية -منخفضة التلوث - ليصرف بعيدابحرية لينتهي بهاالمطافففي محطات معالجة مياه الصرف الصحي العامة. هذا الوضع يزيد من الضغط على وحدات معالجة المياه العادمة، وكذلك على تكاليف التشغيل الخاصة بها. وبالنظر إلى هذا التقليد من الفاقد أثناء الوضوء تنبثق الحاجة، دون مبالغة، إلى اتباع نهج مستدام لإنقاذ الكم الهائل من الموارد المائية الثمينة والمكلفة، مع تحقيق تخفيض كبير في مياه الصرف الصحي التي تذهب إلى محطات معالجة مياه الصرف المحلية. تقترح هذه الورقة مشروع يشير بعناية لإعادة تصميم نظم امداد مياه الوضوء ومنطقة المرحاض والحمامات بالمسجد، عبر إدخال نظام لإعادة التدوير بغرض معالجة المياه الرمادية المجمعة من الوضوء لإعادة استخدامها حول حرم المسجد.

وسوف يستخدم هذا النظام المقترح - ذي الحلقة المغلقة - لتنظيف مقعد المرحاض غير المحمول بعيد استخدامه من قبل المصلين، ليستغل لهندسة المناظر الطبيعية لتجميل المساجد. وخلافا لأي مشاريع أخرى مماثلة أجريت في أماكن أخرى، يسعى هذا المشروع لتحقيق وتطوير حلول وعملية من شأنها تكامل التكلفة المنخفضة والحلول الهندسة المستدامة للإدارة العامة لنظام مياه المسجد. من الممل لهذا المشروع تحديد أفضل طريقة لإعادة تعريف التصميم الهندسي لمرحاض المسجد، والهندسة المعمارية لمنطقة الوضوء، للمساهمة في تلبية هدف المستدام للتنمية على النحو المنصوص عليه في الرؤية ٢٠٣٠ ووفق مبادئ الأهداف المستدامة للتنمية المعدة من قبل الأمم المتحدة.

الكلمات الدالة

المسجد، إعادة استخدام المياه الرمادية الناتجة من الوضوء، الإدارة المستدامة للمياه، تنظيف دورة مياه الحمام، المناظر الجمالية، الهندسة وإعادة التصميم المعماري، رؤية ٢٠٣٠، الأهداف التنموية المستدامة.

1. INTRODUCTION

KSA, located in an extremely arid region, is characterized with limited renewable fresh water supplies, acute scarcity of rainfall and a high evaporation rate. KSA relies mainly on very slowly renewable fossils groundwater and costly energy intensive seawater desalination process to meet its water demands. In recent decades, the excessive increase in water and energy demands to satisfy the kingdom's need for a massive infrastructural development in all sectors coupled with an ever increasing population and a high living standard demands a significant change in water and energy management strategies (Ouda 2014).

Most of the produced potable water ends up also used for non-potable applications. Moreover, wastewater generated goes to treatment plants that involve high engineering technicalities coupled with excessive utilization of energy. This makes treatment plant operating at an increasing cost. With the rapid KSA development, millions of cubic meters of wastewater effluents generated from different sectors across the Kingdom, cost-effective treatment and reuse of wastewater will no doubt provide sustainable contribution to meeting KSA water demands. Consequently, there should be a rethink towards sustaining future water footprints in KSA.

As such, the need for a sustainable approach to meet the water and energy demands for the whole Kingdom necessities introduction of new policies that ensure adequate water conservation as well as explore alternative sources of water and energy. To meet policy makers' vision of establishing sustainable water and energy, wastewater reclamation and reuse has become a key target as enshrined in Vision 2030 that goes in line with SDGs of United Nations.

1.1. Contribution of the mosque in water consumption in KSA

Mosque attendee's ablution ritual consumes very large amount of clean tap water. Even though, no data was found quantifying the amount of water consumption and discharge from mosques in KSA, however, the expected quantity would be a significant component that need not to be neglected in water management strategy. This is so considering the

- vast number of medium to mega mosques of mosques in each and every KSA city and town and their outskirts and fringes
- five (5) daily ritual prayers practice

- proportion of Muslims population in KSA that attend mosque prayers and other gatherings in the mosques

1.2. Project objectives

The objectives of the project are enumerated as follows:

- To investigate and identify robust and low cost, but effective engineering as well as architectural design concepts of mosque toilet/ablution area and water supply system for sustainable reusing of treated grew water
- To raise public awareness and inculcate the attitude of water reuse, saving and management as a duty to every Muslim
- To harness public contributions in increasing the level of achieving greater sustainability in water management in KSA communities
- To reduce the pressure on WWTPs units which could extend their service life
- To reduce consumable requirement as well as overall cost for running public WWTPs,
- To enhance multi-disciplinary approach via collaboration of different professionals and sectors in community problems solving.

2. Proposed Design Idea for Reusing Treated Ablution Grew Water

The water saving idea herein suggests redesigning of ablution and toilet area of a mosque via a recycling system for treating collected ablution grey water for reuse within mosques premises. The proposed close-loop system would be used for non-portable toilet flushing usage by worshippers attending the mosques services. Additionally, the water saving in this proposed system can also be used for landscaping for mosques beautification. This idea is illustrated in Figure 2 and 3

2.1. Mosque water system: conventional vs proposed

The current conventional water system in mosques across KSA and the proposed concept are clearly shown in flow charts illustrated in Figures 1 and 2, respectively. The conventional system (Figure 1) is characterized by a single water supply pipe to the mosque and single wastewater collection pipe that discharges to public treatment plants. Hence, the drain contains a mixed

wastewater (grey plus black water) in single pipeline which are directed towards the wastewater treatment plant.

Meanwhile, the proposed approach (Figure 2) suggests two sources of water for servicing worshippers, i.e. via introducing a segregated wastewater collection drain pipes that separate between grey and black water. The grey water from personal hygiene areas is directed to the local treatment unit (slow sand filtration and disinfection) introduced in the mosque while the black water goes to the public wastewater treatment. One source of water to the mosque would be from the city water supply which goes to a tank that serves the areas where there is direct personal contact i.e., ablution, shower, toilet cleaning, wash hand basin. The other source of the water would be from the treated ablution and wash hand basin grey water which would be piped to the toilet for flushing and also can be used for landscaping.

2.2. Mosque ablution grey water treatment system

Based on the proposed system in Figure 2, proper plumbing arrangement to separate ablution grey water from black water that comes from toilet flushing would be provided. The treatment system would require robust engineering design that would include different units, pumps and additional tanks that may include

- Sand trap for removal of soil particles
- Storage for raw grey water and treated grew water
- Transfer pumps
- Screens for screening of bigger and floating objects
- Slow filtering for removal of odour and contaminants
- Disinfection unit: disinfection process (chemical or solar), with emphasis on solar
- pH balancing

3. LITERATURE REVIEW

As a consequence of the robust economic growth, economists predict that by 2020-2030 the world will need at least 50% more energy and water for meeting domestic, industrial and agriculture demands than today (Alexandratos et al., 2006). It is expected that by the year 2050, the world's population living in water-stressed countries (arid and semi-arid region) will

increase dramatically (Alexandratos et al., 2006; Scheierling et al., 2011). Similarly, the KSA scenario is not far from the aforementioned global scenario considering the arid region (Abderrahman 2000; de Jong et al. 1989). This projection put such countries more endangered as far as meeting future water and energy demands is concerned (Alexandratos et al., 2006).

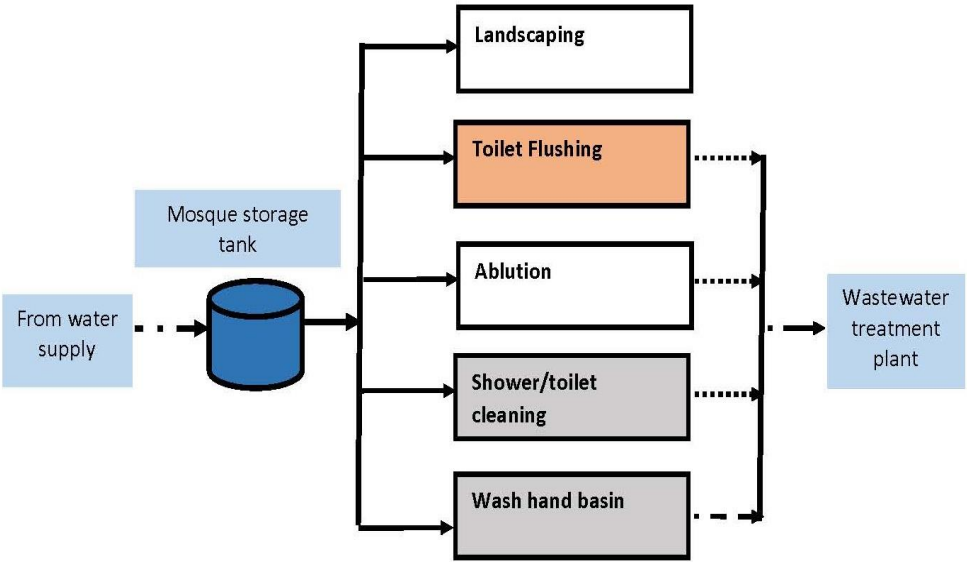

Figure 1: Conventional Mosque water supply and collection system

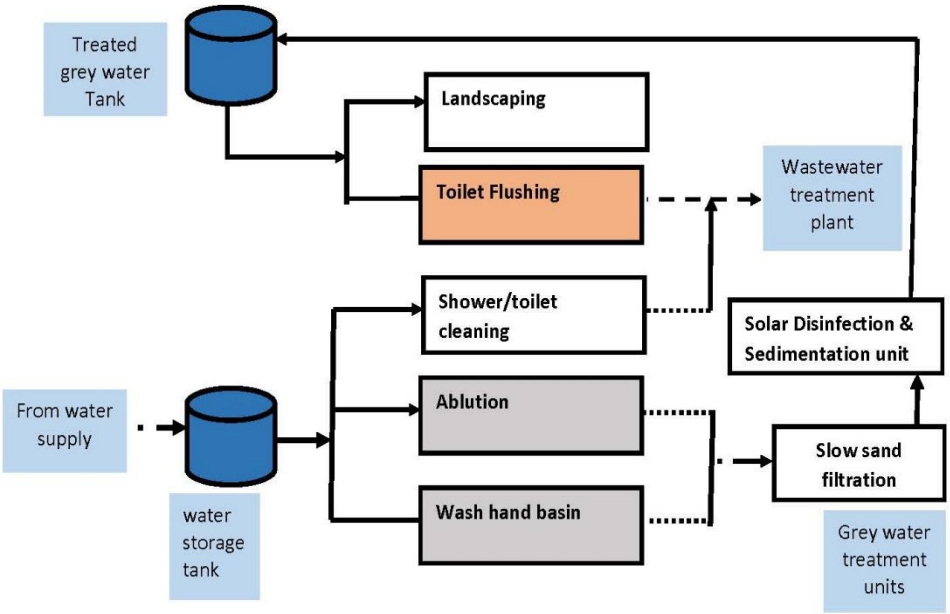

Figure 2: Framework for Integrating Engineering and Architectural Conceptual Models

Inferably, alternative sustainable or non-conventional sources of water supply such as treated wastewater (TWW) are needed especially in such areas characterized by limited natural fresh water sources. As such, there is no doubt that sustainable water conservation requires the substantial reuse of treated wastewater to meet the ever increasing water demands (Meda and Cornel, 2010; Palese et al., 2009; Trinh et al., 2013).

Owing to the fact that reclaimed wastewater is capable of serving several purposes, when harnessed properly, it can upset the local water demand in more sustainable manner (Drechsel and Karg, 2013). Additionally, the quantity of wastewater produced daily is sufficient to completely eliminate or at least drastically reduce the current complete reliance on groundwater and natural climate source of water such as rainfall. These allow the possibility of continuous recycling of TWW and utilization in some sectors while preserving the limited freshwater supplies for meeting other more critical demands. As such, wastewater recycling and reuse for various applications policy has been implemented in many arid and semi-arid countries with great successes (Drechsel and Karg, 2013).

3.1. Problems associated with reusing treated wastewater

The direct use of wastewater or even treated wastewater is faced with many challenges which limit its potential utilization for effective water conservation. These challenges could be enumerated as follows:

- poorly treated domestic effluent raises the concern of possible presence of pathogens in the wastewater which could have ill impact on public health,
- the above mentioned problem necessitates adequate effective removal or inactivation of pathogens from wastewater effluent prior to rendering it suitable for use.
- economic and energy cost implications associated with some of the current disinfection treatments are alarming, while the efficacy of some are very limited as per the removal of some resistant waterborne pathogens.

Consequently, these necessitate effectively, overcoming these challenges to ensure safe and efficient utilization of reclaimed WWTP effluent in various sectors. This could be achieved by using appropriate combination of biological and physico-chemical treatment process to improve the treated water quality to desired level for target reuse.

3.2. Quality of Ablution Grey Water in Mosques

Interestingly, the treated grey water (TGW) from mosques' ablution area could be exempted from the aforementioned problems. This is due to the fact that grey water quality from ablution has less risk of having pathogens (Mamun et al., 2014; Pereira, 2005; Prathapar et al., 2006; Suratkon et al., 2014). Nevertheless, as the water may contain detergents, suspended and dissolved impurities with likelihood of small amount of micro-organisms, there is need for treating it prior to reuse even for non-potable purposes figure3.

Figure 3: Qiblatain mosque in Medina and ablution area and water use for ablution.

3.3. Reuse of Treated Mosque Ablution Grey Water

Recent reviews indicated earlier investigation related to the recycling of TGW from mosque ablution area for reuse within the mosque premises. Prathapar et al. (2006) investigated the reuse of grey water from ablution area from which they design a cost-effective, low maintenance treatment system, to collect, treat and reuse ablution water for irrigation from small to medium-sized mosques. Suratkon et al. (2014) introduced a concept termed " Smart WUDHU" in a university community Mosque. The system consisted of simple recycling system designed to collect, treat and reuse the ablution water. The recycling system could supply the TGW for both potable and non-potable uses such as toilet flushing, general washing, plantation and drinking.

They implemented the system by employing filtration to remove sediments and other fine particles, and then pumping the filtered grey water to high raised storage tank where sedimentation and disinfection via

chlorination took place prior to recycling the water for various purposes other than ingestion. Mamun et al. (2014) studied the feasibility of reuse of TGW from University mosque ablution for landscaping and toilet flushing.

They developed a conceptual model and theoretically designed the water treatment system. Based on laboratory studies, they recommended that the grey water be filtered by sand filter and the size of the sand filter be determined based on an overflow rate of 39.1 m/d. However, these studies did not consider the potential of establishing a sustainable system. Moreover, architectural concepts were not incorporated into the design for cost-effectiveness and improved sustainability.

3.4. Public Acceptance of Reuse of Grey water in KSA

For past decades, understanding public opinion about treated wastewater has drawn serious interest to water policy-makers towards achieving integrated water management to ensure meeting water demands. This is to provide vital information regarding the proportion of the public accepting various uses of recycled for different water uses.

Although literature shows that that reuse of treated wastewater has been practiced for many decades, recent reviews have shown that the current trends still follow the same pattern (Dolnicar and Schäfer, 2009; Friedler et al., 2006; Hartley, 2006; Hurlimann and Dolnicar, 2010). Most of these studies arrived at somewhat similar conclusion that the public generally favored the reuse of treated wastewater for applications that are characterized by low personal contact such as landscaping and gardening; however, they were reluctant to accept treated wastewater for drinking or bathing children and infants.

A recent study was conducted on public acceptance of different types of domestic wastewater at Dammam metropolis where 400 copies of the survey were given to general public to answer (percent response was 82.5%). As shown in Figure 4, majority of the respondents accepted the reuse of grey water for non-potable uses. Hence, by using costly potable water for potable uses alone, the valuable limited resources in KSA would be conserved for more generations to come.

This indicates that other sustainable water resources available in KSA such as treated wastewater can be also employed to meeting non-potable demands. This would ensure achieving the target goals of strategies of integrated water resources management for sustainable development.

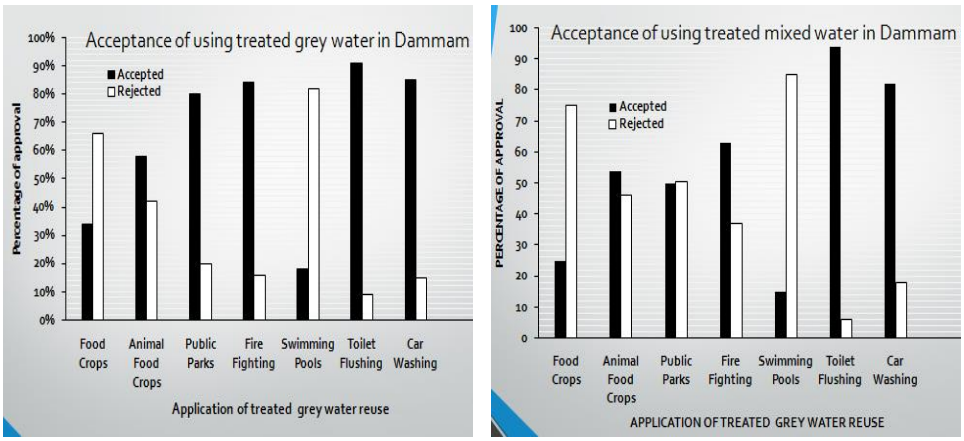

Figure 4: Survey of Public Acceptance level of treated grey and mixed wastewater for various reuse in Dammam

4. METHODOLOGY FOR THE INTEGRATED DESIGN OF MOSQUES

Figure 5 illustrates the framework for integrating engineering design concept with architectural concept for increased cost-effectiveness, improved sustainability and serviceability. The solution methodology to achieving the integrated system is enumerated as per the following steps:

- Selection of suitable mosque(s) for the study
- Quantitative and qualitative assessments of the grey water collected from ablution (as well as wash hand basin) areas from the selected mosque(s)
- Preliminary design of slow sand filtration and disinfection units
- Preliminary architectural design concept of ablution and toilet area
- Laboratory and pilot scale tests of slow sand filtration and disinfection units
- Final engineering design of the grey water treatment system (including plumbing and pumping system)
- Integrating final architectural design concept of ablution and toilet area
- Implementation and testing of the final integrated design concept

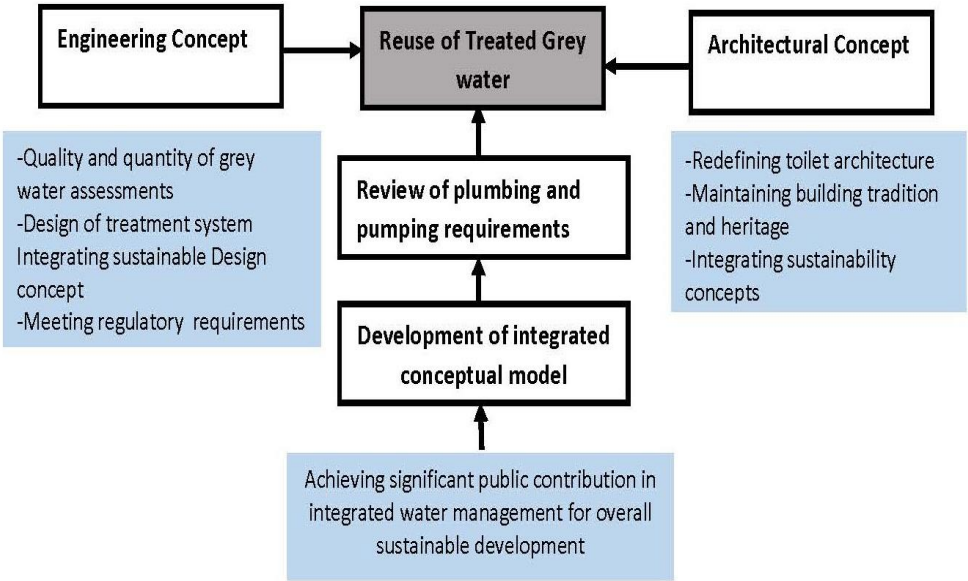

Figure 5: Framework for Integrating Engineering and Architectural Conceptual Models

5. CONCLUDING REMARKS

The approach to toilet and ablution area water system targeted in the proposed project presented in this paper is expected to provide cost-effective and realistic engineering solutions integrated with architectural design concept. It would provide practical management of mosque water which goes in-line with the Islamic values of savings and for ensuring meeting sustainable development target goals.

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STRUCTURAL BEHAVIOR OF THIN FERRO-CEMENT CONCRETE DOMES REINFORCED WITH COMPOSITE MATERIALS

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Abstract

This paper presents experimental and theoretical studies on the structural behavior of thin Ferro-cement concrete domes. The main objective of the current research is to estimate the structural performance of thin Ferro-cement domes reinforced with composite materials. The study involved casting and testing up to failure of two Ferro-cement domes. All specimens were of 1000 mm diameter and of 500 mm height, and they were reinforced with galvanized welded wire meshes. The second dome was the same as the first dome except that the second dome had two openings with 100mm × 100 mm dimensions to indicate the effect of the openings in the structural behavior of Ferro-cement domes. Also, finite element (FE) simulations were employed for all the tested domes.

The experimental results show that the dome reinforced with galvanized welded steel mesh reached the highest serviceability load, ultimate load and achieved highest ductility ratio and energy absorption properties. Additionally, the results of FE simulation match the experimental results. Another six types of circular Ferro-cement concrete domes having diameters of 2.5, 5, 7.5, 10, 12.5 and 15 m were designed with various thicknesses varying from 25mm to 100mm with and without openings. All the twelve designed domes were tested theoretically by using FE analysis. The variables studied were strength, volume fraction, number of mesh layers, and specific surface area of reinforcement and number of skeletal steel bars. The developed Ferro-cement domes were tested under the effect of (D.L. +L.L. +W.L.). All the developed domes achieved higher strength, better deformation characteristics and cracking pattern with great economic saving of materials, which are very useful in the construction of Ferro-cement domes for both developed and developing countries.

Keywords

Ferro-cement domes; Polypropylene fibers; Welded galvanized steel mesh; deformation characteristics, Ductility and; Energy absorption; Finite element simulation; Principal stresses.

السلوك الانشائي للقباب الخرسانية الفيروسيمنتية الرقيقة السمك المسلحة بمواد مركبة

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المستخلص

يقدم هذا البحث دراسة عملية ونظرية للسلوك الإنشائي للقباب الخراسنية الفيروسيمنتية رقيقة السمك المسلحة بمواد مركبة ويشمل البحث عمل اختبار ٢ قبة قطرها١متر وارتفاع نصف متر بدون فتحات ومسلحة بأسياخ تسليح قطر ٦مم في الاتجاهين والأخرى بفتحات وأسياخ التسليح شبك معدني مجلفن وقد تم تعيين الممنطولية وحمل الانهيار والطاقة المختزنة وحمل التشغيل وحمل التشرخ الأول وأقصى حمل. وقد وجد أن هناك توافقاً كبيراً بين النتائج العملية وتلك النظرية بطريقة العناصر المحددة.

وقد تم تصميم عدد ٦ قباب دائرية بأقطار مختلفة ٢,٥م و٥ متر و ٧,٥متر و ١٠متر و ١٢,٥ متر و ١٥ متر وذلك بأسماك مختلفة متغيرة من ٢٥مم إلى ١٠٠مم بدون فتحات. وقد تم تصميم أيضاً عدد ٦ قباب بفتحات وبنفس الأسماك السابقة والأقطار السابقة وتم اجراء الاختبارات النظرية باستخدام برنامج العناصر المحددة لعدد ١٢ قبة خرسانية فيروسيمنتية رقيقة السمك والمتغيرات هي الحجم الجزئي لصلب التسليح وعدد طبقات الشبك المعدني الملحوم المجلفن والمساحة السطحية لصلب التسليح وعدد أسياخ صلب التسليح في الاتجاهين وتم اجراء الاختبارات النظرية باستخدام برنامج العناصر المحددة للقباب المصممة بفتحات وبدون فتحات وذلك تحت تأثير الأحمال الميتة والأحمال الحية وأحمال الرياح وقد توصلت النتائج للقباب المبتكرة إلى تحملها قوة عالية وتوزيع أفضل للانفعالات وتشرخات أفضل بفوائد اقتصادية عظيمة في انشاء القباب الخرسانية الفيروسيمنتية واجهادات أقل كثيراً من اجهاد الشد الغير مباشر لمادة الانشاء الخرسانية الفيروسيمنتية وهذه النتائج ذات فائدة قيمة وعظيمة للدول النامية والمتقدمة على السواء.

