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The Impact of Architectural Design Parameters on the Energy Performance of Mosques in the Arabian Gulf Region: A Case Study of Dammam City.

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Abstract: The study typifies basic characteristics of mosque design, as a base for of the conduction of systematic and detailed computer simulation studies for energy performance of mosques. Main geometrical parameters are considered over practical ranges and common construction materials of main envelope components are addressed by parametric studies. A simple index for electrical consumption is used for comparative energy performance evaluation. The effectiveness of the different geometrical and constructional parameters are investigated and their energy saving potentials are revealed. Comparable performance improvements are shown for the geometrical parameters ranging up to 6%. Wall block constructions are of limited effectiveness. Double-glazing is most effective of the glazing design with a performance improvement of up to 6%. Roof construction in general offers greater advantages of up to 10%. The application insulation offers advantageous improvement ranging up to 10 and 20 % for wall and roof constructions, respectively.

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. With modern development, increased affluence and the use of new building materials, appropriate environmental levels are mostly achieved by artificial support system. This led to total reliance on A/C system for the provision of thermal comfort. As a result, the electrical energy consumption of mosques is evidently large, as illustrated by the annual consumption in the Eastern Region of the Kingdom, which amounts to about 90 GWh for the year 1417-H. [1]

In the light of the general concern for improved energy efficiency, the design of mosque should reflect the enshrined Muslim principle of efficiency in usage of resources. However, no attention is yet given to the study of mosque energy performance. Previous studies gave limited scientific exposure to mosque performance and mainly dealt with architectural aspects, acoustical and lighting considerations. [2-5] This paper focuses on the energy performance of mosques as part of an on going comprehensive research program, which deals with scientific and technical evaluation of mosque performance. It addresses issues related to geometrical design and construction aspects.

The importance of envelope construction and architectural geometrical design in determining fabric heat gain, building cooling load and energy performance has been shown by previous studies. [6-7] This study considers the energy efficiency for mosque design, and realistically addresses the architectural and constructional determinants of envelope design and assesses their energy saving potentials.

Typification and Specification of Mosque Designs

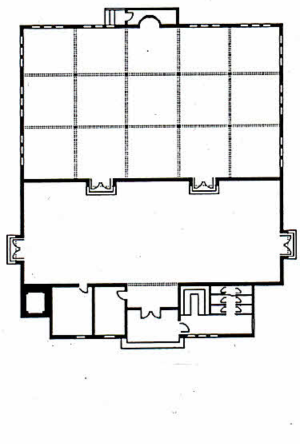
Mosques can vary greatly in size and character. These range from the local, Jamaa, mosque, to the large Friday, Jumaa, mosque and to the grandeur city mosque. The construction design and materials commonly used also shows greater variability. Such architectural and constructional variability arises from the fact that mosques are built by authorities as well as by private individuals. This necessitates the need to categorize and typify mosque designs and to define their primary determinants in order to pursue systematic performance evaluation.

The Technical Department of the Ministry of Islamic Affairs, Endowment, Da'wa and Guidance of the Eastern Province, was instrumental in establishing standard designs for mosques. Two main designs known as type "H" and "O" were extensively built during the past five years. [8] This study, therefore, typifies and adopts these two mosque types as standard reference base designs. These enable definition of the ranges for parametric studies and comparative energy performance evaluations.

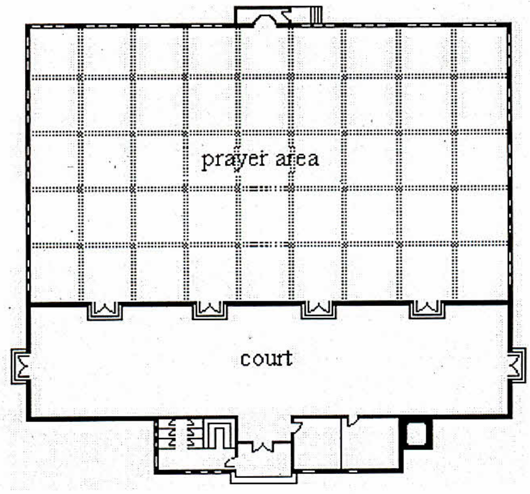
Basic Geometric and Construction Characteristics

The typified mosque designs are generally of rectangular plans. Type "H" is a local Jamaa mosque with dimensions of 15 x 25 x 4 meters. Type "O" is a Friday mosque with larger dimensions of 25 x 45 x 5 meters. Qibla orientation is a basic constraint of mosque design, showing a westerly direction in the eastern region. This Qibla direction shows limited angular variability along the Gulf coast. The architectural layouts for the two typified mosques are shown by (Fig. 1).

The structural design of the typified mosques is essentially of concrete frame structure. Common concrete block construction is basically used for wall filling. A/C 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 and A/C system specifications of the typified mosques are summarized in (Table 1).



Type "H"



Type "O"

Fig. 1: Plans of typified mosques.

Table 1: Characteristics and specifications of typified standard mosque designs.