الكلمات الدالة

القباب الفيروسمنتية – ألياف البولي بروبلين – الشبك المعدني الملحوم المجلفن – خواص الانفعالات – الممطولية – الطاقة المختزنة – العناصر المحددة الدقيقة – الاجهادات الرئيسية

1. INTRODUCTION

The structural concept of Ferro-cement has been shown to possess excellent mechanical properties in terms of crack control, impact resistance and toughness, which are achieved by close spacing and uniform dispersion of reinforcement within the matrix. These unique qualities of structural performance can be exploited in design and construction for a variety of applications, provided precautions are taken to ensure uniform and adequate cover for the steel a dense impermeable matrix. These will provide sufficient protection from corrosion for the steel, whilst at the same time forming a water-tight structural element that will prevent steel exposure through abrasion and erosion.

Traditional and conventional forms of Ferro-cement construction can sometimes lead to both direct chemical attack of the reinforcement and seepage of water. Both these possible deficiencies can be overcome by simple modifications that can be readily practiced in any country. Firstly, grouping the reinforcement meshes and tying them to skeletal bars into a rigid cage can simplify fabrication, make it more efficient and economic, and above all, achieve the desired location and cover for the mesh (Swamy and Spanos, 1985). Secondly, the impermeability properties of the matrix can be considerably enhanced by pore refinement through the use of pozzolanic cement replacement such as fly ash (Swamy and Spanos, 1985).

These two basic modifications to construction can make Ferro-cement a durable material even in very hostile environments. If, in addition, the serviceability stress in the reinforcement and crack width in the matrix are controlled through design (Ravindraraja and Tam, 1984) Ferro-cement can become a formidable challenger to all other forms of concrete construction. The high strength to weight and stiffness to weight ratio, corrosion and fatigue resistance of Ferro-cement composite makes them attractive for use in the construction of new developed Ferro-cement domes (Swamy and Shaheen, nd & 1990). This paper presents finite element models to determine the distribution of stresses of Ferro-cement domes (Shaheen, 2000).

This paper extends these innovations to the development of thin reinforced concrete domes with high static and dynamic strength, crack resistance and durability, suitable for conventional and unconventional applications. This research presents results of experiments on the structural performance of two Ferro-cement domes reinforced with welded galvanized

steel meshes and skeletal steel bars. The results of two tested domes comprised load- vertical and horizontal curves, crack patterns, first crack load, ultimate load, serviceability load, ductility and energy absorption properties (Shaheen et al., 2014). There is a good agreement between the experimental results and theoretical results obtained by finite element (FE) ANSYS program. The FE models were developed to determine the distribution of stresses in the proposed Ferro-cement domes without openings and with openings, having diameters varied from 2.5m to 15m and thicknesses from 25mm to 100mm. The developed domes were subjected to (D.L+L.L. +W.L.).

2. EXPERIMENTAL DETAILS

Since the mortar matrix has the greatest influence on the behavior and long term stability of Ferro-cement elements, these mixes were designed for high 28 days' compressive strength, low water-cement ratio and high workability. The mix thus consisted of 50% cement replacement by fly ash, sand-cement ratio of 1.6, water-cement ratio of 0.28 to 0.30, and a super plasticizer, 2% by weight of cementitious materials. These mixes produced a slump in excess of 100 mms; the 28 days compressive and flexural strengths averaged 60-65 MPa and 7.5 to 8.0 MPa respectively whilst the incorporation of fly ash enabled continuous strength gain development to 95-100 MPa in compression and 9.5 to 10 MPa in flexure respectively at one year. The matrix had a modulus of elasticity of 31 to 32 GPa at 28 days, and Poisson's ratio of 0.19. Fig. 1 shows stress strain curve of the matrix used.

A wide range of steel meshes and skeletal steel bars were used, alone or in combination, to optimize the specific surface or volume fraction of the reinforcement. In addition, comparable conventional reinforced concrete dome was also tested to assess the effectiveness of welded galvanized steel mesh reinforcement. The experimental program included casting and testing two spherical domes, D1and D2. The diameter and the height of all specimens were 1000 mm and 500 mm respectively.

In each dome, steel bars of 5 Ø 6 mm in the ring direction and of 16 Ø 6 mm in the meridian direction were used as skeletal steel bars as shown in Fig.1. Fig.2a emphasizes the polypropylene fibers e300 used.

The domes D1 and D2 were reinforced with one layer of welded galvanized steel mesh with 1.5 mm diameter and with 12.5 mm ×12.5 mm

size of openings as shown in Fig.2b. The properties of the used welded steel mesh were obtained from testing three samples by using Instron Universal Testing Machine. From the test results, the proof stress, ultimate stress and modulus of elasticity could be achieved as 450 MPa, 650 MPa and 190 GPa respectively.

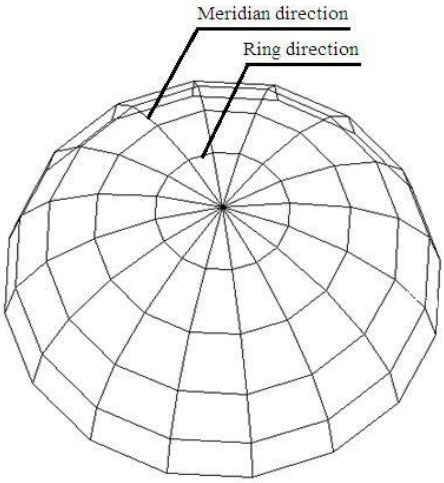


Fig. 1 Cage of Skeletal steel bars

Fig.2-a Polypropylene fibres e300

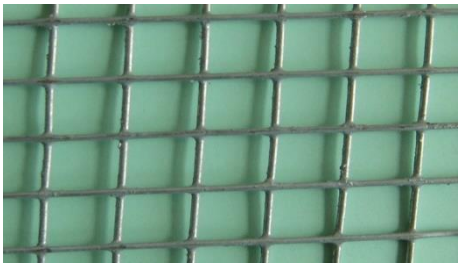


Fig.2-b Galvanized welded steel mesh

3. FINITE ELEMENT SIMULATION

ANSYS computer program was utilized for analyzing the structural components involved in the current study. Three-dimensional brick element (Solid65 element) was used to simulate the mortar. Solid65 element has the capability of cracking in tension and crushing in compression. The element was defined by eight nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions. Up to three different rebar specifications may be defined. The rebar capability is available for modeling reinforcement behavior.

Reinforcement was specified by its material, volume ratio and orientation angles. The volume ratio was defined as the rebar volume divided by the total element volume. The orientation was defined by two angles in degrees (θ and φ) from the element coordinate system as shown in Figure 3. Link8 element

was used to simulate steel bars. The 3-D spar element (Link8 element) was a uniaxial tension-compression element with three degrees of freedom at each node: translations of the nodes in x, y, and z-directions. No bending moment was considered by using this element. Considering this element, plasticity, creep, swelling, stress stiffening, and large deflection capabilities could be considered in the analysis. The support was defined at all lower nodes as hinged support, and the load was concentrated at seventeen nodes as seen in Figs. 4 and 5 (Shaheen et al., 2014).

$$E_c = 4400\sqrt{F_{cu}} \quad (1)$$

$$Stress = \frac{E_c \varepsilon}{1 + (\varepsilon/\varepsilon_0)^2} \quad (2)$$

$$\varepsilon_0 = \frac{2F_{cu}}{E_c} \quad (3)$$

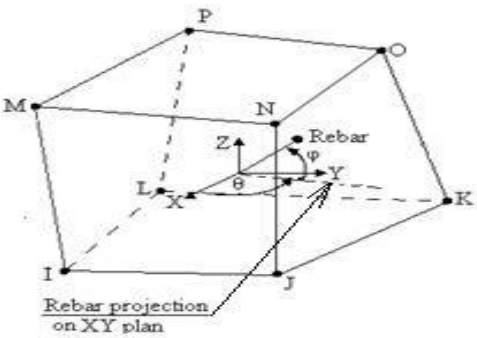


Fig. 3 Solid 65 element without opening

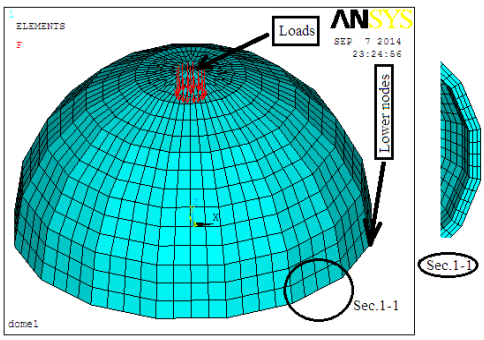


Fig. 4 Finite element simulation for domes

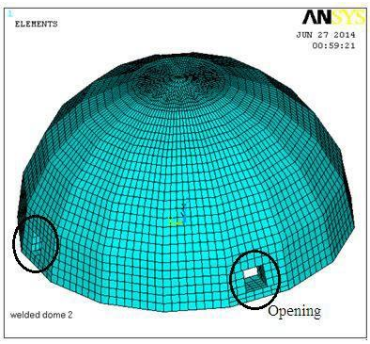


Fig. 5 Finite element simulation for dome with opening

4. RESULTS AND DISCUSSION

The experimental results for two domes included first crack load, ultimate load, service load, displacements at the first and ultimate load, ductility ratio and energy absorption, as summarized in Table 1. The energy absorption was calculated as the area under the load-deflection (vertical displacement) curve while ductility ratio was defined in this investigation as the ratio of the vertical displacements at ultimate load to that at the first crack load. Service load (Ps), or flexural serviceability load, was defined according to CP110 as a function in the ultimate load (Pu) and the dead load (DL) of the dome (its own weight) as shown in Eq. (4).

$$P_s = \frac{P_u - 1.4DL}{1.6} \quad \ldots\ldots (4)$$

Table 1: Test Results of Domes, D1 and D2

NO. of sample	First crack load (kN)	Service load (kN)	Ultimate load (kN)	Displacement (mm) at the first crack			Displacement (mm) at the ultimate load			Ductility ratio (%)	Energy absorption (kN.mm)
				PH1	PH2	PV1	PH1	PH2	PV1		
D1	65	63.91	105	10.6	9.5	7.3	20	17.2	14.4	1.9726	756
D2	60	57.67	95	9.5	9.3	9	13.8	14.0	14	1.5556	665

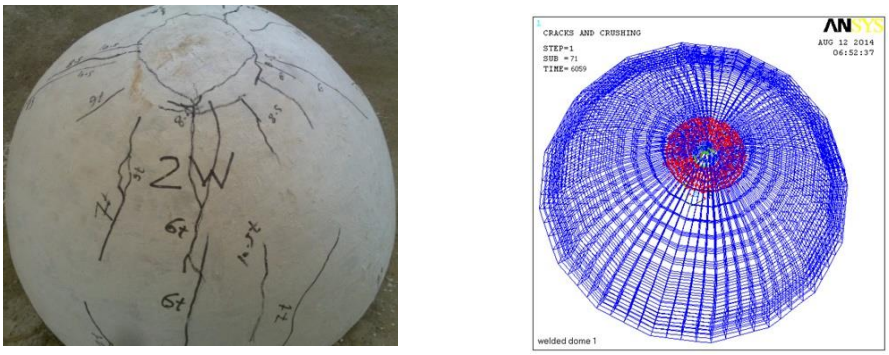


Fig. 6-A : Cracking patterns for all tested domes D1

Fig. 6-A & 6-B shows cracking patterns for the tested domes D1 and D2. It is interesting to note that there is no spalling of concrete cover resulting

from controlling of cracks by employing welded galvanized steel mesh; this is predominating.

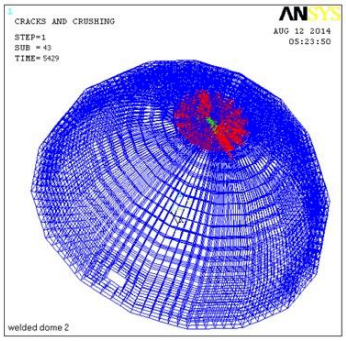


Fig. 6-B : Cracking patterns for all tested domes D2

5. ANALYTICAL MODEL

The FE models were developed to determine the distribution of stresses in the designed Ferro-cement domes Table 2. A specialized commercial FE program was used according to the following assumptions:

1. The stress – strain relationship for concrete mortar is linearly elastic – perfectly plastic in compression and linearly elastic in tension up to the cracking strength.
2. The stress – strain relation for wire steel mesh and skeletal steel bars is linearly elastic – perfectly plastic with the same yield stress and modulus of elasticity in tension and compression.
3. Only material non- linearity due to cracking of mortar, tension stiffening effect of mortar between the cracks and the non- linear stress – strain relationships for the mortar, wire steel mesh and skeletal steel bar are considered.
4. Geometrical non- linearity, bond slip between the reinforcement and mortar, time dependent effects and thermal effects are not considered.

The modulus of elasticity of the composite in the elastic stage can be predicted by the law of mixtures as follows:

Ecomp. = Ematrix x Vol. matrix+ Esteel x Vol.steel (5)

Table 2: Reinforcement configuration of all designed Ferro-cement Domes

Diam.., m	Thickness, mm	Skeletal steel bars reinforcement		Steel mesh reinforcement	E composite KN/mm^2
		2.5	In Meridian direction	Number of layers of Galvanized welded Steel mesh, 12.5x12.5mm, d=1.6mm	
2.5	25	5Φ6mm	16Φ6mm	2	36.23
5.0	35	10Φ6mm	20Φ6mm	4	37.595
7.5	50	15Φ8mm	30Φ8mm	6	40.325
10.0	75	20Φ8mm	40Φ8mm	8	43.055
12.5	85	25Φ10 mm	60Φ10mm	10	45.103
15.0	100	30Φ12 mm	80Φ12mm	12	47.15

6. RESULTS AND DISCUSSION OF DEVELOPED DOMES

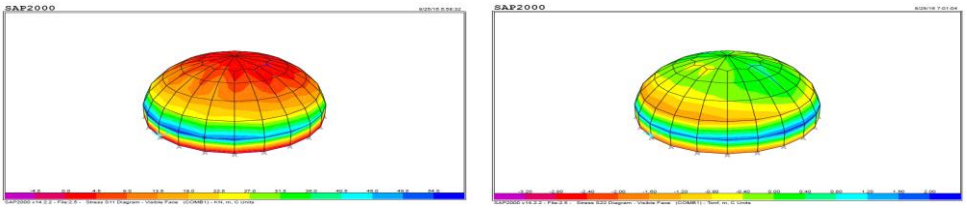
Table 3 presents comparison of maximum and minimum stresses of solid domes and domes with windows and subjected to combination of (Dead. Load +Live load+ Wind load). It is interesting to note that the obtained stresses are less than those of indirect tensile strength of the used matrix. Figs. 7-12 show distribution of maximum and minimum stresses for all domes having diameters of 2.5m, 5m, 7.5m, 10m, 12.5m and 15m respectively, while Figs. 13-18 emphasize the distribution of maximum and minimum stresses for domes with windows having diameters of 2.5m, 5m, 7.5m, 10m, 12.5m and 15m respectively. It is interesting to note that the developed maximum and minimum stresses are smaller than those of the employed matrix.

Table 3 Comparison of maximum and minimum stresses of solid domes and domes with windows.

Diam., m	Solid Domes				Domes with windows			
	Stresses, t/m^2		Stresses, t/m^2		Stresses, t/m^2		Stresses, t/m^2	
	Max. SS11	Min. SS11	Max. SS22	Min. SS22	Max. SS11	Min. SS11	Max. SS22	Min. SS22
2.5	5.472	-0.512	2.28	-3.478	27.972	-19.712	3.95	-23.05
5.0	12.48	-13.22	2.744	-17.58	94.16	-78.99	11.737	-71.058
2.5	5.472	-0.512	2.28	-3.478	27.972	-19.712	3.95	-23.05
7.5	13.125	-13.071	2.214	-17.95	78.438	-63.271	9.89	-59.41

Table 3 - Continued Comparison of maximum and minimum stresses of solid domes and domes with windows.

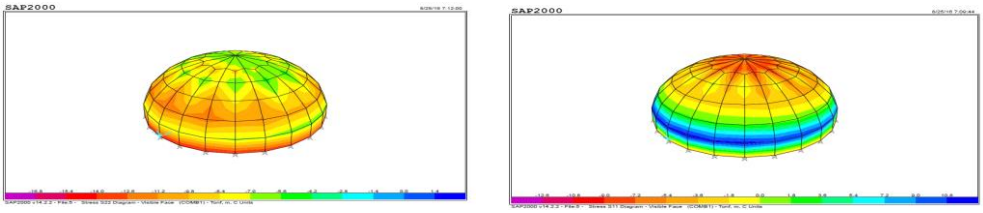
Diam., m	Solid Domes				Domes with windows			
	Stresses, t/m^2		Stresses, t/m^2		Stresses, t/m^2		Stresses, t/m^2	
	Max. SS11	Min. SS11	Max. SS22	Min. SS22	Max. SS11	Min. SS11	Max. SS22	Min. SS22
10.0	15.281	-15.021	2.137	-21.431	91.89	-72.51	11.65	-70.33
12.5	17.864	-17.608	2.447	-25.088	101.99	-80.936	13.134	-77.59
15.0	20.466	-20.291	2.170	-28.788	115.24	-92.45	15.071	-88.15



Max.(DL+LL+ wind) stress (S11) = 5.472 t/m²
Min. (DL+LL+wind) stress (S11) = -0.512 t/m²

Max. (DL+LL+wind) stress (S22) = 2.28 t/m²
Min. (DL+LL+wind) stress (S22) = -3.478 t/m²

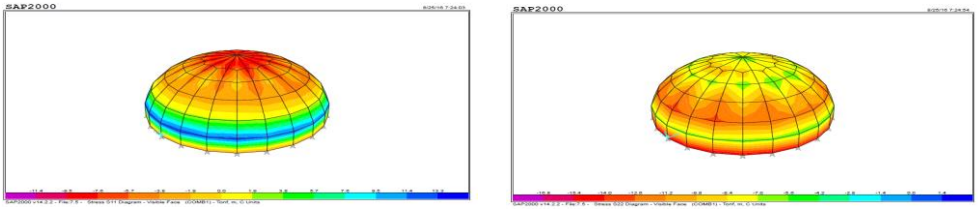
Fig. 7 Principal stresses of Dome, d=2.5m



Max. (DL+LL+wind) stress (S11) = 12.48 t/m²
Min. (DL+LL+wind) stress (S22) = -17.58 t/m²

Max. (DL+LL+wind) stress (S22) = 2.744 t/m²
Min. (DL+L+wind) stress (S11) = -13.22 t/m²

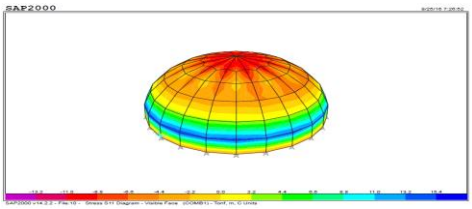
Fig. 8 Principal stresses of Dome, d=5m

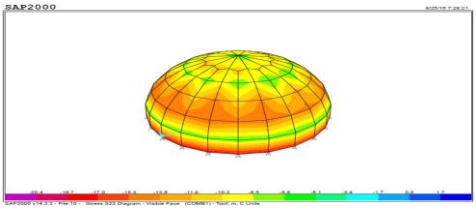


Max. (DL+LL+wind) stress (S11) = 13.125 t/m²
Min. (DL+LL+wind) stress (S11) = -13.071 t/m²

Max. (DL+LL+wind) stress (S22) = 2.214 t/m²
Min. (DL+LL+wind) stress (S22) = -17.95 t/m²

Fig. 9 Principal stresses of Dome, d=7.5m

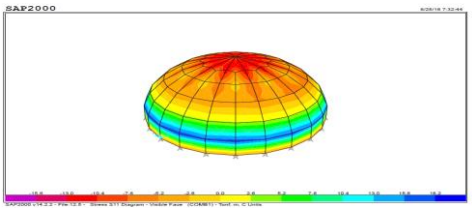


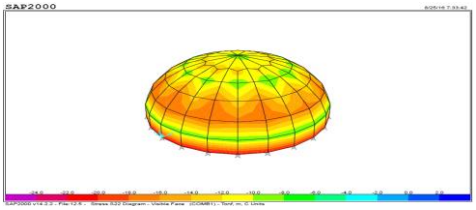


Max. (DL+LL+wind) stress (S11) = 15.281 t/m²
Min. (DL+LL+wind) stress (S11) = -15.012 t/m²

Max. (DL+LL+wind) stress (S22) = 2.137 t/m²
Min. (DL+LL+wind) stress (S22) = -21.431 t/m²

Fig. 10 Principal stresses of Dome, d=10m

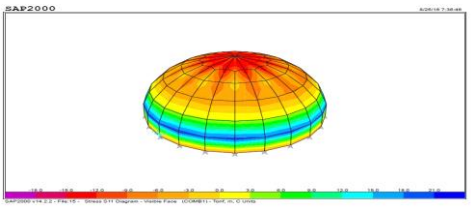


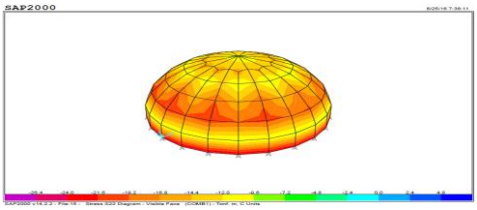


Max. (DL+LL+wind) stress (S11) = 17.864 t/m²
Min. (DL+LL+wind) stress (S11) = -17.608 t/m²

Max. (DL+LL+wind) stress (S22) = 2.447 t/m²
Min. (DL+LL+wind) stress (S22) = -25.088 t/m²

Fig. 11 Principal stresses of Dome, d=12.5m

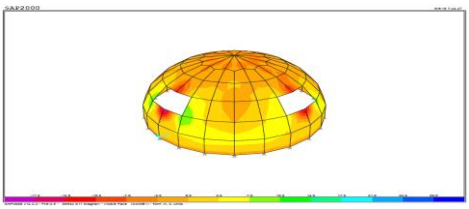


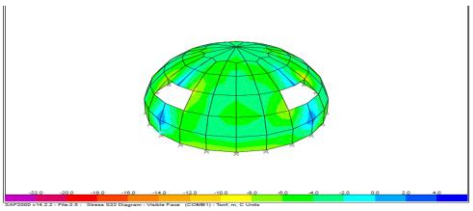


Max. (DL+LL+ wind) stress (S11) = 20.466 t/m²
Min. (DL+LL+wind) stress (S11) = -20.291t/m²

Max. (DL+LL+wind) stress (S22) = 2.779t/m²
Min. (DL+LL+wind) stress (S22) = -28.788 t/m²

Fig. 12 Principal stresses of Dome, d=15m

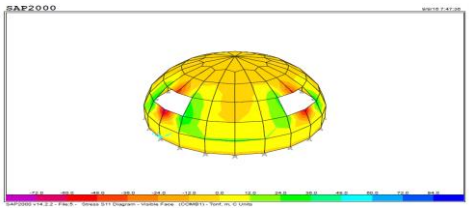


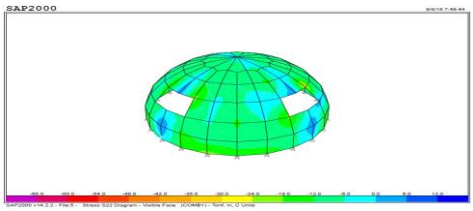


Max. (DL+LL+ wind) stress (S11) = 27.972 t/m²
Min. (DL+LL+wind) stress (S11) = -19.712 t/m²

Max. (DL+LL+wind) stress (S22) = 3.95 t/m²
Min. (DL+LL+wind) stress (S22) = -23.05 t/m²

Fig. 13 Principal stresses of Dome with windows, d=2.5m

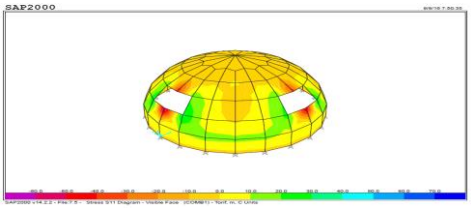


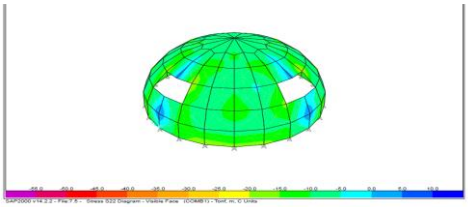


Max. (DL+LL+wind) stress (S11) = 94.16 t/m²
Min. (DL+LL+wind) stress (S11) = -78.99 t/m²

Max. (DL+LL+wind) stress (S22) = 11.737 t/m²
Min. (DL+LL+wind) stress (S22) = -71.058 t/m²

Fig. 14 Principal stresses of Dome with windows, d=5m

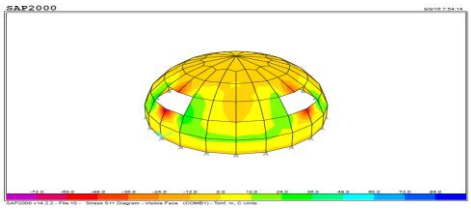


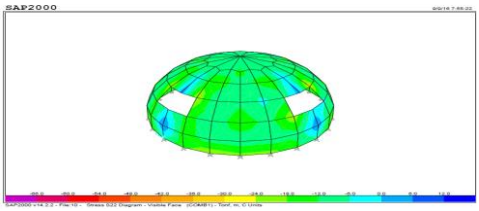


Max. (DL+LL+wind) stress (S11) = 78.438 t/m²
Min. (DL+LL+wind) stress (S22) = -63.271 t/m²

Max. (DL+LL+wind) stress (S22) = 9.89 t/m²
Min. (DL+LL+wind) stress (S11) = -59.41 t/m²

Fig. 15 Principal stresses of Dome with windows, d=7.5m

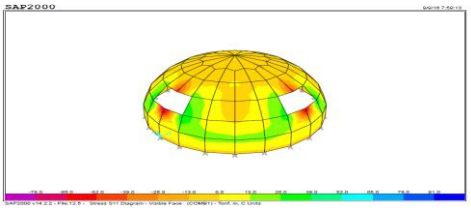


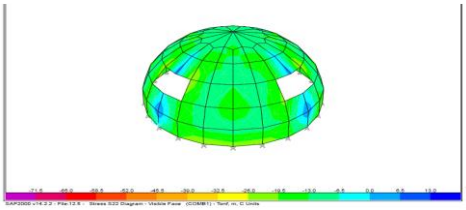


Max. (DL+LL+wind) stress (S11) = 91.89 t/m²
Min. (DL+LL+wind) stress (S11) = -72.51 t/m²

Max. (DL+LL+wind) stress (S22) = 11.65 t/m²
Min. (DL+LL+wind) stress (S22) = -70.33 t/m²

Fig. 16 Principal stresses of Dome with windows, d=10m

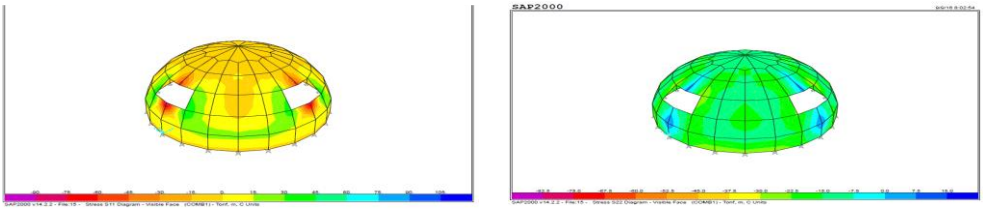




Max. (DL+LL+wind) stress (S11) = 101.199 t/m²
Min. (DL+LL+wind) stress (S11) = -80.936 t/m²

Max. (DL+LL+wind) stress (S22) = 13.134 t/m²
Min. (DL+LL+wind) stress (S22) = -77.59 t/m²

Fig. 17 Principal stresses of Dome with windows, d=12.5m



Max. (DL+LL+wind) stress (S11) = 115.24 t/m² Max. (DL+LL+wind) stress (S22) = 15.017 t/m²

Min. (DL+LL+wind) stress (S11) = -92.45 t/m² Min. (DL+LL+wind) stress (S22) = -88.15 t/m²

Fig. 18 Principal stresses of Dome with windows, d=15m

7. CONCLUSIONS

The following conclusions could be drawn from the current study:

1. Thin Ferro-cement domes were developed with high strength, crack resistance, high ductility and energy absorption properties useful for dynamic and earthquake applications.
2. Irrespective of dimensions of Ferro-cement domes, the obtained maximum stresses were predominantly beyond the indirect tensile strength of the matrix used.
3. Better choice of reinforcement geometry, which can force an orthogonal cracking grid cracks, is possible irrespective of the type of reinforcing materials, metallic or non-metallic. Size of opening of mesh used has a dominant effect in controlling crack width; the smaller the opening the better the results.
4. There is no spalling of concrete cover at failure; this is predominant.
5. Superior results and high energy and cost savings could be reached by employing Ferro-cement concrete Ferro-cement domes. The developed concept can be used to great economic and technical advantages in both developed and developing countries.

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STRUCTURAL MEASUREMENT OF OLD MOSQUE TO CONTRIBUTE THE BUILDING MAINTENANCE

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Abstract

Hagia Sophia, Istanbul, was constructed in 537 as the church and was used as the mosque since 1453. It also shows a huge, complex and beautiful structure. Since 1935, Hagia Sophia has been opened as the museum and studied their structural characteristics. In spite of many earthquake attacks, Hagia Sophia has been survived and has shown the ancient status as the world heritage structure. However, the deformation of the structure has grown after completion of the structure and several structural problems can be found. To maintain such structure in the future, the appropriate renovations or the restorations are important. The structural assessments are also required by using the nondestructive measurements. In this paper, the structural behavior of Hagia Sophia was analyzed by use of vibration record of the structure.

Keywords

Hagia Sophia, vibration analysis, monitoring, structural analysis, numerical analysis

استخدام القياسات الانشائية للمساهمة في صيانة المساجد القديمة

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المستخلص

انشئ مسجد ايا صوفيا في عام ٥٣٧ ككنيسة وقد استخدم بعدها كمسجد في عام ١٤٥٣. يعتبر مسجد ايا صوفيا من المباني الضخمة المركبة والجميلة. في عام ١٩٣٥ تم افتتاحه كمتحف بعد دراسة خصائص هيكله الانشائي.

بالرغم من تعرضه لعدد من الزلازل الا انه ما زال قائما وهو يعتبر الان احد المباني التاريخية القديمة ، الا انه ظهرت هناك العديد من التشوهات في الهيكل الانشائي والتي تفاقمت فيما بعد.

وللحفاظ على مثل هذه المباني التاريخية فإنه يلزم عمل تجديد ملائم للمبنى مع المحافظة على القيمة التراثية للمبنى مما ادى الى الحاجة الى القيام باختبارات وفحوصات واخذ قراءات دون اللجوء الى الاضرار بالهيكل الانشائي للمبنى.

تتناول هذه الورقة تحليل الهيكل الانشائي لمسجد ايا صوفيا باستخدام طريقة الاهتزازات وتسجيلها للهيكل الانشائي

الكلمات الدالة

آيا صوفيا، وتحليل الاهتزاز، الرصد ،التحليل الإنشائي، التحليل الرقمي

1. INTRODUCTION

Mosques are the typical buildings and the central monuments in Islamic countries. Several types of mosque have been constructed. Among them, the domical structures are complex structures but these concepts have been applied to the current large span space structures. Hagia Sophia, Istanbul, was constructed in 537 as the church and was used as the mosque since 1453. It also shows a huge, complex and beautiful structure. Since 1935, Hagia Sophia has been opened as the museum and studied their structural characteristics and the function of each structural element by many researchers (Çakmak, et al 1995, Main stone 1998, Hidaka, et al 2004, Hara et al 2015, 2016. etc.). Figure 1 shows the western view of Hagia Sophia. It consists of main structure, three stone minarets and one brick minaret.

The main  building shows particular characteristics. Huge dome of 31m diameter is supported by four

Figure 1 Hagia Sophia

main arches, the tympanum and the piers. To stabilize them, the semi domes, the buttress and the pendentives are arranged. These are also supported by the complex structure (see Figure 2).

Despite many earthquake attacks, Hagia Sophia has survived and has shown the ancient status as the world heritage structure. However, the deformation of the structure has grown after completion of the structure and several structural problems can be found (see Figure 3). To maintain such structure in the future, the appropriate renovations or restorations are important. The structural assessments should also be required by employing the nondestructive measurements.

In this paper, the structural behavior of Hagia Sophia was analyzed by using vibration record of the structure. The vibration record was measured by the micro tremor meters.

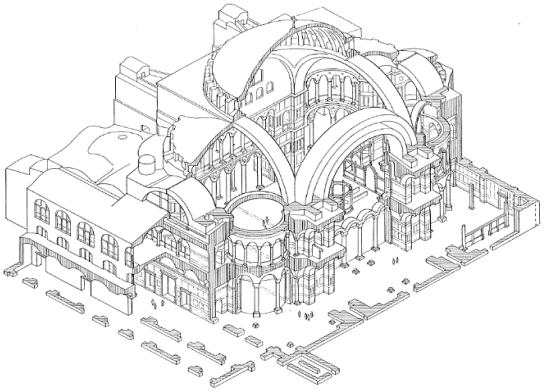


Figure 2 Structure of Hagia Sophia (Mainstone 1998)

(a) Cracks of the wall (b) Inclination of column (c) Sliding of the column

Figure 3 Deterioration of the structural elements

2. VIBRATION MEASUREMENT OF MAIN BUILDING

From the drawing by Van Nice (1965), the height of the roof top is about 56m and the diameter of the main dome in N-S and EW directions are 31.805m and 30.855m, respectively. The structure of Hagia Sophia consists of many structural elements and provides huge spaces in the dome (see Figure 2). The structure was constructed using the bricks and stones up to the gallery layer and masonries were used for the building. The building had been attacked by several strong earthquakes, and was also affected by penetration of the water and moisture. Therefore, several problems such as cracking of the walls and the domes, inclination of the columns and water penetration, are detected (see Figure 3).

In addition, due to the different depth of the bed rocks and the large deformation of the materials, the building structure shows a lot of damages on the surfaces and represents incredible structural deformation. To restore and conserve such a huge heritage structure, the structural inspections are

required in detail. In the vibration measurement, the natural frequencies were analyzed and compared with the results by other researches (Çakmak, et al. 1995; Hidaka et al. 2004). Then, the vibration modes were investigated. From these results, the characteristics of the total structure were clarified and the structural problems were identified.

2.1. Measuring the Tremor

The purpose of dynamic measurement is to acquire the structural data of an existing building without destructions and to assess its structural performance. In this paper, the acceleration tremors were measured to obtain the structural data. Then the natural frequencies and the vibration modes of the main building were determined. Eight micro-tremor meters were applied in this analysis. Each tremor meter consisted of three acceleration pickups, which could measure the accelerations in orthogonal direction simultaneously.

Figure 4 shows the micro tremor meter applied in this investigation. Figure 5 shows the measuring model and nodal points on the skeleton of the structure in this investigation. The main structure shown in Figure 5(a) was transformed into skeleton as shown in Figure 5(b). Measuring point numbers are denoted at each node. Each tremor was measured with 40Hz sampling frequency and 3600 seconds time duration.

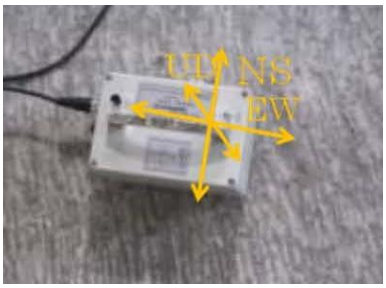


Figure 4 Micro tremor meter

While measuring the tremors, one micro-tremor meter was fixed on the base floor and the other 7 micro-tremor meters were movable from point to point. Firstly, the tremors at the base floor, the gallery level, the second cornice and the dome cornice on the northern side of main building were measured. Secondary, tremors on the southern side of main building were measured in a similar manner.

Finally, the piers at the entrance gate and the piers under apse dome were measured. The tremors were measured at a total of 29 nodes. All the tremor data obtained in this measurement were collected and were analyzed by FDD (Frequency Domain Decomposition). Then the natural frequency and the vibration mode were obtained.

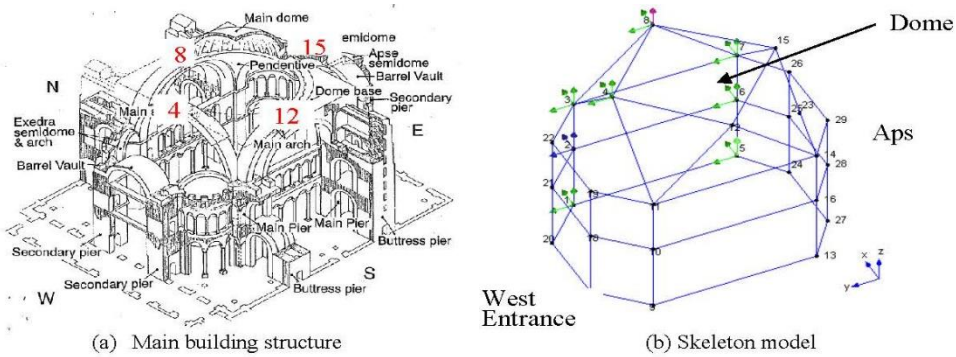


Figure 5 Measuring model

2.2. Dynamic Characteristics of Main Building

Using the FDD analysis, the frequency domain expressions of four measuring record sets were combined and represented. The response in the frequency domain is presented in Figure 6. From the measurement, the first two frequencies were obtained as1.85Hz and 2.09Hz, which were the same as obtained by Hidaka (2004) and Çakmak (1995). The values 1.85Hz and 2.09Hz are natural frequencies for the predominant vibration in N-S direction, respectively. The vibration modes of 1.85 Hz and 2.09Hz are shown in Figures 7. However, in addition, in this analysis, the peak frequency was obtained as 2.93 Hz. The vibration modes of 2.09Hz and 2.93 Hz in Figures 7 show interesting vibration. In this case, the building at south west pier moved, even it is a column base. Çukmak (1995) reported that the southern portion of the building has deeper foundation than the northern portion. It may cause the column movement mode.

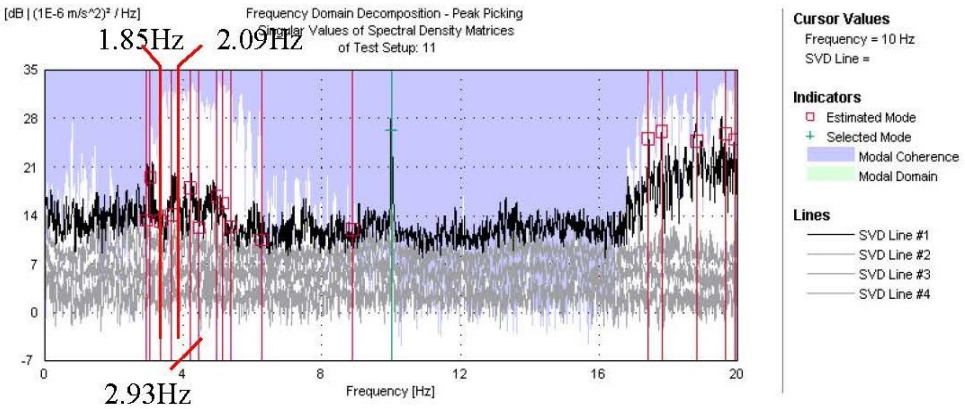
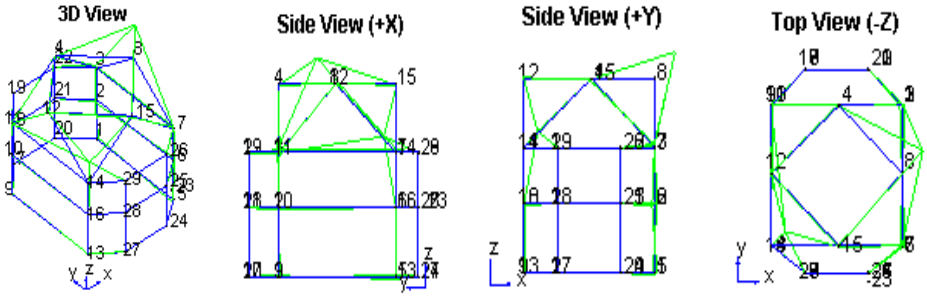
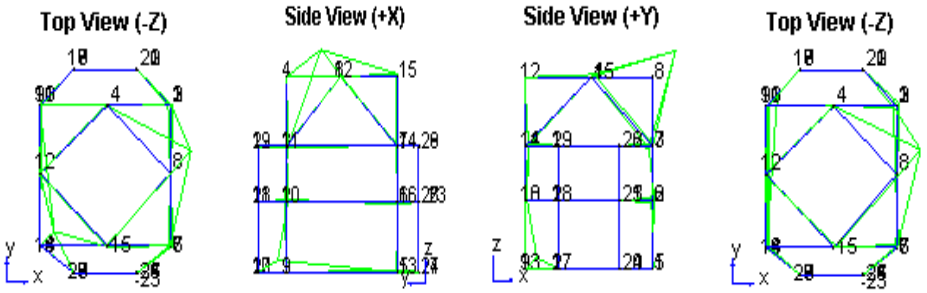


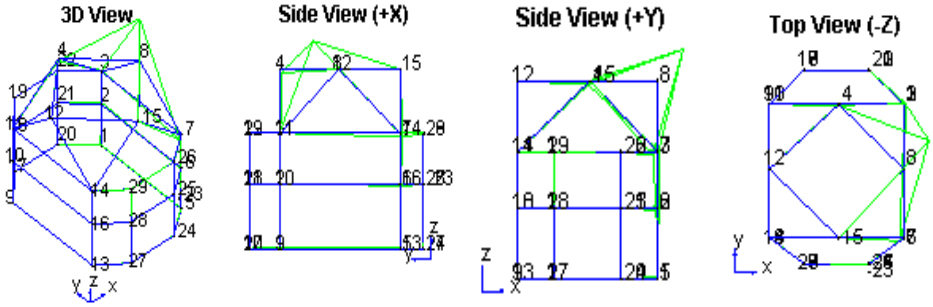
Figure 6 Frequency domain responses



(a) Mode Shape (1.85Hz)



(b) Mode Shape (2.09Hz)



(c) Mode Shape (2.93Hz)

Figure 7 Mode Shape of the Main Building

2.3. Estimation of the Building deterioration

The mode shape of the building obtained from the vibration analysis shows the deterioration of the building structure. In case of 2.09Hz, the building at south west pier moved, even it is a column base (Figure 7b). Usually, no movement occurred at the building column base. Çukmak (1995) reported the problem of the southern portion of the building. It may cause the

column movement mode. Also, for each mode shape, the northern wall over second cornice moves.

However, the southern wall does not move. The inspection of water penetration team detected the water penetration and the deficiency of the northern wall (Ishizaki et al 2014). The northern wall may have structural problem. The investigation of the northern wall will be required in detail. From the vibration measurement, the deterioration of the mosque could be detected by using FDD mode analysis.

3. VIBRATION MEASUREMENT OF SECOND CORNICE

Figure 8 shows the plan of the second cornice level (Van Nice 1965). In Hagia Sophia, there is the main dome at the center and the main dome is supported on four main arches. Two arches are supported by the buttress in northern southern direction. Also, other arches are supported by the semi-domes in eastern western direction. Each semi-dome has two sub-domes. The second cornice is attached to the sub-dome arranged on the exedra. At each corner of the ends of the semi-dome (see thin circles in Figure 8), complicate stress status appeared and the stone blocks on the second cornice work loose. Especially, the corners close to the main dome come loose.

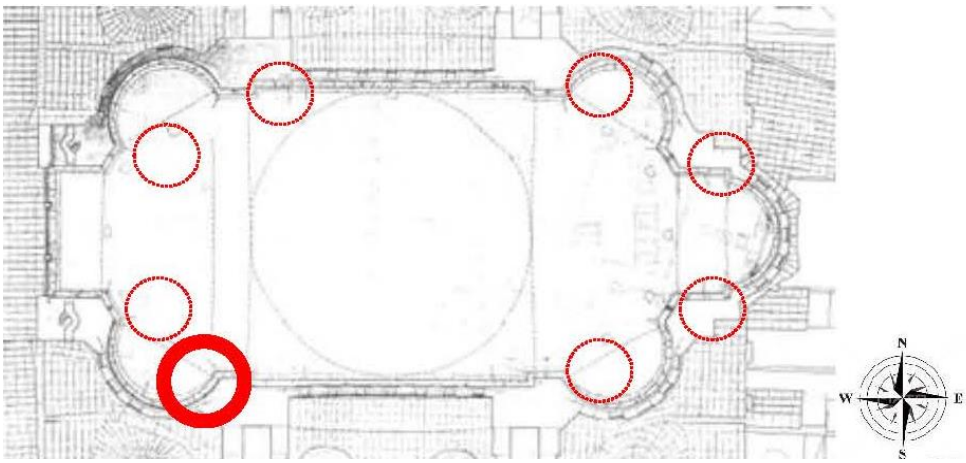


Figure 8 Plan of the level of second cornice.

At the eastern corner on the south west cornice (see Figure 8), the deformation of the second cornice and the movement of the composing stones were

detected and the inspection was noted. From the observation, the same phenomena were detected at each corner of the second cornice on the main piers. There are particular deformations. Therefore, the movement of the cornice at south west corner was investigated as an example. Figure 9 shows the picture of the problem of the south western cornice. The first three stone bricks from the east corner moved vertically (see Figure 9).

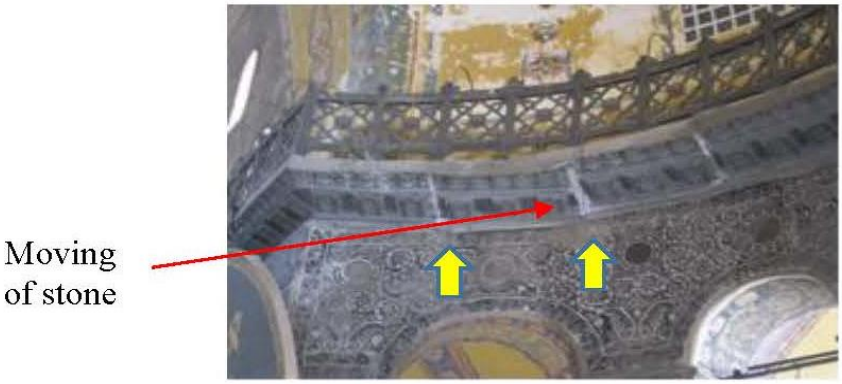


Figure 9 Problems at the south west second cornice.

3.1. Measuring the micro tremor of second cornice

In this analysis, six tremor meters were placed along the cornice equidistantly. Figure 10 shows the arrangement of the tremor meters on the second cornice under sub-dome. Each tremor was measured at 40Hz sampling frequency and 3600 second time duration. From FDD analyses, the predominant natural frequency is 9.70Hz. This frequency is quite different from the total main building (see Section 2.2). Therefore, the deformation of the second cornice shows locally. The natural mode is shown in Figure 11.

The total movement of the second cornice shows large amplitude at the central portion of the cornice. At both the east and the west ends, the second cornice is restrained by the main pier and the entrance wall. Therefore, in the deformation of the second cornice at ends, the small deformation arises. Consequently, the second cornice under sub-dome moved with the movement of sub-dome. However, the central portion shows larger deformation than others. horizontal cracks are detected at the connection between the semi-dome and the cornice.

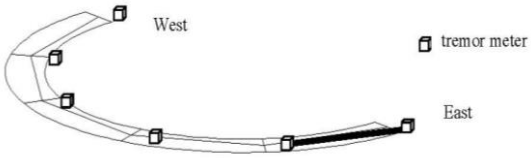


Figure 10 Arrangement of tremor meters along the cornice

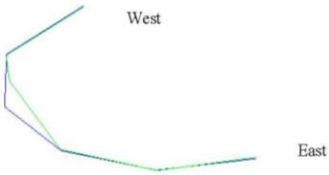


Figure 11 Vibration mode of the second cornice (9.70Hz).

3.2. Measuring the Tremor of Stones at East End of the Second Cornice

To investigate the deformation mode at east end precisely, the tremors of the first three stone bricks from the east end were measured. Figure 12 shows the stone bricks in the second cornice that is shown in Figure 10 as the fat line. Figure 12 also shows the position of tremor meters.

From the measurement of twelve tremor meters, at the east end of the south west cornice, three stones vibrate with predominant natural frequency 2.91Hz. It was independent from the total vibration of the second cornice (Figure 11). Figure 13 shows the vibration mode of three stone bricks. From this Figure, three stone bricks moved independently and showed their discontinuity. Therefore, the stone bricks are unstable at the east end of the south west cornice. The deformation of the three bricks represented the behavior of loose rock, as shown in Figure 9. These phenomena were detected at all junctions of main piers and showed the particular deformation of the second cornice.

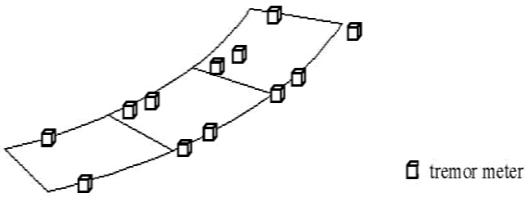


Figure 12 Arrangement of tremor meters at east end (the fat line in Figure 10)

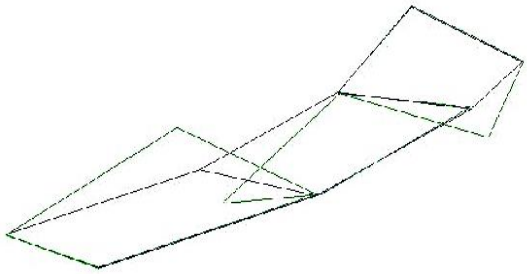


Figure 13 Vibration mode of the three stone bricks at east end of the cornice (2.9Hz)

4. NUMRICAL EVALUATION AND FUTURE WORK

4.1. FE Analysis Supported by the Vibration Record

To represent the particular deformation and stress states of the cornice around the south west sub-dome under complex stress states as shown in Figures 11 and 13, the finite element analyses were performed (Hara et al 2013, 2014, 2015). The structure is composed of the shell elements and the columns. Therefore, solid elements were adopted. Figure14(a) shows the FEM model adopted in this analysis. Considering the symmetry of N-S and EW directions, a quarter of the model was adopted. The model was divided into 52154 elements and 84619 nodes. The material was assumed to be isotropic and elastic. The material properties of the structure are shown in Table 1.

Table 1: Material properties

Young's Modulus (E)	1.69GPa
Density (□)	$20.0*10^{-6}$kg/mm^2

Applied load was the self-weight and additionally, the lateral load on the x-z plane that was applied as the thrust. Under the self-weight of the main dome, the thrust occurred due to the expansion of the dome. The boundary condition at the bottom of the model was fixed in the vertical direction and the symmetrical boundary conditions were applied to other cutting edges.

Figure 14(b) shows numerical results as the equivalent stress and the deformation. The cornice did not deform at the west end because the second cornice was supported by the stiff entrance wall. Also, the second cornice did

not deform at the east end because of connecting the main pier. However, east end of the second cornice moved horizontally.

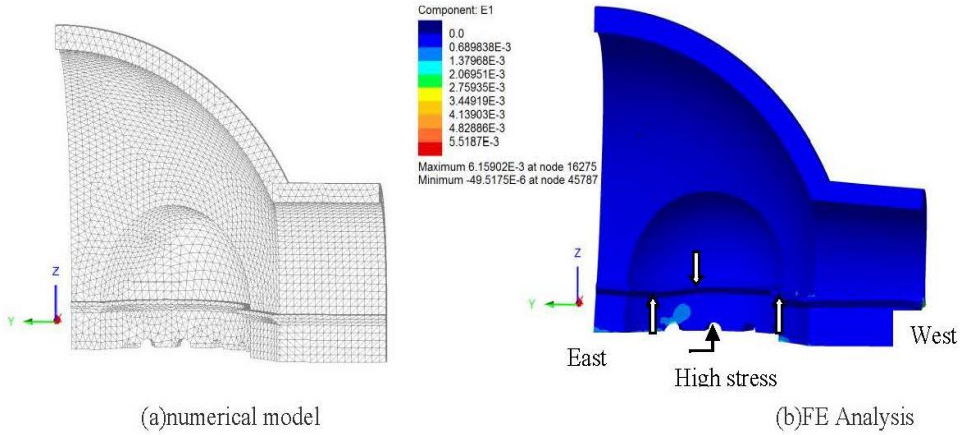


Figure 14 Equivalent stress by FE Analysis

The second cornice deformed downward near the east end. Therefore, the second cornice was twisted at the east end as shown in Figure 14(b). The twisting may lose the constraint of the stone bricks and may represent the particular vibration shown in Figure 13. The central portion of the second cornice also deformed upward. The cornice deforms vertically like S shape. The deformation coincides with the deformation mode by the vibration analysis of the tremor records as shown in Figure 10.

The equivalent stress shown in Figure 14(b) represents the small deviations in the structure. However, the cornice at the east end on the exedra shows higher stress. These stress deviation also affects the particular local deformation of the stone bricks shown in Figure 13.

4.2. Future Analysis

To evaluate the deterioration of the dome (mosque) structure, the vibration analysis by tremor meters and the results of the FE Analysis are effective. Each method and evaluation by combination of these methods are useful. In addition, the laser scanned data will also be useful. The digital data from the laser scan provide us the current situation of the dome structure and the periodically repeated measurements bring us the progressive deformation data. These digital data will be adopted for the FE analysis. Figure 15 shows the Ortho data of cutting Hagia Sophia in EW vertical direction.

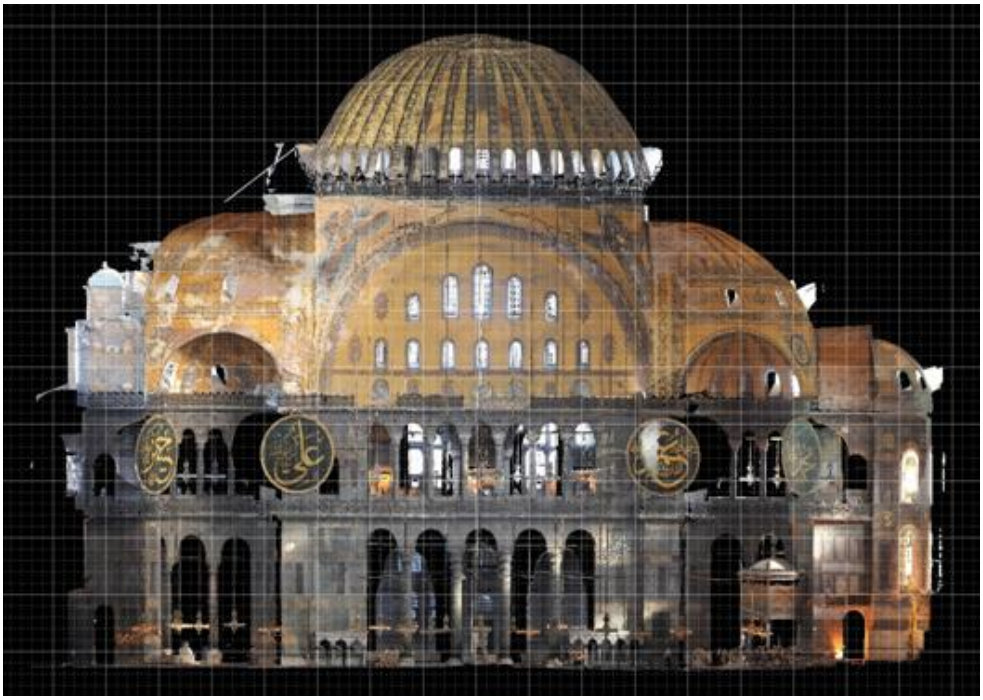


Figure 15 Ortho data of inside view of Hagia Sophia

5. CONCLUSION

In this study, the vibration characteristics of the main building of Hagia Sophia were measured and the particular deformation of the second cornice was analyzed. Also, the numerical analyses of the second cornice were performed. From the analysis, following conclusions are obtained.

1. FDD analyses of recorded data show the vibration characteristics of the structure precisely.
2. Hagia Sophia shows the global type of deformation of the structure. Also, several particular deformations and the local failures have been detected on the cornice.
3. The local deformations appear on the south west cornice incorporated with the global deformation.
4. Numerical analyses match with the experimental analyses well and help to understand the knowledge of the deformation mechanisms of Hagia Sophia.

The recorded data will be utilized to obtain the response of structure precisely by using FE Analysis by combining the earthquake record. The local deformations shown on the south west cornice bring us the information to understand and to maintain the building structure. By the vibration analysis of main building, particular deformations such as large amplitude of the north tympanum and the deformation of the southwest pier were detected. The FE analysis assists to find the causes of these deformations.

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AN INDOOR POSITIONING SYSTEM FOR FACILITATING PERCEPTION AND NAVIGATION OF BLIND PEOPLE IN MOSQUE INDOOR ENVIRONMENTS

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Abstract

The World Health Organization estimated in 2014 that 285 million people worldwide are visually impaired: 39 million are blind and 246 million have low vision. Islam is a universal religion; achieving equality is one of its most important values. Islam is a faith community in which everybody interacts with everybody else. The Holy Quraan mentioned the disabled as part of our life, discussed their rights and urged to take care of them in more than one place. Therefore, everyone has a responsibility to contribute to the best of their ability. In order to achieve equality for blind people, a suitable environment should be offered to them to facilitate their mobility in public spaces and holy spaces like Mosques.

Mobility and orientation are very challenging for blind or visually impaired persons. Difficulties in wayfinding may cause stress and anxiety, which may discourage them to visit unknown places. Therefore, blind Muslims have the right to navigate inside mosques without any direct help, providing essential information for them, such as Qibla direction, ablution places and other facilities. Several mobile applications have been developed to help blind or visually impaired people to find their ways in large spatial environments, yet religious environments require such applications to help B/VI people navigate inside mosques without direct help. Most of these applications depend mainly on GPS. However, it is argued that GPS is inadequate for indoor localization due to the loss of GPS signal indoors. Accordingly, this paper introduces an indoor positioning system, relying on Bluetooth devices.

Thanks to the increasing number of portable devices, this study aims to utilize indoor positioning system techniques to potentially facilitate the navigation and the perception of blind people in mosque indoor environments. The study offers a conceptual approach that investigates how Bluetooth localization can be used as a promising technique for that aim by distributing low energy beacons along the floor plan of the mosque which are uniquely identified by the user's smart phone and can be accessed using voice recognition technique. Decisions are accordingly communicated to users via virtual verbal guidance. The paper also opens a discussion about the potential challenges and concerns which future explorations, scientific research and real-world applications of indoor positioning systems will encounter.

Keywords

Blind, Visually Impaired, Indoor Positioning System, Bluetooth Low Energy Beacons, Mosques, Equality.

نظام تحديد المواقع في الأماكن الداخلية كمدخل لتسهيل الإدراك والتجول للمكفوفين في بيئات المساجد الداخلية

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المستخلص

قامت منظمة الصحة العالمية في عام ٢٠١٤ بتقدير أن ٢٨٥ مليون شخص في العالم يعانون من ضعف البصر: ٣٩ مليون مصابون بالعمى و ٢٤٦ مليون يعانون من ضعف في الرؤية. الإسلام هو دين عالمي وتحقيق المساواة هي واحدة من أهم القيم في الإسلام. وقد كفل الإسلام حق المعاقين فى التعايش كجزء من المجتمع، كما دعا الإسلام لحماية حقوق الأشخاص ذوي الإعاقة، بما في ذلك الأشخاص المكفوفين أو ضعاف البصر. من أجل تحقيق المساواة للمكفوفين يجب علينا خلق بيئة مناسبة لهم كي يتمكنوا من التعامل في الأماكن العامة وخاصة في الأماكن المقدسة مثل المساجد.

قد يتجنب المكفوفين وضعاف البصر الخروج من المنزل أو زيارة أماكن مجهولة بسبب صعوبة التنقل وصعوبة اكتشاف الأماكن الجديدة بمفردهم. وكما ذكرنا فمن حق المكفوفين التنقل داخل المساجد بمفردهم دون أي مساعدة مباشرة، ومعرفة بعض المعلومات الاساسية، فعلى سبيل المثال تحديد اتجاه القبلة أو أماكن الوضوء أوغيرها من المرافق.

وقد تم تطوير العديد من تطبيقات الهواتف النقالة لمساعدة المكفوفين أو ضعاف البصر لتسهيل حركتهم في البيئات الكبيرة نسبياً، لذلك فإن البيئات الدينية تحتاج إلى تطبيقات تساعد المكفوفين وضعاف البصر للتنقل داخل المساجد دون مساعد مباشرة. بعض هذه التطبيقات تعتمد على نظام تحديد المواقع العالمي، ولكن هذا النظام يعتبر غير فعال في الأماكن المغلقة ويرجع ذلك إلى فقدان إشارة نظام تحديد المواقع العالمي في البيئات المغلقة. وعلى هذا، فإن البحث يقترح استخدام نظام تحديد المواقع في الأماكن المغلقة.

بفضل العدد المتزايد للأجهزة المحمولة، تهدف هذه الدراسة إلى استخدام تقنيات نظام تحديد المواقع في الأماكن المغلقة لتسهيل تنقل المكفوفين في المساجد. ويقدم البحث مدخل نظري لكيفية استخدام تقنية البلوتوث منخفضة الطاقة فى تحديد الأماكن داخل المساجد وذلك من خلال توزيع منارات الطاقة المنخفضة على نقاط محددة بالمسقط الأفقي للمسجد، والتي يتم تحديدها بشكل فريد من خلال الهواتف الذكية للمستخدم، ويقوم المستخدم بتلقى وجهته من خلال رسائل صوتيه من جهازه المحمول. كما يناقش البحث بعض التحديات والمخاوف، والتي يحتمل أن يواجهها التطبيق العملي لأنظمة تحديد المواقع في الأماكن المغلقة.

الكلمات الدالة

المكفوفين، ضعاف البصر، نظام تحديد المواقع في الأماكن المغلقة، تقنية البلوتوث منخفضة الطاقة، المساجد، المساواة.

1. INTRODUCTION

Blind people or those who have low vision generally have special needs, especially in environments which are unfamiliar to them. Many blind and partially sighted people of all ages are unable to lead independent lives because they are not getting the appropriate support they require. The needs of people who lose their sight vary from one to one. Accordingly, supporting their needs should be personalized in order to meet their individual needs. One of the major needs they have is facilitating their mobility and getting them familiar to their environments. Since the wayfinding is one of the most crucial aspects of identifying an environment, there are several endeavors to facilitate the guidance of the blind or visually impaired (B/VI) people and to help them in finding their way in different environments.

The pre-Islamic society used to boycott people with special needs, isolate them and prevent them from leading normal lives, such as their right to marriage or even interaction with people. For instance, people of Madinah before Islam used to prevent the blind and the diseased people from sharing food with them, because they deemed them disgusting.

However, the Quraan has been revealed as a mercy for all people including the people with special needs, consoling, relieving, and supporting them. Islam saves them from the most dangerous psychological diseases that may affect them if they happen to suffer from isolation and withdrawal from social life. On the other hand, mosques are considered the representation of Islam and the Islamic Value. Consequently, guiding and helping B/VI people to easily find their ways should be applied firstly inside mosques.

Therefore, this paper introduces a conceptual approach to facilitate the navigation and the perception of blind or visually impaired people by the utilization of an indoor positioning system techniques (Bluetooth localization) inside Mosques. This approach focuses on a) defining the location of the user (localization), b) guiding the user to reach the required destination (navigation), c) receiving the instructions (interaction), and d) enhancing the safety and independence (familiarization).

2. RELATED WORK

Wayfinding is considered one of the most crucial aspects of identifying an environment. Therefore, there are several endeavors to facilitate the guidance of the blind or visually impaired (B/VI) people and to help them in finding their way in different environments. In this section, we discuss some

of the works related to guiding blind people to easily find their ways in public environments. Table 1 summarizes a comparison among some of the methods or mobile applications that use different techniques and positioning systems to help B/VI people, focusing on the advantages and the disadvantages of the different methods. Table 1 shows comparison among multiple systems, most of which depend on positioning systems concept which is a mechanism for determining the location of an object in space.

There exist a lot of technologies that uses positioning system ranging from worldwide coverage with meter accuracy to workspace coverage with sub-millimeter accuracy. Some of these systems are used outdoors based on global positioning system (GPS) which is a space-based navigation system that provides location and time information in all weather conditions, anywhere on or near the Earth where there is an unobstructed line of sight to four or more GPS satellites. The GPS also provides critical capabilities to military, civil and commercial users around the world. The United States government has created the system, maintains it and makes it freely accessible to anyone with a GPS receiver.

Table 1 Comparison of wayfinding signage methods for B/VI people (Source: Author)

Method	Description	Pros	Cons	Date
Talking Tactile Map (Knapp, 2009)	When a user touches the map, s/he receives an audio description of the function located in this place.	Allowing the user to quickly scan through the building's function and services.	Static and stationary, which facilitate only orientation and route decision.	2009
RFID Torch (Knapp, 2009)	The RFID Torch uses RFID tags as geographic markers . Each tag triggers the torch to speak the information describing that location.	The markers are interfaces to unlimited quantities of information, accessible whenever the user needs it via a wiki-style website called WikiNav.	▪ The read range of the prototype device is about 15 cm. ▪ External torch was used.	2009
The smart camera (Knapp, 2009)	The system uses 'Quick Response' codes, two-dimensional barcod es. These black and white icons contain digital information that is	▪ The user can speed the voice instructions up, slow it down, adjust the emotional range of the speech, change the voice of the person speaking, etc.	It requires Internet connection.	2009

	instantly decoded the moment the camera recognizes them. Each icon contains a URL address, which directs the attached mobile phone to retrieve the information stored there, and voice instructions are given to the blind user.	▪ It also incorporates information depth control.		
ICane mobilo[1]	It combines obstacle detection with navigation and provides tactile warnings and directions using a unique 'Tactile Arrow' that is integrated in the handle of the cane. The navigation is based on the ICane Go Application.	Obstacle warning is intended to alert for obstacles above the white cane at chest and head height of the user.	It does not guide the person through all routes.	
GPS "Street Talk, Sendero" [2] (Crandall et al, 2001)	It utilizes the GPS technique to find the ways.	It works very well outdoors.	It has poor resolution in urban settings and it is unavailable indoors.	1999
Infrared signage (Crandall et al, 2001)	It broadcasts information received by a hand-held receiver.	It has full routes guidance.	It requires costly installation and maintenance.	
Wayfinding based on a camera cell phone (Coughlan et al, 2006)	It is held by the user to find and read aloud specially designed signs in the environment. These signs consist of barcodes placed adjacent to special landmark symbols.	It has full routes guidance.	The read range is small.	2006

[1] www.i-cane.org/
[2] http://www.senderogroup.com/

Path-Guided Indoor Navigation for the Visually Impaired Using Minimal Building Retrofitting[3]	▪ The system consists of two major components: a) wall modules deployed in building, and b) user end comprising of a waist-worn device coupled with a mobile phone. ▪ An accelerometer is used in high precision pedometers. It returns the number of steps traveled by the user. When it is multiplied by the average step length, it gives the distance traveled.	The system is easy to learn.	▪ The system was developed only for android mobile phones. ▪ The system requires installation of about 20 modules per floor in a typical public building.
Signage Recognition Framework for Visually Impaired People (Foong et al, 2011)	Images of common public signage such as caution wet floor, bus stop, danger, closed, open were taken using built-in camera from a mobile phone then stored in database. When a user capture an image, the image is translated to a speech from the stored database images.	The system is easy to use.	It only guides for specific signage.

Facilitating the mobility in large spatial environments is mainly depending on GPS. However, it is argued that GPS is inadequate for indoor localization due to the loss of GPS signal indoors. Accordingly, a different

[3] http://web.media.mit.edu/~djain/media/Roshni/Roshni-ASSETS-2014.pdf

type of positioning system that efficiently run indoors was introduced “Indoor Positioning System” (Curran et al, 2011). It is a system to locate objects or people inside a building using radio waves, magnetic fields, acoustic signals, or other sensory information collected by mobile devices.

It is worth to mention that although the market has several commercial indoor positioning systems, till now there are no standards for the indoor positioning systems. Indoor positioning systems use different technologies, including distance measurement to nearby anchor nodes (nodes with known positions, e.g., Wi-Fi access points), magnetic positioning or dead reckoning.

They either actively locate mobile devices and tags or provide ambient location or environmental context for devices to get sensed. The localized nature of an indoor positioning system has resulted in design fragmentation, with systems making use of various optical, radio or even acoustic technologies. Other systems depend on RFID like RFID Torch, and normally each system has its own advantages and disadvantages.

Consequently, it is essential to determine a localization technique, which is most suitable to be utilized in wayfinding for blind people and to be applied inside mosques. Accordingly, the most common positioning systems used in localization and location detection different techniques are discussed in Table2.

Table 2 Comparison of common positioning systems used for localization.

System	Accuracy	Principles used for localization	Coverage	Power cons.	Cost	Remarks
GPS	6m–10m	Time of Arrival (ToA)	Good outdoors Poor indoors	Very high	High	▪ Satellite based Positioning. ▪ Processing time and computation is slow.
Infrared	1m-2m	Proximity, ToA	Good Indoors	Low	Medium	▪ Short range detection. ▪ No invasion of multipath.

Table 2- Continued Comparison of common positioning systems used for localization. Source: Farid et al, 2013

Wi-Fi	1m–5m	Proximity, ToA, TDoA, Received signal strength indication (RSSI) Fingerprinting, and RSSI theoretical propagation model (Iglesias et al, 2012)	Building level (outdoor/indoor)	High	Low	▪ Infrastructure available everywhere. ▪ Initial deployment is expensive. ▪ Multipath susceptible slightly.
Ultrasound	3cm–1m	ToA, Angle of Arrival (AoA)	Indoor	Low	Medium	▪ Sensitive to environmental. ▪ No invasion of multipath.
RFID	1m-2m	Proximity, TOA, RSSI theoretical propagation model	Indoor	Low	Low	▪ Real time location system. ▪ Response time is high. ▪ Manual programming.
Bluetooth	2m–5m	RSSI fingerprinting and RSSI theoretical propagation model	Indoor	Low	Low	▪ Data transfer speed is high. ▪ Limitation in mobility.
ZigBee	3m–5m	RSSI fingerprinting and RSSI theoretical propagation model	Indoor	Low	Low	▪ Low data transmission rate. ▪ Nodes are mostly asleep.
FM	2m–4m	RSSI fingerprinting	Indoor	Low	Low	▪ Less susceptible to objects. ▪ It covers large areas because the signal is strong.

3. PROPOSED APPROACH

This study offers a conceptual approach in which B/VI can be familiarized with the surrounding space inside the mosque using an indoor positioning system, receiving an auditory information from their smart mobile phones. There are many applications depending mainly on GPS, which

facilitate the mobility of B/VI in large spatial environments. However, it is argued that GPS is inadequate for indoor localization due to the loss of GPS signal indoors. Accordingly, this paper introduces a different type of positioning system that efficiently run indoors, relying on Bluetooth devices, as illustrated in the taxonomy of positioning systems shown in Figure 1.

Bluetooth, as clarified in Table 2, is a wireless standard for wireless personal area networks (WPANs). Almost every Wi-Fi enabled mobile device, such as mobile phone or computer, also has an embedded Bluetooth module. Bluetooth operates in the 2.4GHz ISM band (Subhan et al, 2011). The benefit of using Bluetooth for exchanging information between devices is that this technology is of high security, low cost, low power and small size. Each Bluetooth tag has a unique ID, which can be used for locating the Bluetooth tag. Many of the recent indoor localization systems are Bluetooth-based systems. Subsequently, the study suggests the utilization of Bluetooth beacons, which are small devices that transmit Bluetooth signal to visitors' smartphones. This occurs via a recently new technology Bluetooth Low Energy (BLE), built in iPhones and iPads since 2010, in Macs since 2012, and in many higher-end Android devices since 2013.

Therefore, the study proposes a potential mosque case study that aims to identify beacons' potential for facilitating the mobility of B/VI people by offering solutions to their tracking, routing and mapping.

The study aims to answer the following questions:

- Q1. Which kind of wayfinding information do B/VI people need to know in mosques?
- Q2. How should B/VI people receive the required information?

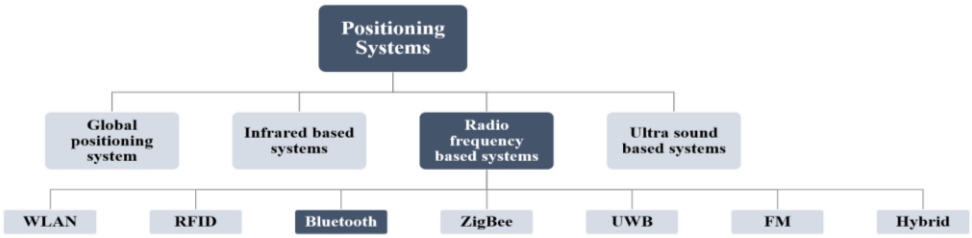

Figure 1 Taxonomy of positioning systems.
Source: Farid et al, 2013 modified by the author.

Accordingly, the navigation system of B/VI people generally has to cope one or more of the following challenges:

- **Localization**: a localization system assists a user to identify his/her location (and orientation in some cases) within a given environment. Various methods and systems are used for localization in both indoors and outdoors. However, the most suitable localization system should be cheap, highly efficient and accurate (Karimi, 2015).
- **Navigation**: it is about the system capability of planning and communicating effective paths to the user. Localizing the user and planning a path to the user's desired destination go hand in hand. Once a user has been localized, the optimal path to his/her destination can be determined and communicated to the user in accessible instructions. Most navigation systems for sighted users choose the shortest path. However, this may not be ideal when the user is visually impaired (Karimi, 2015 and Jain, 2014).
- **Interaction**: it is about the ease of use and how the user can interact with the system. The B/VI user needs to use a series of prompts through an accessible touch screen interface and vocal orders to get directional guidance and instructions from his/her mobile device (Karimi, 2015).
- **Familiarization**: being familiar with an environment is considered the key factor in enhancing the safety and independence of B/VI impaired people during indoor navigation. Technology can play a role in increasing the opportunities for B/VI people to familiarize themselves with indoor spaces (Karimi, 2015).

  This familiarization usually happens with the guidance of an orientation and mobility specialist, but using technologies such as tactile maps or the help of sighted friends can also play a role in increasing the opportunities for independent travel for individuals who are B/VI. While it is not substitute to experiencing the real space with the guidance of an orientation and mobility specialist, technologies such as virtual navigation environments and narrated maps have demonstrated great potential to encourage and assist B/VI people with familiarization, providing safe exploration and navigation of indoor environments.

The potential case study of a mosque, illustrated in Figure 2, is devoted to answer the above questions and to investigate the impact of utilizing Bluetooth localization to facilitate wayfinding for blind people. This case

study assumes that each user (B/VI) vocally enters what he/she wants to know (e.g. ablution place); then the system detects the current position of the user, and sends a message to all the nearby beacons, waiting for a reply from all ablution beacons. Since each beacon sends a unique ID to the user's portable device in order to support decision making, the user gets the message(s) only from ablution beacon(s). In case of more than one ablution place, the system calculates only the nearest one.

The user vocally gets the instructions to go to the nearest ablution place. With regard to the orientation, the system simply detects the Qibla direction, and then it sends a voice instructing the user to turn right or left the required angle until reaching the correct direction of the Qibla.

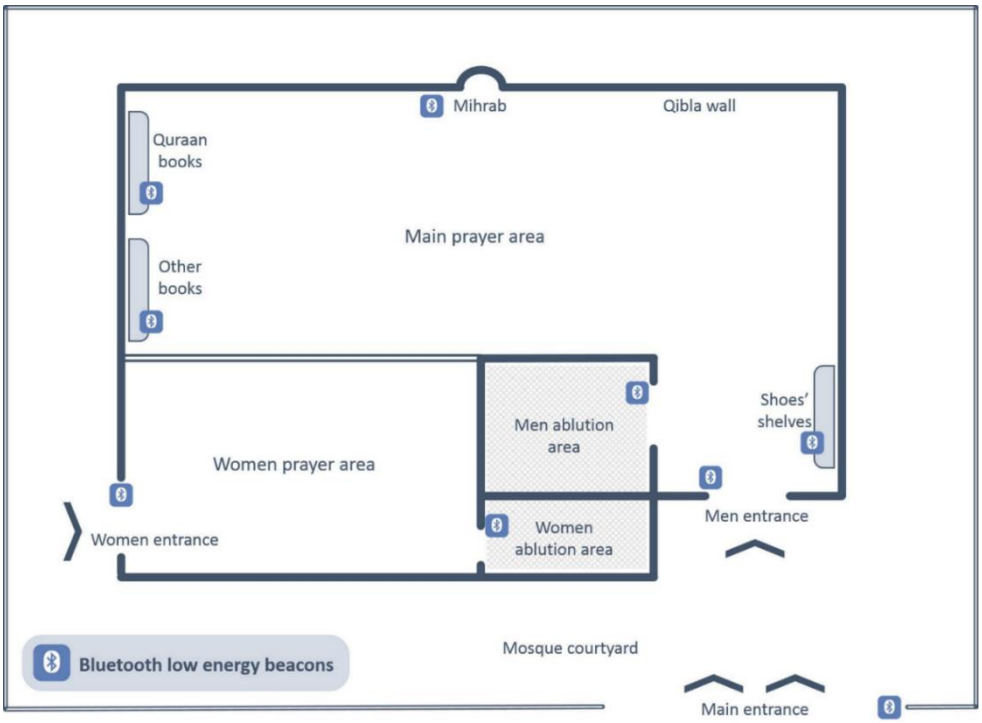

Figure 2 Schematic of the proposed approach. Source: Author.

4. DISCUSSION

This paper introduces a positioning system that can be applied in mosque indoor environments to potentially facilitate the navigation and the perception of B/VI people. This section raises some challenges; the proposed approach

may face. It also discusses how mosque indoor environments differ from other environments, and how this difference affects the proposed technique.

4.1. Challenges of Indoor Positioning System in Mosques

Bluetooth Low Energy (BLE) beacons indoor localization technique determines the position of user mobile devices with respect to access points. Due to accuracy reasons, at least three location detection techniques are needed to unambiguously find a location. The utilization of Bluetooth technology in localization poses some challenges, such as the running of the device discovery procedure in each location finding, which significantly increases the localization latency (10–30 s) and power consumption.

The cost of the BLE beacons is also challenging, as it is considered relatively high; however standard beacons cover an approximate range of 70 meters, which is appropriate enough in small and medium sized mosques. It is anticipated that this cost might be affordable within few years like many other emerging technologies. The relation between B/VI people and smart phones is also another challenge, because normally B/VI people face some problems dealing with smart phones. The usage of smart phones should be easy enough and should depend mainly on vocal instructions, encouraging blind people to use such devices.

4.2. Distinct Features of Mosque Indoor Environments

Since indoor environments are very complex, the development of an indoor localization technique is connected with a set of confrontations, such as the influence of various obstacles (e.g. walls, other users, doors, furniture, etc.). These obstacles influence the propagation of electromagnetic waves. Therefore, a higher accuracy is required indoors to locate a user properly. In contrast, mosques differ from other building (e.g. hospitals or shopping centers) in this regard. For instance, mosques don’t include a lot of furniture or vertical divisions, as mosque floor plan is mostly based on one space. This potentially avoids the reflection and attenuation of the signals, giving more accurate results.

5. CONCLUSION

In this paper, the navigation problem of B/VI people in indoor environments has been discussed. A comparison between the various positioning systems that used for localization, and how they vary from indoors to outdoors, is also presented. Subsequently, this paper has introduced

a different type of positioning system that efficiently runs indoors, relying on Bluetooth devices. The proposed system potentially facilitates navigation and perception of B/VI people in mosque indoor environments.

The study has investigated how Bluetooth localization can be used as a promising technique by distributing low energy beacons along the floor plan of the mosque which are uniquely identified by the user's smart phone and can be accessed by using voice recognition technique. Accordingly, users could receive the instructions via virtual verbal guidance. Finally, the paper opened a discussion about the potential challenges and concerns which future explorations, scientific research and real-world applications of indoor positioning systems probably will encounter.

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CONSERVING THE RELIGIOUS AND TRADITIONAL VALUES OF MUSLIMS WITH A DOME-LESS MOSQUE ARCHITECTURE: A CASE STUDY OF SHAH FAISAL MOSQUE, ISLAMABAD

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Abstract

The mosque occupies a central position in the social as well as religious life of Muslims. It is not only a place of worship where rituals are performed, but also serves as a social space where Muslims take part in welfare activities. The design and architecture of the mosque have local as well as global influences, representing religious, economic, and aesthetic dimensions of Muslim social organization. Generally, the Muslim architecture has three notable things: domes, arches and minarets. There are very few examples of mosques which lack any one or all of these architectural features, but still they are maintaining the Muslims' traditional values. In this case-study, the Shah Faisal Mosque of Pakistan, a dome-less mosque situated in the heart of Islamabad, has been discussed in detail. This mosque is one of the best examples of modern Muslim architecture. This paper discusses the development of innovative architectural and design elements of the mosque and their benefit to the various functions in terms of space planning, proportion and aesthetics. A theoretical analysis is also performed to assess the effectiveness of the cultural and religious role being played by the mosque at national and global level.

Keywords

Domeless Mosque; Modern Architecture; Innovation; Faisal Mosque

المحافظة على القيم الدينية والتقليدية من المسلمين مع بنية مسجد بدون قباب: دراسة حالة لمسجد شاه فيصل في إسلام أباد

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المستخلص

يحتل المسجد مكانة مركزية في الحياة الاجتماعية وكذلك الدينية للمسلمين. فهو ليس فقط مكانا للعبادة يتم تنفيذ الطقوس الدينية فيه ولكنه أيضا فضاء اجتماعي حيث يتشارك فيه المسلمون الأنشطة الخيرية. تصميم المسجد وعمارته له تأثيرات عالمية كما له تأثيرات محلية تعكس الأبعاد الدينية والاقتصادية والجمالية للتنظيم الاجتماعي للمسلمين. عموما تتميز العمارة الإسلامية بثلاث أشياء بارزة، القباب والأقواس والمآذن. والمساجد التي تفتقر لأي من هذه السمات المعمارية مجتمعة هي قليلة جدا ولكنها ما تزال تحافظ على القيم التقليدية للمسلمين.

في هذه الورقة نوقش مسجد فيصل شاه في باكستان، وهو مسجد بدون قباب (Dome-less) يقع في القلب النابض لإسلام أباد، كحالة دراسية مناقشة معمقة. يعتبر هذا المسجد واحدا من أفضل الأمثلة على العمارة الإسلامية الحديثة. تتناول هذه الورقة تطور العمارة المبتكرة للمسجد والعناصر التصميمية وخدمتها للوظائف المتعددة للمسجد في ظل التخطيط الفراغي المطلوب والتناسب والجماليات. كما وقد تم تنفيذ تحليل نظري لتقييم فعالية الدور الثقافي والديني للمسجد على المستويين المحلي والعالمي.

الكلمات الدالة

مساجد بدون قباب، العمارة الحديثة، الإبتكار، مسجد فيصل شاه

1. INTRODUCTION

The architectural style has been a means of expression of thought in constructive form. Every civilization developed its own architectural style which became its identity. The dome is considered as one of the most important elements in the architecture of mosques in particular, and Islamic architecture in general. The use of domes in Islamic architecture started from the Umayyad period in Jerusalem in 691 AD. It is known that the dome was influenced by Byzantine architecture at its inception. The continued use of domes in Islamic architecture, in its various forms, led to the development of domes' concept among Muslim architects to become one of the most important elements in the Islamic Architecture because of its inspirational symbolism. But with the passage of time and advancement in various fields of science and technology new innovative methods were also adapted in the architecture field. An example of such a modern innovative architecture is Shah Faisal Mosque at Islamabad, Pakistan.

4.1. Location

The Shah Faisal Mosque (written henceforth as Faisal Mosque) is the largest mosque in Pakistan, located in Islamabad, the national capital city. It was designed by Turkish architect Vedat Dalokay in resemblance to a desert Bedouin's tent, and completed in 1986. It is known to the world as an iconic symbol of Islamabad. It is situated at the north end of Faisal Avenue, putting it at the northern most end of the city and at the foot of Margalla Hills, the western most foothills of the Himalayas as shown in figure 1. The mosque is located on an elevated terrain. This enviable location represents the mosque's great importance and allows it to be seen from miles around day and night.

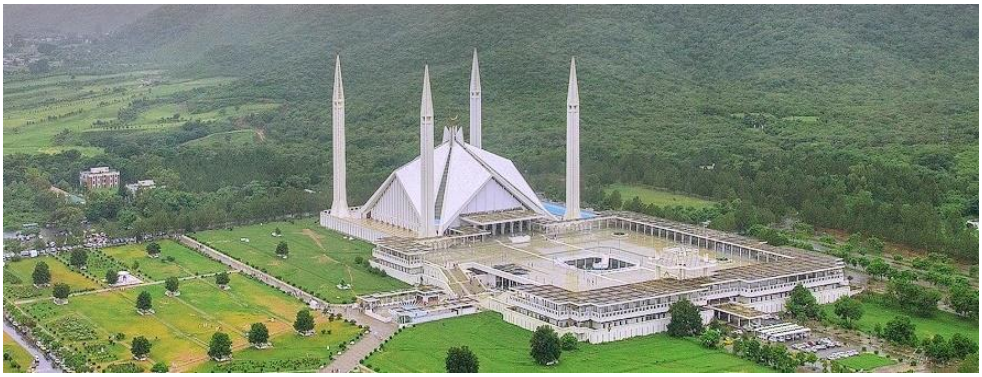

Figure 1. The Faisal Mosque, Islamabad, Pakistan,
Source: Syed Mehdi Bukhari

4.2. Capacity

The Faisal Mosque has covered an area of 5,000 m^2. It can accommodate 20,000 worshipers in the main prayer hall, 24,000 in porticoes, 100,000 in the courtyard and another 200,000 in the adjoining ground. Each of the Mosque's four minarets are 90m high. Entrance is from the east, where the prayer hall is fronted by a courtyard with porticoes. The mosque houses a library, lecture hall, museum and cafe. The interior of the main tent-shaped hall is covered with white marble and decorated with mosaics and calligraphy by the famous Pakistani artist Sadequain, and holds a spectacular Turkish-style chandelier at the middle. The mosaic pattern adorns the west wall, and has the Quranic verses written over them. Fig.1 shows an aerial view of the mosque.

4.3. Faisal Mosque in Literature

The Faisal Mosque represents a modern phase of architectural decoration in construction form and surface ornamentation. A number of decorative effects in its interior and its exterior have deep aesthetic value. The mosque also presents a traditional phase of art of decoration in Pakistan. Several scholars have offered comments on the building. Khan (1970) writes about the triangular geometry of the mosque and mentions that its roof structure resembles a pyramidal tent and that the prayer hall is a concrete square pyramid. At the same time, he mentions that the mosque’s triangular geometry merges with the hilly back ground. He writes that aqua gold leaf is applied on the ceiling, and that marble and transparent glass covers the arch.

Kamil Khan Mumtaz writes on the construction and some basic information of the mosque. But he does not mention anything about the roof structure of the mosque. According to Holod and Khan (1997), the mosque resembles a small mountain or an enormous white tent, or is a colossal tent like structure having monumentality and modernity.

Here too, a brief statement about the roof is written without any detail, and other structural and surface decorations of the mosque and the techniques, designs and symbolism are not mentioned. They write that the restrained decorative treatment of the interior is limited to calligraphy and a blue-and-gold calligraphic decorative tiles. Several colors are used for completion of the abstract symbolic mosaic work of west wall of the mosque’s sanctuary.

Khan (1970) and Holod and Khan (1997) give brief information about the accommodation for the followers, and the tapered glass-fitted ladder-like

interval in the roof. Petersen (1996) writes only one sentence that the mosque is a huge structure and its roof is a truncated pyramid with four tall pointed minarets. Khan (2008) refers the Faisal Mosque as an open-plan, tent-like concrete structure. But the mosque is not constructed according to the principles of open plan. An open plan mosque does not have a separate facade for the prayer hall entrance.

It has aisles and bays for the construction of the sanctuary. The Faisal Mosque has its facade, portico, frieze and entablature but in an abstract form, and the sanctuary is constructed without aisles and bays. These are not characteristics of an open-plan mosque. So it has characteristics of both open and closed plan in its construction: an open court area and a close independent sanctuary with a facade.

The Faisal Mosque is mentioned on several websites. Three of them inform that its design is a modern but traditional structure of the mosque with sanctuary and minarets. The statement needs further elaboration. Two other web sources say that chandelier of the sanctuary is in Turkish style. The abovementioned sources have called the Faisal Mosque structure as eight-faceted desert tent, Bedouin tent or tent-shape. It is apparent from this brief review of the existing literature that the architecture, design and construction techniques of the Faisal Mosque have not been examined closely or comprehensively studied.

Researchers and scholars have concentrated only on the decorative techniques (Norhayati et al., 2014). They have given only cursory statements about the geometrical design of the roof structure. Due to this lack of information on the type of roof, and cultural and traditional role of the mosque, this study focuses on signifying the value of the dome-less roof, and discusses the religious values of Muslims related to the mosque.

2. IDEA AND DESIGN COMPETITION

During an official visit to Islamabad in 1966, the King Faisal bin Abdul Aziz of Saudi Arabia liked the idea of the Government of Pakistan to construct a grand mosque for the capital city and offered to underwrite the cost for such a project. The Capital Development Authority (CDA) which was authorized to arrange the design and construction process for the mosque, initially decided to hold a competition within the country.

But after looking at the scale and importance of the project it was mutually decided to announce an international competition (Neelum, 2005).

Hence the competition was held in 1969 in which skilled and famous architects from 12 countries submitted 38 proposals. To take a decision about the best suited proposal, a panel of jury members was formed which conferred in Rawalpindi (the adjoining city of Islamabad) to examine the submitted material. The report of the Rawalpindi meetings is rather detailed and provides a fair idea of how the jury arrived at the final verdict. The jury members assessed all the proposals on the basis of site development and landscaping, plan organization and circulation, structure and design elements.

After lengthy discussions the last session of the jury ended on the 20th of November, 1969, and the agreement with the first prize winner, Vedat Dalokay, a Turkish architect, was finalized. It was felt that this design would be suitable as a mosque and a national monument for Islamabad. Construction of the mosque began in 1976 by National Construction of Pakistan which assigned skilled Pakistani engineers and workers for its execution. King Faisal bin Abdul Aziz was instrumental in the funding, and both the mosque and the approach road were named after him.

3. DESIGN PERCEPTION AND MAJOR ELEMENTS

The Faisal Mosque's architecture is modern and unique, lacking both the traditional domes and arches of most other mosques around the world. The mosque's unusual design is a departure from the long history of South Asian Islamic architecture, fusing contemporary lines with the more traditional look of an Arab Bedouin's tent, with its large triangular prayer hall and four minarets. However, unlike traditional mosque design, it lacks a dome. The minarets borrow their design from Turkish tradition and are thin as compared to the main structure of the mosque. The shape of the mosque is an eight-sided concrete shell resembling a desert Bedouin’s tent and the cubic Kaaba in Mecca, flanked by four minarets inspired by Turkish architecture. The architect Dalokay discloses his thinking as given below.

I tried to capture the spirit, proportion and geometry of Kaaba in a purely abstract manner. Imagine the apex of each of the four minaret as a scaled explosion of four highest corners of Kaaba – thus an unseen Kaaba form is bounded by the minarets at the four corners in a proportion of height to base. Shah Faisal Mosque akin to Kaaba. Now, if you join the apex of each minaret to the base of the minaret diagonally opposite to it correspondingly, a four-sided pyramid shall be bound by these lines at the base side within that

invisible cube. That lower level pyramid is treated as a solid body while four minarets with their apex complete the imaginary cube of Kaaba.

These words indicate an idealism present in the design of the Faisal Mosque. The concept of the architect was a triangular network of polygonal geometry. A diagonal line from top of each minaret to the base of its opposite minaret. From the cross-section of these lines four invisible symmetrical triangles will appear with the apex of the mosque at the point of their crossing. The same triangular shape is repeated throughout the entire sanctuary as shown in Figure 2.

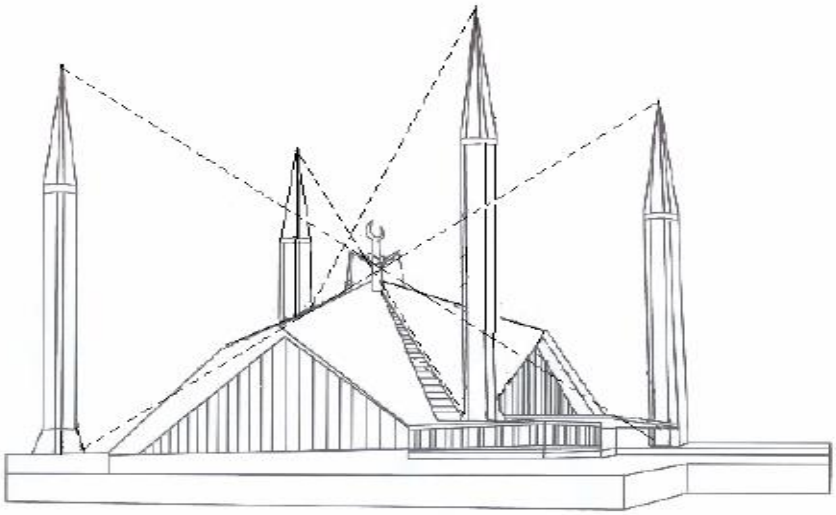

Figure 2. The Architect's Design Perception
Source: (Samina, 2008)

3.1. Dome-less Roof

The most obvious distinguishing feature of Faisal Mosque is that it has no dome and the roof is constructed with triangular slabs. Heretofore the dome had served as an important visual symbol of Muslim identity. From the exterior the sanctuary and minarets are the most prominent features of the mosque. The huge sanctuary has a plan of 60 × 60 square meters. The peak of the roof is 40m above ground level. The four walls are in the form of isosceles triangles (Figure 3) with a base of 70m and sides of 40m, and are constructed of steel and concrete (Samina, 2008).

The roof is a major attraction of the mosque. It is consciously designed by combining historical and modern concepts. The top of the roof is based on

a pyramidal form but the lower part has a gabled roof structure. Every joining of slanting triangular slab makes a gable point. Front beams which make a gable point on the top are connected with a solid rectangular three dimensional block. The gable appearance of the Faisal Mosque is influenced by Greek architecture, and the sloping lines at the corners are inspired by the pyramidal roof.

Figure 3. Triangular walls of the Shah Faisal Mosque

The slopes coming down from all four sides from the apex of the building are a perfect example of pyramidal form. The technical term for this form is hyperbolic paraboloid construction, which is introduced during modern times as discussed below.

The angular setting of the eight triangular slabs of the roof itself is a major decoration in its structural form. A veneer of white marble covers the eight roof panels. The design formed by the various sizes of these marble sections is visible from a distance, and gives a soft impression of a network of vertical and horizontal lines. The eight triangular concrete slabs are arranged in four pairs, with narrow rectangles of transparent glass between them. The double slab roof has hinged beams and cross beams that transmit the load to the girders. The tapered giant concrete girders play an important role in joining the four pairs supporting the roof. The girders coverage at the summit and

their thrust is balanced by the four minarets at the corners of the main prayer hall. These are the usual roofing systems for all mosques, although some simple mosque structures have only a flat or pitched roof. Pyramidal, conical and tapered roofs are variations of pitched roof construction.

Pitched roofs have further differences of shapes and styles which are gable, cross gable, hipped, cross hipped, gambrel and mansard roofs. All these kinds are characterized with diagonal or angular roof construction. The chief characteristic of the gabled roof is that the triangular front and back are covered by rectangular roofing at an acute angle as shown in Figure 4. Gable roofs were used in the construction of buildings in Greek, Roman, Byzantine, Gothic and Medieval architecture. During the Gothic revival (1840-1880) roofing was at its most complex, with gable, cross gable and conical roofs. In the nineteenth and twentieth centuries American houses had angular roofs similar to gable roof construction called Stick Style.

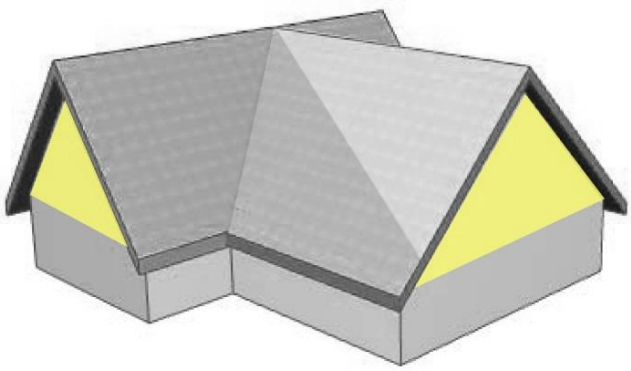

Figure 4. Gable Roof
Source: (Wikipedia)

The gable roof of the Faisal Mosque is an advanced form of hyperbolic paraboloid construction as shown in Figure 5. It is based on shell construction, which can be constructed with large or short span. The main purpose of this concrete shell structure is to cover a large area without any interior supports. The same purpose has been achieved in the mosque which gives huge internal space with no obstructive columns or supports as shown in Figure 6. Pitched roofs having gable or cross gable character are used for the areas of heavy rain and snowfall as a climatic factor such as the northern areas of Pakistan. On the plains of Pakistan, the pitched roof is just an architectural style.

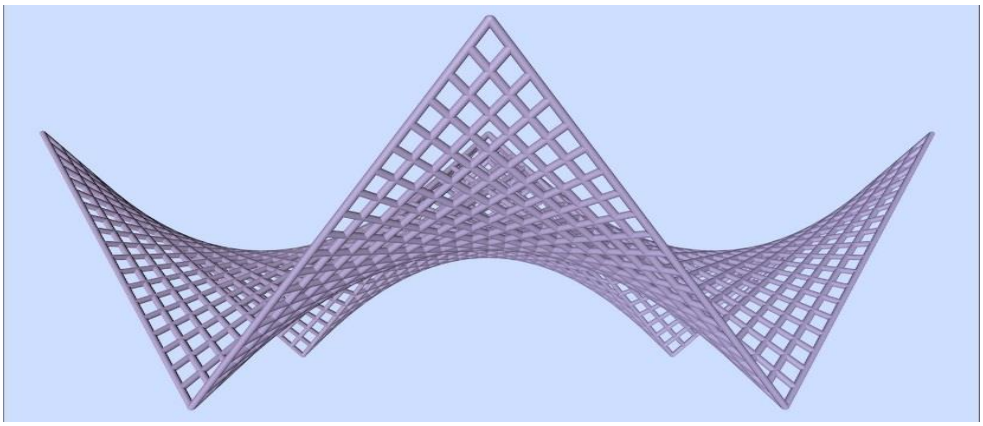

Figure 5. Hyperbolic Paraboloid Shape
Source: (Wikipedia)

3.2. Triangular Walls

The main entrance of the sanctuary is from the east and the entrance wall is divided into nine vertical sections made of concrete filled with crescent motifs. Clear glass is fitted into the crescent shapes, which provides light to the interior. The north and south walls are designed with twenty raised vertical sections, with horizontal lines between the verticals that produce rectangles as shown in Figure 6. Such triangular-shaped walls have never been used in mosque construction previously.

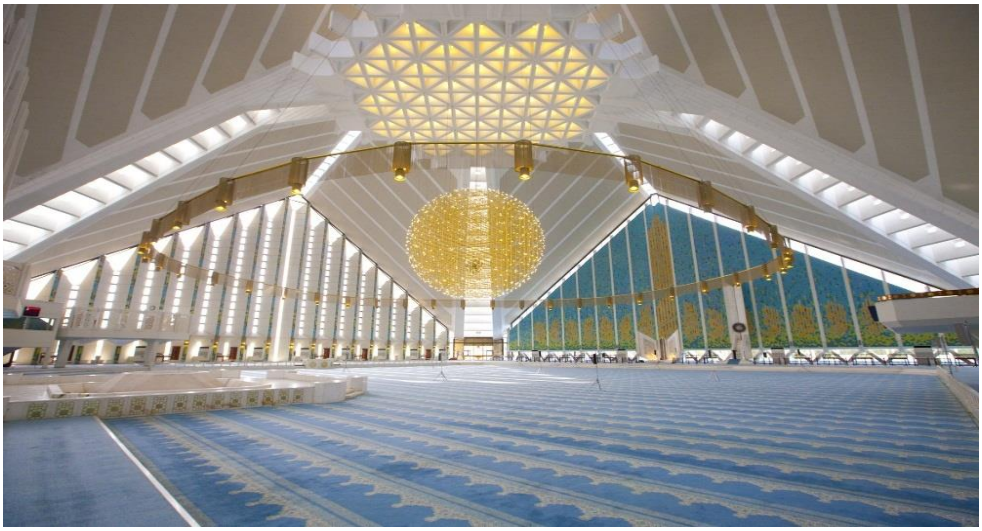

Figure 6. Interior of Main Prayer Hall

The traditional masonry walls are replaced by large glass elements, allowing light to transmit in. The idea of the mosque interior has been totally innovative. The periphery being visually obviated to the centre dissolves the central polarity through declining beams, and by way of a smooth combination the space becomes single element (Şengül et al., 2012). The architect has focused his attention on creating something new, combining abstraction and symbolism.

The triangular shape is prominent in the whole composition of the monument. He balanced the shape of the mosque against the Margalla hills. Actually the roof is designed according to the harmony and continuity of diagonal lines of Margalla Hills. The design of walls is based on triangular shapes in realistic or abstract forms. The architect tried to highlight its white structure by contrasting it with the softness of muddy olive hills, thus making the design dominant with the centre of interest.

3.3. Minarets

The white colour of the structure and touch of brown colour of its design area gives grace to the entire composition. The simplification of its structure looks stylish and supports the geometrical decoration of the mosque with its four minarets, one each at its corner. The north-east and south-east minarets are equipped with electric elevators: the other two are built with 240 steps. The height of each minaret is 90m and the interesting thing is that the distance from one minaret to another is also 90m. This feature gives the whole structure a geometrical look like an imaginary perfect cube.

3.4. Cultural and Traditional Architecture

In Asia, as in most parts of the Muslim world today, the dome and the minaret constitute the mosque even if its function has changed. In a modern mosque the muazzin (one who calls for prayer) does not climb the minaret to call for prayer. The minaret carries one or several speakers and could be designed to fit this purpose only. Similarly, domes were also used to enhance and control acoustics of the mosques in those times when there were no electrical sound systems. With the passage of time due to the advent of modern technology the architecture of mosques has also been revolutionized. Nowadays there are mosques with neither minarets nor domes, yet they serve the very purpose of a mosque.

If, on the other hand we consider the form of the Faisal Mosque within the tradition of the Indian Sub-continent there is another prototype of

significance: The Mughal mausoleum. The mausoleum as a building type was, of course, of Persian Arid Central Asian origin, but in India new emphases were added by the turrets or kiosks at the corners of the structures. The proportions of the main body to the ancillary turrets changed in course of time.

The turrets finally took the shape of real mosque minarets, released from the main structure. The minarets of the Faisal Mosque are pure architectural signs. They contribute to the domination of the main structure. They define and consecrate the space around it. Moreover, the nationality of the architect and the national aspirations of the client merge on the higher semiotic levels; in the historical perspective the great Ottoman mosques - and the converted Hagia Sophia - make a superlative prefiguration.

One more matter to consider is the proportions of covered prayer hall and open courtyard. The Ottoman mosques were surrounded by vast precincts, additional buildings for ablution, study units, etc., but the open space was rather limited under the domes. As per the capacity of the main prayer hall of Faisal Mosque and its adjoining areas, the covered to open space proportion is about the same as in the Mughal mosques situated in Lahore and Delhi.

Many conservative Muslims criticized the design at first for its unconventional design and lack of a traditional dome structure, but most criticism ended when the completed mosque's scale, form, and setting against the Margalla Hills became evident. This fact was also supported by the overwhelming response of the nation who liked and loved the structure of the mosque. Now the Faisal mosque is considered as one of the best examples of modern architecture and has become a landmark and the identity of the Capital of the country.

4. TOOLS FOR ANALYSIS

This tool examines the cultural role of mosque by analyzing it into three key functions; the monotheistic function, the socialization function and the communicative function, out of which beget other functions to form an integrated and complicated system of functions as shown in figure 7. They altogether constitute a general structure of the mosque's cultural role (AbulQaraya, 2015).

The monotheistic function: This is the mother of all, which can be analyzed into three levels such as individual, national and global, and thus it includes three secondary roles: instilling monotheism, and tolerant teachings

of Islam deep in Muslim's mind and soul, unifying the nation (the congregational prayers, Friday prayer, Ramadan and Eid prayers), and inviting others to Islam.

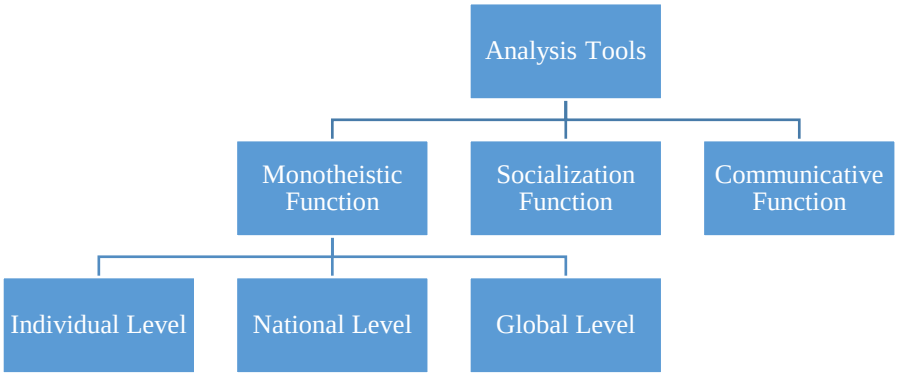

Figure 7. Analysis Tools for Analysing Cultural Role of Mosque

The socialization function: Mosque serves as a Center for educational activities, where Muslims gain knowledge and acquire high moral values that help cultivating good moral personality through a process of instilling positive values, such as wisdom, modesty and tolerance. Furthermore, it helps them to be a real contributor to the civilizing process and producer of knowledge.

The communicative function: Being a frequently visited worship place, mosque plays a significant role in social communication. This role helps spreading love and tolerance among the people. It, also, makes Mosque a communication channel that connects the knowledge seekers with the world, and the ruler with the ruled, to say nothing of the mosque role as mass media platform characterized by honesty, beneficence, and calling for goodness and righteousness. Right after its construction the Faisal Mosque became the point of interest for all the Muslims of Pakistan. People started coming from all over the country to pray in the mosque.

People do not only pray here but visit it's all parts from lower level to the top and to all its widths. They feel refreshed to see the beauty of the structure merged with the greenery of Margalla Hills. Till this time every national of the country feel honored and blessed to have prayed in this mosque. Moreover, tourists from all over the world also keep this place in the to Do List whenever they visit Islamabad. The mosque also holds a large auditorium where religious related international level conferences, seminars and gatherings are arranged frequently.

The mosque remains full during Ramadan, Traveeh and Eid prayers. People from all over the country travel to the Capital to perform Aitikaf (secluded stay in mosque for worship) in the mosque. During visits of the Imam Al Harmain to Pakistan, they are invited to lead the prayers at the mosque. Special announcements are made well in advance and the mosque is seen full with worshippers during such events as shown in figure 8.

A college of religious and Arabic studies is working in the underground floor of the mosque. Students learn various Islamic courses in native language (Urdu) and Arabic. The college admits students from all over the world and has a significant value among the global Islamic institutions. Renowned Muslim scholars are invited from all over the world who deliver lectures and provide workshops on Islamic topics.

Figure 8. Worshipers Praying in Main Prayer Hall

The college also arranges the courses for people of all ages who are keen to memorize the Quran and learn the rules of refined recitation under the guidance of qualified and experienced scholars. The mosque has a separate branch for female students where they are provided with equally good opportunities for learning Islamic studies. The sidewalls inside the main hall of the mosque exhibit very old and valuable scripts of The Holy Quran, well preserved in glass boxes. The mosque also has a national level library which is full of books on Islam and also it holds scripts of Quran in all languages of the world. Children are also encouraged to visit the library and mosque for their better upbringing and to develop love about the religion in their minds.

After this detailed exploration of activities going on in the mosque it can be said with confidence that the Faisal Mosque is playing its required role successfully and satisfies the requirements of the aforementioned analysis tools.

5. CONCLUSION

The Faisal Mosque as a modern representation of religious monument became a symbol of national identity and has international prominence due to its uniqueness of exterior constructive design. The mosque represents a modern phase of architectural decoration in constructive form and as surface ornamentation. With typical mosques around the world to make the dome as the main element, the Faisal Mosque is a unique show with no dome. The place becomes more attractive and effective with the selection of a balanced color scheme.

Its sharp contours with white dominant color give a bold impression against the soft lines of the hills at its background. There is no adverse effect of it being a dome-less mosque and it completely provides the feeling of openness, sufficient natural light and ventilation in the main hall. The mosque is highly praised nationally as well as internationally due to its beautiful design. After performing the theoretical analysis, it has also been observed that the mosque is fulfilling its religious and traditional role with success and serving all the functions efficiently.

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A SOCIO-ECOLOGICAL INTEGRATIVE APPROACH TO MOSQUE DESIGN

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Abstract

The Mosque is the nucleus of any urban agglomeration and is the hub for all Muslim religious, cultural and social activities, as well as being the origin of the heritage of Islamic architecture. The mosque is closely linked to its context and surrounding, forming a prominent architectural landmark where Muslims perform the most sacred and fundamental religious practices upon which all righteousness of daily activities hinge. Due to its prominence in our daily lives, it can affect one's interaction with others, with the built-environment and with nature. The mosque can be perceived as a third teacher where the experience of the users in its internal as well as external spaces can educate on matters of environmental and social significance.

The mosque predominantly acts as a place of worship but increasingly brings social activities of a compatible nature to the program, extending the function to satisfy the needs of the community. These needs can be perceived as tangible (education, communal gatherings, services such as 'maghsala' etc.) and intangible such as social bonding built on common values, beliefs and behaviors. Environmental aspects are equally significant as they directly affect the functioning of the spaces bringing about climatic comfort and stewarding environmental responsibility.

Technological advancements and smart solutions have gone a long way in improving environmental functionality and efficiency in use of limited resources. This paper presents a socio-ecological integrative approach which aims to retain the integrity, urban connectivity and functioning of the mosque maintaining a cohesive society, civic identity and environmental stewardship. The approach builds on theoretical discourses as well as practical experience in mosque design. It brings together concepts of social cohesion, social networks and social support as influenced by the built-environment and embraces innovative and smart solutions for eco-efficiency. Examples from practice are discussed, showcasing the various elements of the approach and exemplifying the benefits of the socio-ecological approach for future design of mosques

Keywords

Socio-ecological, community needs, smart, sustainable, mosque architecture

نهج إجتماعي - ايكولوجي تكاملي لتصميم المساجد

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المستخلص

المسجد هو النواة لأي تجمع حضري اسلامي وهو المحور لجميع الأنشطة الدينية والثقافية والاجتماعية ، فضلا عن كونه منبع للتراث المعماري الإسلامي، فيرتبط المسجد ارتباطا وثيقا بما حوله، مشكلا معلما معماريا بارزا حيث يؤدي فيه المسلمون أقدس وأسمى الممارسات الدينية والتي إن صلحت، صلحت باقي الأعمال حيث انها عماد الدين. نظرا لأهمية الصلاة و التعبد في حياتنا اليومية، فهي تؤثرعلى تعاملنا وتفاعلنا مع الآخرين ومع البيئة المبنية ومع الطبيعة، فالمسجد يمكن اعتباره كمعلم ثالث حيث أن تجربة المستخدم في فراغاته الداخلية وكذلك الساحات الخارجية يمكن أن تعلم وتثقف المستخدم فيما يتعلق بالمسائل البيئية والاجتماعية ذات الأهمية .

المسجد في الأساس مكان للعبادة ولكنه أيضا معني وبشكل متزايد بالأنشطة الاجتماعية ذات الطابع المتوافق مع العبادة و الأنشطة الدينية، حيث يشمل تلبية احتياجات المجتمع الحيوية. ويمكن تصنيف هذه الاحتياجات الى احتياجات ملموسة مثل التعليم والتثقيف والاحتفالات الاجتماعية والخدمات الخاصة مثل المغسلة وأخرى غير ملموسة مثل الروحانيات والترابط الاجتماعي مبنية على القيم المشتركة والمعتقدات والسلوكيات. و تستحوذ الجوانب البيئية على نفس القدر من الاهمية لأنها تؤثر وبشكل مباشر على يسرونجاح استخدام الحيزات لتحقيق الراحة المناخية للمستخدم وكذلك تحمل المسؤولية نحو الحفاظ على البيئة ورعايتها، فنجد أن التطورات التكنولوجية والحلول الذكية قد قطعت شوطا طويلا في تحسين الوظائف البيئية والكفاءة في استخدام الموارد المحدودة.

تقدم هذه الورقة البحثية نهج إجتماعي-أيكولوجي تكاملي يهدف إلى تحقيق الغرض العقائدي والحفاظ على استقامة النشاط الديني والمجتمعي والاتصال الحيوي بالمناطق الحضرية وتحقيق الإستدامة المتوافقة مع التطور التكنولوجي، وذلك للحفاظ على مجتمع متماسك، ذو هوية واضحة، مسؤول عن استدامة البيئة المباشرة و الممتدة بحيث يتوافق المسجد مع بيئته، مع احتفاظه بالخصائص و القيم المعمارية والفنية المميزة و تعبيره الصريح عن مثل الإسلام و قيمه و اندماج تصميمه مع العقيدة انطلاقاً من الألفة بين الفئات وجمع المسلمين لممارسة أنشطتهم الدينية و الحياتية ، في أجواء من الإطمئنان و الأمان و الإستسلام الى الله في خشوع و سكينة. ويستند المنهج على الأسس النظرية فضلا عن الخبرة العملية في تصميم المسجد. فهو يجمع بين مفاهيم التماسك الاجتماعي، والشبكات الاجتماعية والدعم الاجتماعي ويحتضن حلول مبتكرة وذكية للكفاءة الإيكولوجية.يستعرض البحث أمثلة من الممارسة ويناقش من خلالها مختلف عناصر النهج المتبع ويعرض مميزات النهج الاجتماعي-الإيكولوجي التكاملي على مستقبل تصميم المساجد.

الكلمات الدالة

اجتماعي-ايكولوجي، احتياجات مجتمعية، استدامة، ذكية، عمارة المساجد

1. THE MOSQUE IN OUR EVERYDAY LIFE

The first entity to be formed when Prophet Mohamed (PBUH) arrived at the Medina was a mosque. It was the center for all Islamic activities, where the observance of the fundamental values and principles of Islamic thought were effected (Omidifard & Jafari, 2015). The significance of collective prayers was in bringing the community together as a congregation, standing equally side by side, all united in their faith and worship of God. Not only prayers took place, it was a school of knowledge where companions studied the Quran and enquiries were made.

It was a place for governance and reception of delegations from other places. It was a treasury for collection and distribution of Zakah (obligatory charity), from which charity work was done and it was the think tank and planning quarter for all matters of importance including wars, and from the mosque, care was extended to the needy of the orphans and the sick (Athar, 2016). Nowadays, many mosques all over the Islamic world are only places of worship, detached from other everyday needs of its members resulting in very little activity out of prayer times.

Mosques must develop to meet the changing needs of the community and its new generations. The mosque should reassume its traditional place in the heart of the Muslim society and become a beacon of knowledge, a place for social encounter and a ground for the observance of fundamental values underpinning the relationship with God, with nature and with fellow human beings. In other words, become the beating heart of a vibrant and benevolent society. In that respect, it is expected that novel functions and a diversity of roles evolve, according to the needs and requirements of the community.

The goal is to embrace the social and environmental qualities of the 21st century community whilst maintaining the spiritual and inspirational qualities of divine worship. This does not undermine the sanctity of the mosque nor take away its fundamental role as a house of God, it rather expands on the meanings associated with the house of God as maintained in the ayah: “Certainly, the first house which has been built for worship is the same one in Mecca, being full of goodness and blessings as well as guidance for the World” (Al-Imran: 96).

The role of the mosque in our everyday life needs to be revisited where core notions of spiritual experience extend to connections with one another and to nature. This is further discussed in the next two sections where the

social dimension is first unpacked exploring the tangible and intangible aspects; then the ecological dimension explores central Muslim values towards nature and the potential of environmental stewardship, leading to the socio-ecological integrative approach.

2. THE SOCIAL DIMENSION

The Mosque has anecdotally carried the role of serving the needs of the community. As mentioned, the formation of the Islamic society would not have been possible if not for the mosque which earned a central status in the everyday life of early Muslim communities. The discussion of the social dimension recognizes two basics of Islam. First Islam is the religion, which has purposely laid its foundation on the community, where numerous verses in the Quran call people to live in harmony and support one another besides being a religion to be practiced collectively (Movahed, no date). Second, Islam is a timeless religion where core values and religious teachings are maintained, yet jurisprudence conforms to the circumstances of time and place (Nouri, 1996:36 quoted in Omidifard & Jafari, 2015). Mahgoub (2011) argues that the use of historical and traditional images of mosque design was an attempt to freeze it in the past and hinder it from performing a contemporary role, limiting the religious dialogue to historical accounts and teachings.

He maintains that the future of Muslim society will always be tied to the mosque as a place of worship and religious practices, yet it must develop and relate to changing human needs and conditions facilitating progressive and forward looking vision of the society (Mahgoub, 2011). Hence, evolving needs of a society should be constantly identified and efforts geared towards including these needs in mosque design, should the mosque assume its role as the beating heart of a community. Societal needs integral for individual and community well-being can be perceived as tangible and intangible. Tangible needs are clearly reflected in spatial terms, namely; prayer space, ablution space, education facilities, ceremonial spaces…etc. Intangible needs are the encounters or occurrences which do not have a physical presence (Scott, 2011) such as social bonding and emotional support which require flexibility and openness in mosque design.

2.1. Tangible needs

The main parts of a mosque are practical, requiring pragmatism in mosque design, and provide both continuity and a sense of tradition among

Muslims worldwide. These include the prayer hall with a ‘mihrab’ ‘minbar’ and usually covered by a ‘dome’, ablution area and in some instances an outdoor court ‘sahn’ for extension of prayers. Movahed (no date) points to the historical context of mosques where they have often been the complex of buildings associated with it such as hospitals, religious schools (madrasas) and shelters for travelers.

As argued above, community needs for a mosque have extended beyond a place of worship. It now houses classrooms for children and women, libraries for search of Islamic knowledge and further learning, community halls to accommodate community social functions within Islamic guidelines such as ‘Iftar’ parties, marriage or ‘aqeeqa’ ceremonies. It also might accommodate a house for the imam and a ‘maghsala’ before burial. Hence mosques meet the modern needs, popularizing its use and providing effective support for the community.

2.2. Intangible needs

Intangible social needs can be classified as spiritual, reinforced by the praise and worship of God, or communal, reinforced by interaction and collaboration. Intangible communal needs are expressed as symbolic values such as ‘reinforcing a sense of unity and identity’ (Holden, 2004), the ‘creation of social bonds’ (McCarthy et al., 2004), ‘making connections between people’, ‘expression of communal meanings’ (Holden, 2004) and ‘social cohesion’ measured by evidence of social interaction between groups (Scott, 2011). The satisfaction of social needs can lead to increased social capital which in turn means reduced crime, less civil disobedience, citizen safety and the growth of norms of trust and reciprocity (DCMS, 2010). It is also a very important determinant to the creativity, resourcefulness and capacity to learn and adapt the tangible resources and to realize their human and social potential to the highest possible level (Lavergne and Saxby, 2001).

Participation in cultural activities is also assumed to have positive impacts on individuals through exposure to new experiences and through building the confidence and self- esteem that results in well-being and mental health (Matarasso, 1997; Guetzkow 2002; McCarthy et al, 2004; Ruiz, 2004). The communication, interaction and cooperation among community members lead to increased social capital, cohesion and wellbeing, and the greater the level of spirituality, the better the devotion, formation of values, creativity and accomplishment. The extended role of mosques can act as a

catalyst for addressing intangible needs by providing a context for sociability and the enjoyment of shared experiences.

3. THE ECOLOGICAL DIMENSION

Although human beings are seen as the most intelligent life form on earth, they are responsible for almost all the damage to the planet. God says in the Quran: "I place successors in the land" (al-Baqara: 30), which is a privilege to human beings entailing a profound responsibility to develop the land, prudently using resources and not threatening the balance of the ecological system (restore and preserve the balance of nature). Islam also teaches humans that all creatures of God, whether it be the tiny ant or the huge lion, serves a certain purpose in the larger scheme of God's world: "There is neither an animal (that lives) on the earth, nor a being that flies on its wings, but (forms part of) communities like you." (Quran 6:38) Hence, any irresponsible or damaging activity is discouraged in Islam. There is a sanctity to the earth and a strong connection between humans and nature exemplified through the act of prayer (Denny, no date).

The Prophet Mohamed (PBUH) said: "The [whole] earth is a masjid [mosque] for you, so wherever you are at the time of prayer, make your prostration there" (Kotob, 2016). Moreover, clean dust may be used for ablutions before prayer if clean water is not available. The earth is thus postulated as a fit place for human's service of God whether in prayer or daily life. In this context, mosques are in a unique position to champion the preservation and restoration of balance of nature. The environmental dimension will first be explained through the focus of Muslim values towards nature, then the spectrum of environmental stewardship afforded by the mosque.

3.1. Muslim values towards nature

As discussed, a belief is held that we are nothing but trustees of the wealth we possess and of the earth, and consequently should preserve them and return them back to God in the best possible form as declared in the Quran: "Then We appointed you viceroys in the earth after them, that We might see how ye behave" (Quran 10:14). As God has made well everything He has created, Muslims have been commanded to maintain it as such: "Do no mischief on the earth, after it hath been set in order" (7:56). Besides being trustees, Muslims have also been urged to conserve. "But waste not by excess: for Allah loveth not the wasters" (Quran 6:141). This rule is applicable in

ablution as worshipers should be abstemious in the use of water even if a river is at disposal, paying due regard for water and other natural resources (Ally, 2015). Great emphasis is made on planting by the Prophet Mohamed (PBUH). Planting a tree is regarded as an act of continuous charity, the most desirable sort of good deeds.

The Prophet said that if one plants a tree, whatever is eventually eaten from it whether by humans or animals counts for the planter as an act of charity (Ally, 2015). On another occasion he said “When doomsday comes, if someone has a palm shoot in his hand he should plant it" (Denny, no date). The teachings and Quran verses outline the expected attitude of Muslims with regard to conserving goods, causing no harm, respecting all creatures no matter how small, preserving the resources, acting charitably and attempting to add positively to our environment.

3.2. Environmental Stewardship (passive treatments, smart solutions, sustainable choices)

Stemming from the position that Muslims have been summoned to be stewards of the earth and upholders of social justice, besides being intelligent and resourceful, practices and mosque architecture are expected to reflect that position. Certainly, mosque should be vehicle for a green agenda, for all it holds in the everyday life of worshipers and its strong potential to be a third teacher (learning by interacting with the space). As such, internal and external spaces can exemplify sustainable choices and smart solutions.

Kotob (2016) suggests that ‘The Living Building Challenge’ could be quite suitable for mosques and sacred architecture as they focus on seven performance categories: Place, Water, Energy, Health & Happiness, Materials, Equity and Beauty. It views buildings as components of the natural environment that enhance the human connection in mind, body and soul with all that is living. More and more buildings are seeking green certification be it LEED, BREEAM, PEARL …etc. with an aim to reduce the negative impact of this enormous industry on the environment and perhaps incentivize the industry to come up with innovative and smart solutions which could improve the functionality and environmental performance of a building.

Mosque architecture falls under the same scrutiny. As a significant landmark in any community, care is taken in the vocabulary used, building materials and design which often depend on the culture, heritage, and resources of each local Muslim community.

4. A SOCIO-ECOLOGICAL INTEGRATIVE APPROACH

It has been established that the faith of Muslims has an inherent and strong connection with nature, but perhaps how to realize the clear principles of environmental stewardship in our everyday lives and practices requires living exemplars. In allowing the mosque to act as a third teacher, the principles of passive design, use of local materials, smart solutions for water and energy conservation, efficient use of outdoor space, can all educate worshipers in life long practices which they can follow in their everyday lives. Also, the social capacity is built by identifying the needs of user groups in the very local, social and cultural climates, by focusing on the user experience and by providing a context for sociability and enjoyment of shared experiences, thereby allowing a community to realize its potential. A mosque is a place that engages souls in a spiritual experience, connects souls to one another and encourages embracement of nature in all its entirety. This concept underlies the socio-ecological integrative approach.

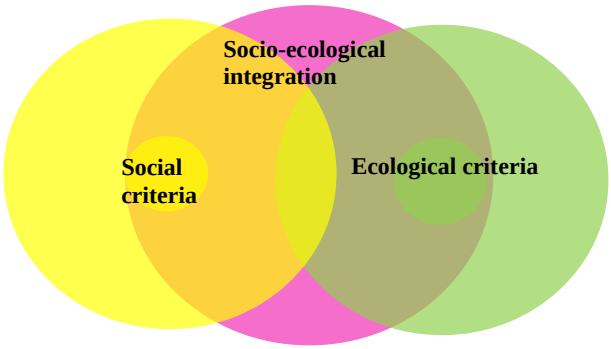

Figure 1. Concept of the socio-ecological integrative approach

4.1. Social criteria:

The social criteria regarding the integrative approach to mosque design have been deduced from the previous discussion of dimensions. They are categorized into criteria to satisfy tangible needs and those to satisfy the intangible needs (See table 1).

4.2. Ecological criteria:

The ecological criteria informing the integrative approach to mosque design (See table 2) have been deduced from the previous discussion and from green certification processes, e.g. LEED and the Living Building Challenge.

Table 1 Social criteria of the approach

	Criteria	Spatial consideration	Social benefits
Tangible needs	Education	Children classrooms, library, women's classrooms, jurisprudence classes	
	Recreation	Event hall	
	Services Civil office Maghsala Clinic	Document production: birth, marriage, divorce, death certificates Washing rooms, separate drive ins, waiting room Outpatient clinic	
	Housing	Travelers housing, Imam quarters, retreats	
	Commercial	Book and convenience shops	
Intangible needs	Spiritual	Prayer hall, retreats, outdoor spaces	Self-esteem, self-pride, solace
	Communication	Outdoor spaces, event hall, education facilities	Self-confidence, identity
	Interaction	Outdoor spaces, event hall, education facilities	Social bonding
	Cooperation	Event hall, service areas	Social network, unity, equity
	Socialization	Outdoor space, Event hall	Well-being, mental health

Table 2 Ecological criteria of the approach

	Criteria	Design consideration
Stewardship	Place, Location & transportation	Pleasantness, accessible, community reach, mobility needs
	Sustainable sites	Outdoor management, species needs
	Landscape	Hard & soft, choice of plants
	Water	Conserved, recycled (grey water)
	Energy & Atmosphere	Renewables, energy efficiency
	Materials & resources	Local and/or certified
	Health & Indoor air quality	Comfort
	Innovation	Passive design & smart solutions
	Well-being & Happiness	Approachable, sociable, sublime, encourages interaction
	Equity & Beauty	Simplicity, part of a whole

The following section shows two examples from practice which have applied the socio-ecological integrative approach in order to demonstrate the approach in practical terms.

5. EXAMPLES FROM PRACTICE

5.1. Al Ummah Mosque (first prize)

Project description: Al Ummah Mosque Project (Figs. 2 to 5) is about 10.5 km north-east of the Holy Mosque. The project is a high profile civic center for Al Usaylah District, acting as a hub of activities attracting the local community and visitors to the area. The architectural character of the mosque is derived from the character of Makkah with a contemporary approach providing a new image and landmark for the area. The Mosque has a capacity of 3,888 prayers where the temporary hall can accommodate a further 444. The extended plaza can provide further praying space for Juma and Eid prayers. Despite serving eight different uses, the dominance is given to the main praying activity and other uses do not interfere or conflict with each other in terms of location and circulation.

Figure 2 Al-Ummah mosque - Elevated plaza with water bodies and landscape

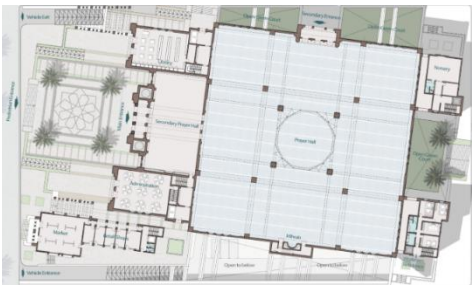

Figure 3 Ground floor (Market, shops, administration, library, main & secondary prayer hall, nursery, workers accom.)

Figure 4 Underground floor (men's classes, ablution, MPH & services, Funeral services, parking)

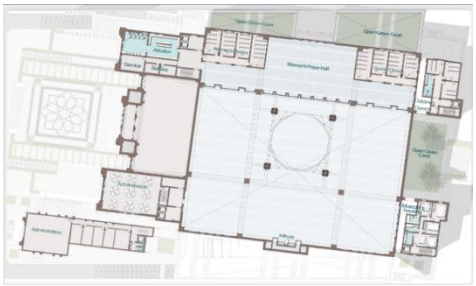

Figure 5 First floor (women's classes, ablution, women's praying hall, children's classes, Imam Quarters, administration)

Project design, social aspects: The elevated plaza provides a welcoming space for the community and defines the zone of the mosque against other

surrounding activities. All public activities such as the library, commercial uses, administrative and funereal services have a clear and easy access from the main road. Pedestrian and vehicular access are separated. Access points for various users have been carefully designed to avoid any intersection, including the imam accommodation. In terms of tangible services, the Al-Ummah mosque complex provides services for different users: women, children, men, groups, workers and Imam. Secluded English courts, the covered main plaza, arcades and pleasant approaches provide outdoor spaces for meditation, socialization and communication. The Multi-purpose hall and education facilities provide a different type of interaction and communication. Social networks are formed here and extended cooperation and support are expected.

Project design, Ecological aspects: Environmental treatment and amenities provide innovative solutions. Use of English courts, sun shading screens and masses, cooled air brought in from the underground level, air shafts in columns and the minaret, photovoltaic cells, green roofs, mashrabeyas and double glazing, water pools for dust control, arcades, local sourcing of materials, and native selected plantations, all serve to create distinctive internal and external environments and encourage social activities figure 6.

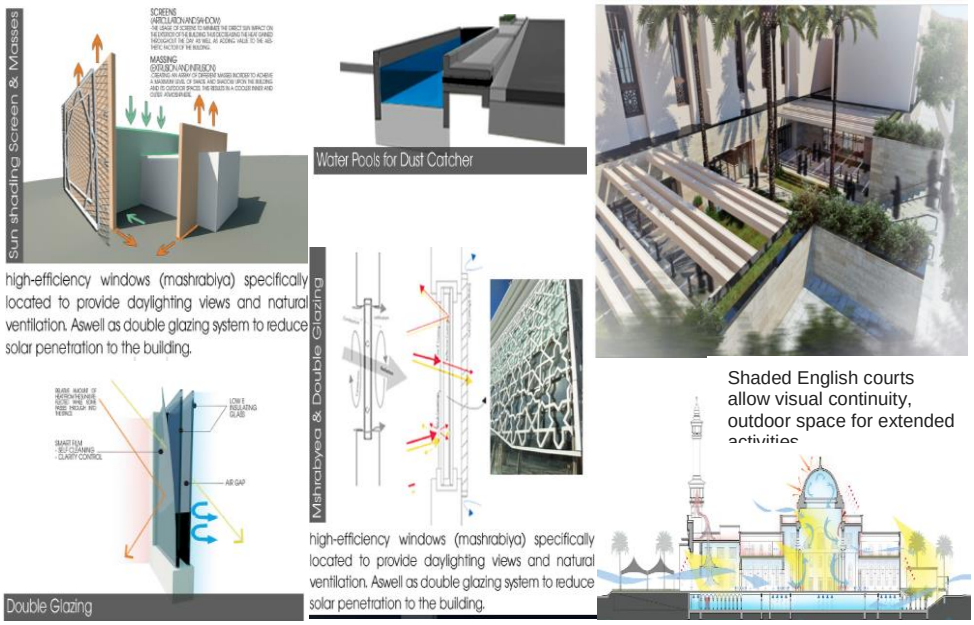

Figure 6 Environmental treatments

In this project, smart solutions were also applied to embrace the ecological approach where conservation of water, energy and space were of paramount importance, besides use of renewables figure 7.

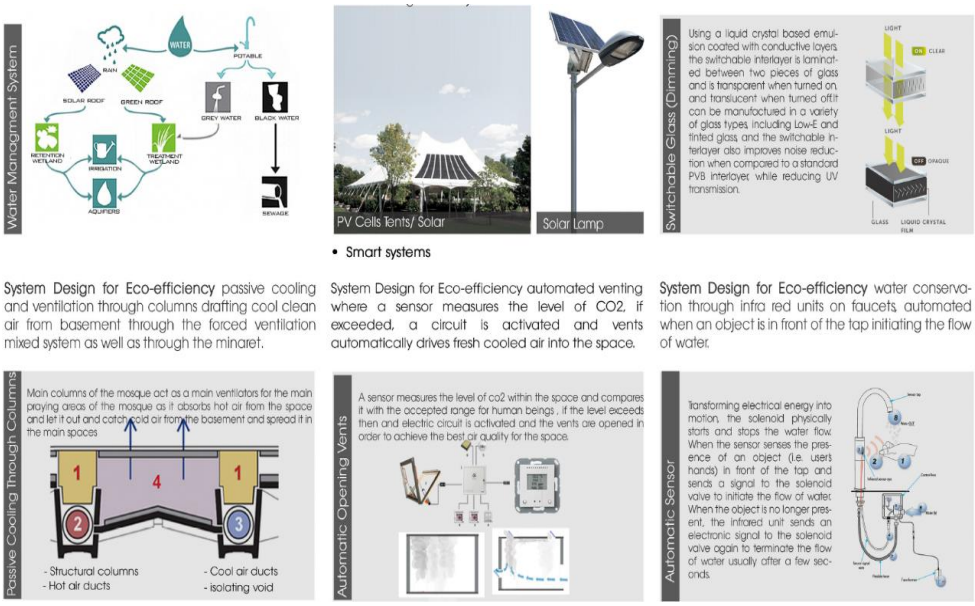

Figure 7 Smart solutions (closed water system, automatic sensors, switchable glass, automatic vents, solar and PV cells)

5.2. Gazan Mosque

<u>Project description:</u> The goal of this project is to demonstrate the relevance of traditional Islamic architecture and diversity of building types in Gazan, Saudi Arabia while creating an exemplar of a sustainable development and to create awareness of traditional methods of design and construction. The mosque complex is built on a platform 50 centimeters above ground level. The general plan is an integration of the classical hypostile and four-iwan mosque combined with domed Ottoman mosque architecture. It consists of a large prayer hall, Saha surrounded by colonnades and two small prayer rooms, one for daily prayers and another for female worshippers with a capacity of between 2500 to 3200 people under both covered and uncovered spaces.

The mosque prayer hall is covered by a concrete dome and is formed as square placed on a right angle to the Qibla axis. This situation created a break in the courtyard grid that helps to emphasize the importance of the mosque.

The mosque has two corner minarets, incorporating a complex design scheme: starting with a square plan, changing to octagonal and finishing in a dome form (Figs. 8 to 12).

Figure 8 Ground floor

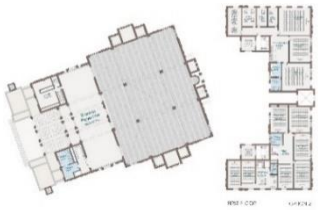

Figure 9 Mezzanine floor

Figure 10 Front Elevation

Figure 11 Top view

Figure 12 View of the Qibla wall

The sanctity of the Qibla was further emphasized by the introduction of "Mihrab" which is normally larger than the other walls creating a back open central courtyard that usually accommodates the ablution and the other services of the complex; this space is accessed through a gateway that differs in design.

6. CONCLUSION

The paper has presented a socio-ecological approach to mosque design. As suggested by the term, the approach has two dimensions - social and ecological. Both dimensions are integral to the design of contemporary mosques which are expected to fulfill much more in terms of the needs of the community and solutions to the current pressing threats. Social challenges vary but can indeed be addressed through the spirit of collectiveness emerging from the mosque. Social equality for example is endorsed through the Zakah, Sadakah and act of praying side by side, emphasizing Prophet Mohamed's teachings that 'There is no superiority for an Arab over a non-Arab nor for a non-Arab over an Arab; neither for a white man over a black man nor a black man over a white man except the superiority gained through God-consciousness (Taqwa)' as stated in his Farwell Speech, delivered on the 9th day of Dhul al Hijjah, 10 H (Saoud, 2001). The communication, interaction, socialization and cooperation helps members of the society develop a clear understanding of the challenges they face, recognizing and respecting each other's needs, working together for the betterment of the society.

The social criteria are divided into tangible and intangible criteria. The practical examples demonstrated the spatial manifestation of both type of needs and how the contemporary mosque can accommodate them without undermining the main function of the mosque as a place of prayer and religious duties. Issues of accessibility and separation of possible conflicting uses is paramount for the functioning of the complex.

The ecological dimension is equally developed in the approach and exemplified in the two examples. Passive design remains the main vehicle for the achievement of human comfort within and outside the mosque. The approach first recognizes the site, its location and means of accessibility, and goes on to the management of the site during and after construction, designing the landscape in accordance with the context and local climate, consideration of various factors contributing to the ecology of the place, conserving resources and devising ways of replenishing water and energy, whilst using local materials are integral. Innovative solutions based on local knowledge as

well as smart technologies have been part of the projects shown. Ecological design has been shown to complement mosque design with masses, shades, details such as openings, mashrabeyas, minarets, columns, etc., contributing to a most pleasant indoor and outdoor environment as well as rich architecture.

The socio-ecological approach has contributed to creative expression, innovation and cultural diversity in mosque design. The mosque building complex stands to educate individuals on matters of co-existence with nature and of the role of individuals towards their community, and to develop values and knowledgeable skills useful for everyday lives. The whole life of a Muslim is meant for the praise and worship of Allah in all daily deeds. The greater the devotion, the better the attitude, interest, relationship and contribution, directing a person from lesser to greater levels of moralization, creativity, choice and accomplishment.

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BENCHMARK FOR MOSQUE ENERGY CONSUMPTION IN HOT ARID CLIMATE, ASSIUT, EGYPT

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Abstract

Reduction of energy consumption in buildings is a major aim and is a particular challenge in hot arid climate. In addition, electrical energy costs of Egyptian mosques are highly subsidized by the government. The aim of this study is to analyze energy consumption and operation strategies of mosques in Assiut, Egypt and find the distribution of energy consumption per unit area in an attempt to establish a trend curve and strategy for energy efficient mosques.

This study analyses monthly and annual energy use per unit area (kWh/m2.yr) over two years (2013-2014) for 25 mosques in Assiut, Egypt using electric bills. A field survey was conducted to analyze energy consumption based on activities, electric equipment and mosque design. The results showed only three mosques have electric energy consumption rate per year less than 50kWh/m2/year. The trend curve of the total energy gives balanced and reasonable distribution of energy consumption per unit area over floor area. It shows that as area increases the energy consumption per unit area decreases. Increased use of natural lighting in Zuhur and Asr prayer times will significantly contribute to energy reduction as the total energy consumed by lighting and ceiling fans is approximately one third of the energy consumption. The results of this research help establish guidelines to achieve conserving electric consumption for existing and future mosques of hot arid climate in Assiut and design smart eco system for mosques in Egypt.

Keywords

Mosque, energy consumption, hot arid climate, electric bills

نموذج قياسي لإستهلاك الطاقة في مساجد المناخ الحار الجاف في أسيوط، مصر

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المستخلص

يعتبر الحد من إستهلاك الطاقة في المباني هو الهدف الرئيسي في مباني المناخ الحار الجاف. وفي مصر، تدعم الحكومة المصرية معدلات إستهلاك الطاقة في المساجد والتي يتم الإعتماد فيها علي الوسائل الميكانية للتبريد، الامر الذي ينعكس علي زيادة أعباء والتزامات الحكومة. وأصدرت وزارة الأوقاف بيانا لترشيد الطاقة داخل المساجد لتكون قدوة لتغير سلوكيات المواطنين والعمل علي ترشيد الطاقة داخل المباني السكنية والحكومية.

تهدف الدراسة الي تحليل معدلات إستهلاك الطاقة وإستراتيجيات التشغيل داخل مساجد مدينة أسيوط، مصر وحساب معدلات إستهلاك الطاقة بالنسبة لوحدة المساحة وذلك من اجل تحسين معدلات ترشيد الطاقة داخل المساجد. تعرض هذه الدراسة تحليل مفصل لمعدلات إستهلاك الطاقة داخل ٢٥ مسجد في أسيوط خلال العامين (٢٠١٤-٢٠١٣) وإجراء المسح الميداني لتحليل إستهلاك الطاقة من حيث الأنشطة الداخلية، تصميم المسجد والأجهزة المستخدمة.

أظهرت النتائج أن منحني إجمالي إستهلاك الطاقة يعطي توزيع متوازن لمعدل إستهلاك الطاقة بالنسبة لوحدة المساحة. يدل ذلك أن معدل إستهلاك الطاقة بالنسبة لوحدة المساحة يتناسب عكسيا مع وحدة المساحة. ويعتبر إستخدام الإضاءة الطبيعية في صلاة الظهر والعصر يساهم في تقليل طاقة. كما أظهرت نتائج المسح الميداني أن معدل إستهلاك الإضاءة ومراوح السقف داخل المساجد يمثل ثلث إستهلاك الطاقة. وتساعد نتائج هذه الدراسة في وضع مبادئ إسترشادية للمحافظة علي إستهلاك الطاقة داخل المساجد الحالية والمستقبلية في المناخ الحار الجاف وإقتراح تصميم نظام بيئي للمساجد في مصر.

الكلمات الدالة

المساجد، معدل استهلاك الطاقة، المناخ الحار الجاف.

1. INTRODUCTION

Buildings consume much energy during their entire life (Zimmermann et al., 2005). Mosques are characterized by the schedule imposed by prayer times. The Ministry of Awqaf in Egypt seeks to rationalize electricity consumption and help resolve the problem of energy. The mosque is one of the most important buildings to achieve the highest values of thermal comfort for prayers in order to make their bodies thermally comfort and pray in convenience. Mosques are used not only during prayer time but also in other special occasions such as lecturing, wedding, and similar activities where people tend to stay longer times.

Mosques are important to Muslim communities. Many researches have studied thermal environment, developed climate responsive design and explored different ways for energy conservation inside mosques (Mushtahaa and Helmy, 2016; Ibrahim et al., 2014; Al-Sallal et al., 2013; Abdul Hamed, 2011). Monitoring energy use and thermal comfort was performed inside mosques of hot humid climates in the Kingdom Saudi Arabia. Important findings showed reduction of energy consumption by thermal insulation of mosque envelope (Al-Homoud et al., 2009; Budaiwi, 2011). A study (Saeed, 1996) on thermal comfort for occupants during Friday prayer was done in the hot arid climate of Riyadh.

The selected mosque is located within Housing Compound of King Saud University. It was concluded that most people feel comfortable and few prefer cooler conditions (Saeed, 1996). Abdou et al., 2002 developed a systematic approach for energy audit of mosques in Dhahran. This study focuses on mosque performance in terms of energy consumption. Also, they studied mosque design and the energy system used in mosque and its operation (Abdou et al., 2002). A recent research (Hussin et al., 2014) evaluated indoor thermal comfort in a mosque operating with air conditioning in Malaysia. The results concluded with a new range of thermal comfort temperatures based on PMV model prediction (Hussin et al., 2014). Al-Homoud et al. (2009) described design guidelines for thermal performance of medium sized mosques in Riyadh and Jeddah.

The study focused on the operating characteristics for typical mosques and their thermal environment Al-(Homoud et al., 2009). Al-Hemiddi (2003) analyzed energy consumption in two types of mosques in Riyadh based on electric equipment and effect of weather data. He concluded that energy consumption for lighting is considerable although the mosques used natural

lighting (Al-Hemiddi, 2003). Al-Ajmi (2010) conducted thermal comfort measurements and questionnaires for a total of 140 subjects in Kuwait mosque buildings. The study analyzed thermal comfort sensations for Muslims during the prayer time (Al-Ajmi, 2010). Another research (Abdou et al., 2005) analyzed annual energy consumption for five typical mosques in the hot humid climate of Saudi Arabia based on electric energy bills of five years in order to evaluate the history of energy consumption (Abdou et al., 2005).

Therefore, examining literature indicates that there is a lack of research on mosque energy performance and thermal comfort in Egypt. The aim of this study is to analyze energy consumption of mosques in Assiut, Egypt and find the trend curve for energy consumption in order to establish a strategy for energy efficiency in Egyptian mosques. This study helps to establish guidelines to optimize electric consumption for existing and future mosques in the hot arid climate of Assiut and design smart eco systems for mosques in Assiut, Egypt.

2. METHODOLOGY

Investigation was done for 47 mosques located inside and outside Assiut city. The electric bills of 47 mosques were collected from the Ministry of Electricity (Assiut sector) for 2013 and 2014. The electric energy bills help provide a reasonable estimate of the overall annual energy consumption for each mosque and find out the annual energy pattern. Annual energy use index per unit area (kWh/m2.yr) was used in order to compare mosques based on unit area. This helps minimize the inaccuracy and possible errors from monthly meter readings.

The two-year monthly and annual electric energy use and indices were investigated. 25 mosques were selected for calculating energy use index per unit area based on mosque high energy consumption, mosque capacity and easy access. Also, 12 mosques were excluded; small mosques with low energy consumption (≤60000kWh for two years) and others were eliminated due to difficult access from Assiut city. In order to collect information from mosques, field surveys were conducted.

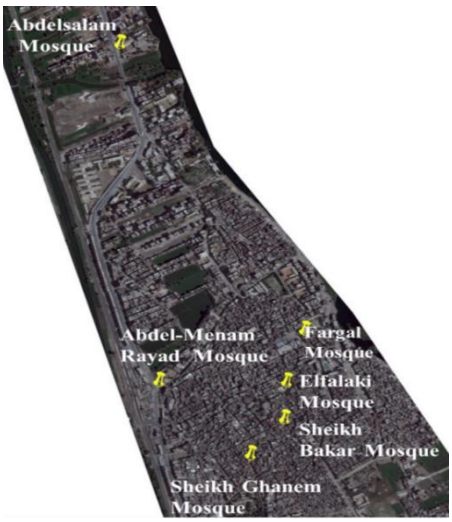
The audit process requires the collection of base information, field data, energy bills for mosques and electric equipment in order to analyze energy consumption in mosques and their relation to mosque area, activities and electric devices. The data collected for each mosque was classified according

to lighting system; A/C system, air circulation fan, mosque dimensions' data and mosque design. The surveyed mosque information was utilized to categorize mosques according to annual energy consumption per unit area into three categories.

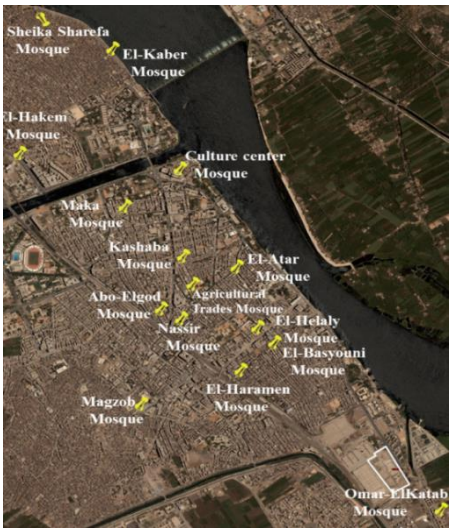
3. RESULTS AND DISCUSSION

Investigation of 16 mosques inside Assiut city was carried out: different areas and located in different places in Assiut city and field survey was used. Also, investigation of 9 mosques outside Assiut city was carried out. Figure 1 shows the location of the investigated mosques on satellite images for Assiut city.

Annual and monthly electric bills can provide useful information about energy performance and build a history for mosques energy consumption in Assiut city. Figures 2 and 3 show the annual energy use index per unit area (kWh/m2.yr) for two years (2013-2014), for mosques inside and outside Assiut city respectively. There is a clear variation of annual energy consumption for the years 2013 and 2014. These variations can be attributed to many factors, notably the variations in weather conditions from one year to another in addition to differences in operating patterns of energy systems in those mosques, and closing most of the mosques after the prayer time due to the country regulations.



Mosques outside Assiut city (Abo Tig)



Mosques inside Assiut city

Figure 1. The locations of the investigated mosques on satellite image inside/outside Assiut city

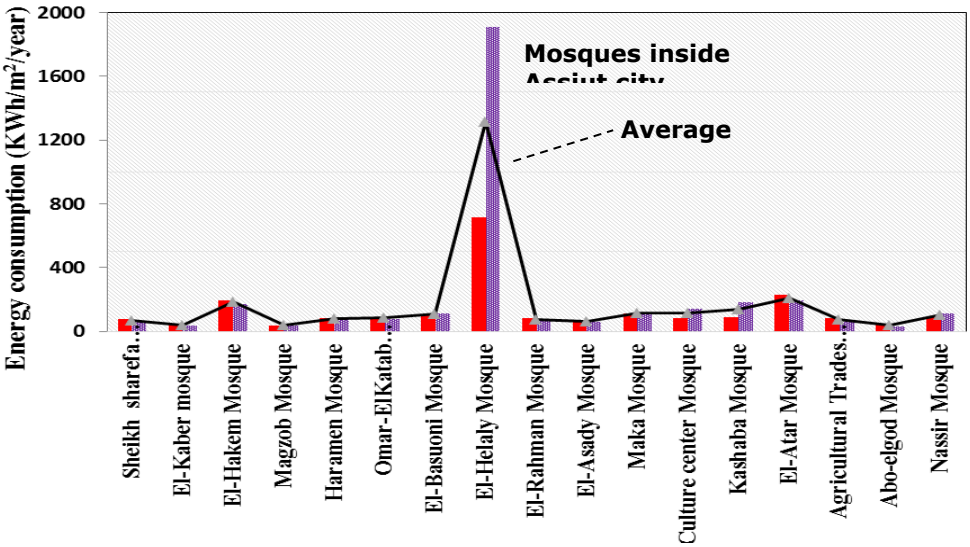


Figure 2. The annual energy use per unit area (kWh/m2.yr) for two years (2013-2014) for mosques inside Assiut city

It is observed that the maximum average annual energy use index is 1314 kWh/m2.yr in El-Helaly mosque due to opening the mosque most of the day and performing different activities (meetings, funeral prayers and wedding ceremonies). Meanwhile the average annual energy use index for other mosques fell below 115 kWh/m2.yr, except for El-Atar mosque and El-Hakem mosque. The main reason is that the walls of most mosques are characterized by high thermal mass that reduces cooling demand and energy consumption. The lowest average annual energy use index of 39kWh/m2.yr is for Majzob mosque. This mosque is characterized by having shaded Friday prayer zone outside the mosque building that causes shade for the mosque wall and thick walls of old bricks with a unique old architectural style that decreases cooling demand and need for air conditioning. This strategy is expected to cause less energy consumption.

Figure 3 shows the monthly pattern of energy consumption for four mosques. It is clear that electrical energy consumption (EEC) is low in winter and high in summer. A significant increase in energy consumption occurs in certain months (July and August) with a maximum of 13000 KWh in Nasser mosque during August 2012. This is caused during the Ramadan month (Arab calendar month); which met the summer in these years. Ramadan month is an Arab calendar month which is dependent on lunar calendar year that consists of 354 days. In this month, Muslims spend a lot of times inside mosques for praying and worshiping.

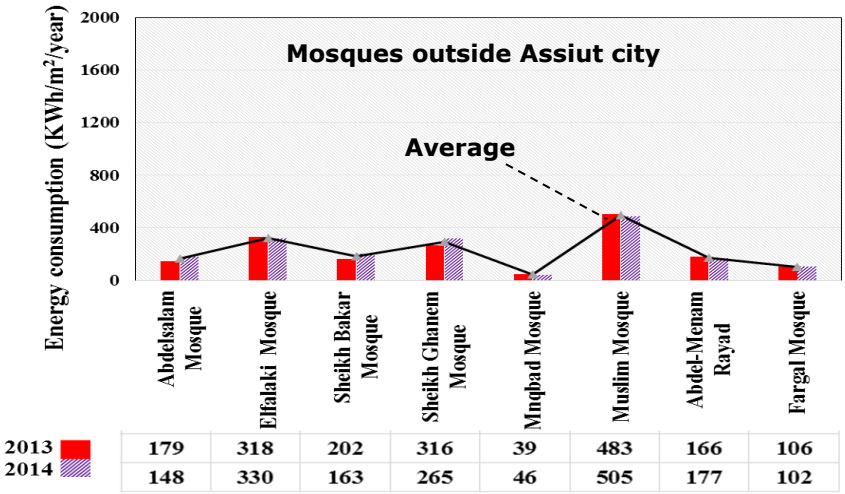


Figure 3. The annual energy use per unit area (kWh/m2.yr) for two years (2013-2014) for mosques outside Assiut city

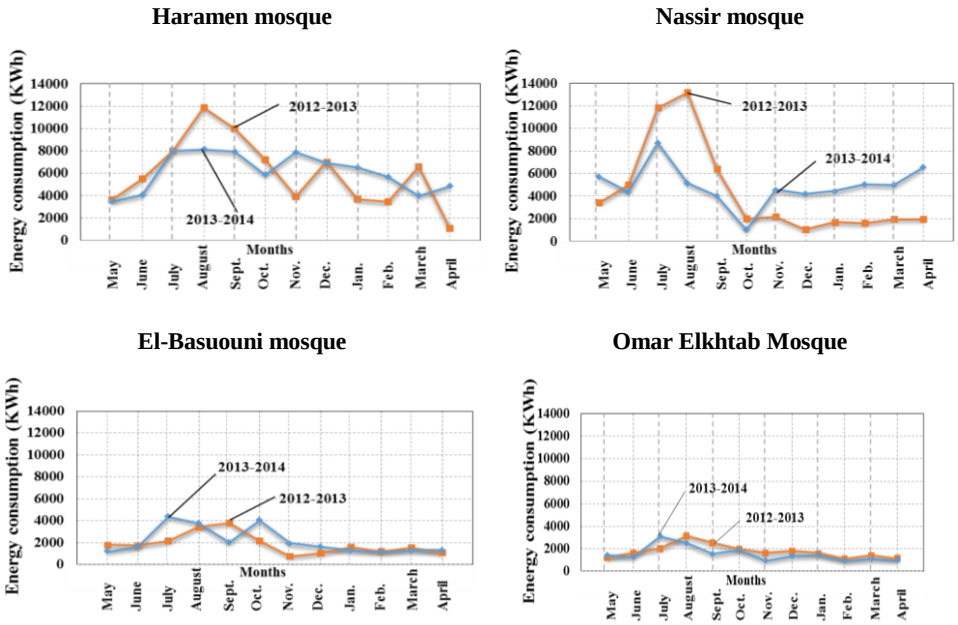
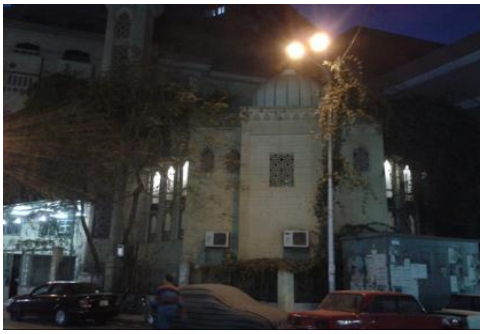


Figure 4. The monthly energy consumption profile for four mosques inside Assiut city.

As Ramadan month is based on Arab calendar, this explains the shift of energy consumption peaks from 2012-2013 to 2013-2014. Therefore, the

maximum energy consumption criteria are not similar each year Figure 4. Figure 5 shows the exterior views of four mosques in Assiut city.

Nassir mosque



Maka mosque

Sheikh Bakar mosque

Sheikh Ghanem mosque

Figure 5. Exterior view of Nassir mosque, Maka mosque, Sheikh Bakar, Sheikh Ghanem mosque.

3.1. Classification of mosques according to energy consumption

Mosques are classified according to their energy consumption per unit area into three categories as shown in Figure 6. The first category “A”; mosques with small area (less than 300 m2), these mosques have high number of HVAC and lighting that consumes high energy; representing 50% of mosques. In category A there are three sections of energy consumptions, low AL, medium AM and high AH energy consumptions.

The second category “B”; Mosques with medium areas (between 300 and 600m2) and these mosques have moderate energy consumption values per unit area. These mosques represent 35%. In category B there are two sections of energy consumptions, low BL and medium BM energy consumptions. The third category “C”; mosque with large areas (more than 600 m2) and these

mosques have low value of energy consumption per unit area. In category C there is only one section of energy consumption around 100 kWh/m2/year, it is a low CL energy consumption rate.

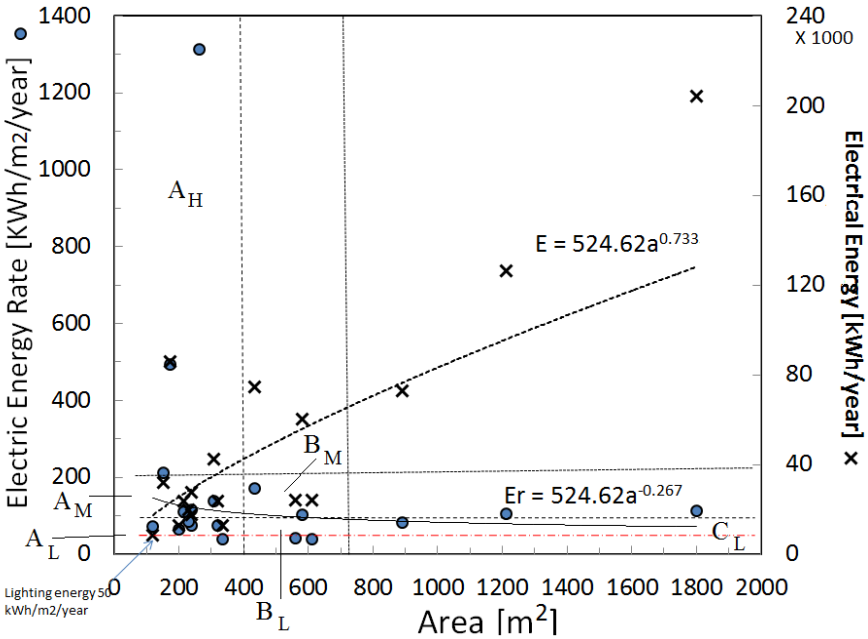


Figure 6. The relation between annual energy consumption and rate per unit area and mosque floor area.

The relation between annual energy consumption per unit area and floor area gives a trend curve governed by the following equation;

$$E_r = 524.62\ (a^{-0.26})$$

This equation gives a balanced and reasonable distribution of energy consumption per unit area over floor area. Such data is based on mosque surveys. It shows that as area increases the energy consumption per unit area decreases for the surveyed Mosques. Meanwhile, the relation between energy consumption and floor area gives a trend curve with equation;

$$E = 524.62\ (a^{0.733}) \approx E_r.a$$

This equation gives a balanced and reasonable distribution of energy consumption over floor area. Such data is based on mosque surveys. It shows that as area increases the energy consumption increases for the surveyed Mosques.

As such data is based on mosque surveys, the relations are not clearly showing different electric device used and different social activities held in the mosque such as weddings and meetings. But a 524.62 kWh is noticed as a fixed load and it is not dependent on the mosque area. This load could be considered as water heater, water cooler, ventilating fans and others. As shown in Fig. 6, the dash dotted line is the lighting energy consumption per m2 per year for five hours for the five prayers and it is 50 kWh/m2/year. The ceiling fans energy consumption is 12 kWh/m2/year. The summation of lighting and ceiling fans energy consumption is approximately one third of the energy consumption. This agrees with the data survey in a small mosque. Fig. 7 shows the different items of load distribution for a small mosque.

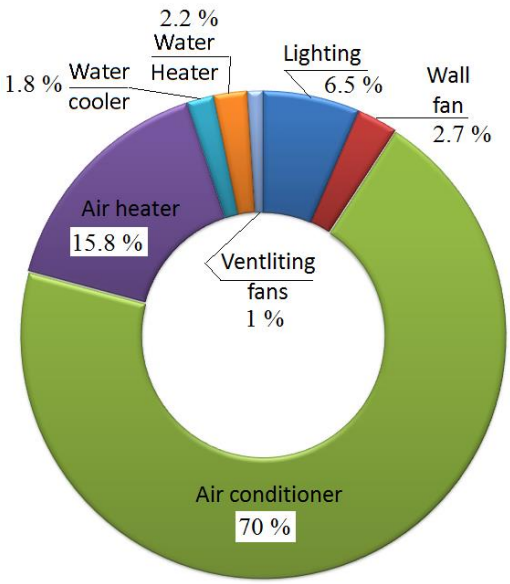


Figure 7. Different load distributions in a small mosque

3.2. Exploring strategies to reduce energy consumption inside Assiut mosques

Since small mosques are the major percentage of mosques in Assiut as shown from the study, in some cases they have high energy consumption even more than large area mosques. Also, large area mosques will cost high for the similar energy reduction plan. A summary of of mosques load characteristics and reduction plan recommendations is shown in Table 1. A number of alternative technologies for energy reductions were assumed (Santamouris

and Asimalopoulos, 1996; Antinucci et al., 1992; Scheatzle et al., 1989). In total, three main directions for possible energy reduction were investigated, namely; reducing energy of artificial lighting, cooling, and heating systems.

Table 1 Different loads in mosques and operation criteria

Device	Relation with area	Working time	Recommendation
Lighting	Dependent	All the year	- Using day light - Using LED - Occupancy sensors
Air condition	Dependent	Summer period	- Thermal insulation - Night ventilation - Natural ventilation
Air heater	Dependent	Winter period	- Thermal insulation - Day ventilation
Water heater	Not Dependent	Winter period	- Reducing water use - Solar heater
Water cooler	Not dependent	Summer period	- Water controller
Ceiling Fans	Dependent	Summer, spring and autumn	- Natural ventilation
Ventilating fans	Not dependent	All the year	- Occupancy sensors

3.2.1. Energy conservation from artificial lighting

Energy conservation from artificial lighting can be of primary importance in mosques, since the entire mosque area must remain illuminated during prayers and sometimes outside prayer times. A reduction of the consumed electric energy for the artificial lighting of interior spaces in mosques can be achieved by the use of more efficient lamps and utilization of natural day lighting. Also, the performance of artificial lighting can be improved by increasing the reflectivity of the ballast and improving the design of the diffuser. The use of natural lighting helps reduces the need for artificial lighting, especially during the two prayer times (Zuhur and Asr) with a reduction of the cooling load and minimizing the internal gains. Increasing usage of natural lighting in Zuhur and Asr prayer times would contribute to energy reduction significantly.

3.2.2. Energy conservation from cooling

A reduction of the consumed energy for the cooling of buildings can be achieved by optimizing indoor environments of mosques, the use of high performance cooling systems and the use of alternative technologies and systems for cooling. A number of techniques can be used for reducing the primary causes of the cooling load, such as using natural cooling techniques,

night ventilation and adapting ceiling fans. This can decrease external loads (direct gains from solar radiation, higher outdoor temperatures). The internal loads of a building are caused by two sources; human activity and artificial lighting. The first one is somehow flexible, since it depends on the prayer times (5 times: Fajr, Dhuhr, Asr, Maghrib and Isha) and operation of the mosque during special occasions. However, the heat gains from artificial lighting can be reduced if light emitting diode LED lamps with low heat emissions are used where possible. LED lamps can reduce the cooling load significantly.

4. CONCLUSION

The study presents an assessment of energy consumption using mosque survey and electric bills for mosques inside/outside Assiut city in order to develop a curve trend and a benchmark model for mosque energy consumption. The main results of this study are as follows:

- The unique old architectural style of some mosques decreased cooling demand and energy consumption.
- The reasonable distribution of energy consumption per unit area over floor area shows that as area increases, the energy consumption per unit area decreases.
- Prediction of the trend curve of total energy use in mosques of Assiut, Egypt relative to their corresponding areas is given by:

$$E_r = 524.62\ (a^{-0.26})$$

- The lighting energy consumption is 50 kWh/m2/year, for the five prayers. Increasing usage of natural lighting in Zuhur and Asr prayer times will contribute significantly to energy reduction as the energy consumption for lighting and ceiling fans is approximately one third of the total energy consumption.
- Mosques with small area consume high energy, due to the high number of HVAC and lighting fixtures.
- Energy consumption in mosques depends on several factors; mosque volume, the activities of Muslims inside the mosque (meeting, wedding, and long prayer time during Ramadan) and the number and type of electric devices used in operating hours.

Additional analyses and monitoring of mosque energy consumption, will be performed in one of the small mosque to design smart eco system for mosque in Assiut, Egypt. Future studies using numerical models will be done to develop low energy mosque buildings with some sustainable strategies.

ACKNOWLEDGMENT

The author gratefully acknowledges the cooperation of officials of The Ministry of Electricity (Assiut sector) for their help in providing electric bills of 47 mosques in Assiut. Also, the author gives special thanks to postgraduate students (2015) for their participation in part of the field survey.

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