		Type 'H'	Type 'O'
Geometry	Floor Area	378 m²	1125 m²
	Plan Proportion	1.67:1	1.8:1
	Height	4.05 m	5 m
	Opaque wall area	295 m²	631 m²
	Glazing area Glazing to floor area ratio:	37 m² 10%	m² 6%
	Qibla façade Side facades Back facade	4 % 2 x 2.3 % 2.4 %	1.6 % 2 x 1.2 % 2.0 %
Wall Construction	Internal and external plaster		
	20 cm heavy weight conc. block		
Roof Construction	Standard built-up roof finish		
	20 cm reinforced concrete slab		
	Internal plaster		
Floor Construction	Slab on grade + tiles + carpet		
Glazing Type	6 mm clear single glazing		
	Shading coefficient	0.95	0.95
Lighting System	Suspended fluorescent	6.4 W/m²	6.4 W/m²
No. of users	Av. no. of persons: regular prayer Friday prayer	4.8m²/person 0.9m²/person	
Infiltration	Air change	0.75 ac/hr	0.75 ac/hr
A/C System	Package terminal air conditioner	DX system	DX system
	Thermostat setting: Cooling	25.5 °C	25.5 °C
	Heating	21°C	21°C
	Relative humidity	50 %	50 %
	Heating source	Electric	Electric

Performance Indexation

Assessment tools and performance indicators are needed for practical energy performance evaluation. The study uses annual electrical energy consumption, which directly relate to cooling load performance and A/C system capacity. It is a simple performance indicator, given as a standard area measure index expressed per square meter of floor area. The index defines electrical energy consumption as kWh /m²/Year. It, thus, enable direct and practical assessment of mosque energy performance.

Preliminary performance evaluation of some existing mosques is established through a limited local survey. The survey covered a number of typical mosques in the Dammam area. This enabled estimation of an average value for the electrical consumption index, with reference to floor area and metered electrical consumption, as reported by the utility company (SCECO East). [1] The estimated average for the electrical energy consumption index is established as 180 kWh/m²/year. This is useful in providing a practical base value of index for comparative performance evaluation.

Simulation Studies

A realistic and practical exposure of the impact of architectural design parameters of mosques on its electrical energy performance is readily achieved by computer simulations. Computer simulations enable an expanded scope of investigations and prompt consideration of wide ranges and combinations of parametric studies. This study uses the PC-DOE program, a version of the DOE 2.1 B program and enhanced for PC environment. Simulations of mosque energy performance are conducted on hourly basis and for full year duration.

Accurate simulations require realistic representation of primary input data. These comprise climatic condition, occupancy, A/C specifications and operational use, as well as architectural geometrical design and constructional characteristics. Standardized conditions need to be defined for the purpose of parametric studies, and relate to the following:

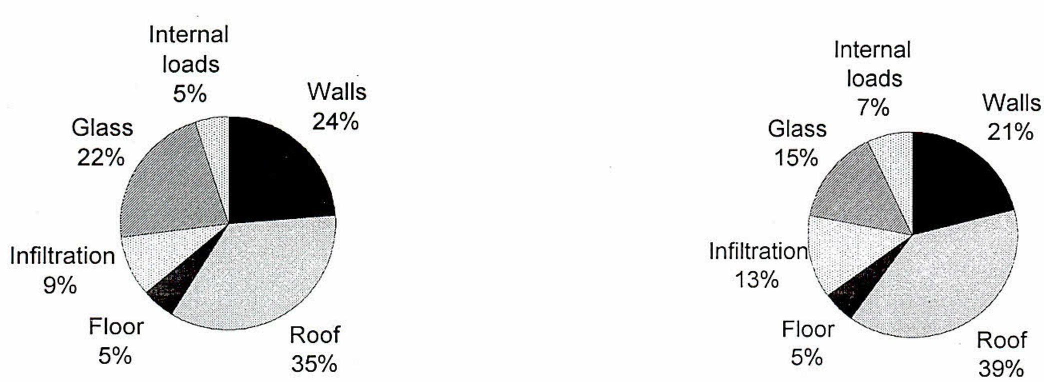
Climatic condition: The study deals with the Gulf region, with its characteristic sever maritime desert climatic condition, and typically represented by Dammam weather file of hourly values for a full year.

Operational use: Mosque occupancy, lighting and A/C operation are directly determined by the fixed 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 and two hours duration for Friday prayer. Occupancy is estimated based on partial mosque capacity for regular prayers and full capacity for Friday prayer.

Parametric Studies

Preliminary simulation analyses of the energy performance of typified mosque designs explain the relative contributions by different components of cooling load, and provide insight about the effectiveness of their determining factors. The most effective components of cooling load include wall and roof conduction and glazing gains (Fig. 2). The cooling load directly relates to A/C system capacity and electrical energy consumption.

The construction and architectural geometrical variables of envelope, evidently, influence the components of cooling load and electrical energy performance. [6,7] The study, thus, focuses on the geometrical and construction aspects of mosque design in an attempt to reveal the impact of their determining parameters and energy saving potentials for the facilitation of optimized mosque design.



Type H **Type O**

Fig. 2: Annual cooling load components of typified mosque designs.

Two sets of parametric simulation studies are conducted with reference to geometrical and constructional parameters.

Geometrical simulation studies; are initially based on typified standard construction specifications for mosques, as given in (Table 1).

Construction simulation studies; are similarly conducted based on the standard geometrical designs for the two typified mosques, as given in (Table 1).

Geometrical Variables

The main geometrical variables addressed by the study include floor area, plan proportion, height and glazing area. The practical ranges and limits of the parametric studies are inferred from the geometrical characteristics of the two typified mosque designs, and systematically varied at regular increments. These include:

Floor area: This is taken as a primary geometrical variable of mosque. The limits for the range of area variability considered by the parametric studies are practically set to vary from 400 m^2 to 1200 m^2, and at 200m^2 increments.

Plan Proportion: This defines plan shape variability and is represented by the index "P", which expresses the ratio of length to width. It is taken to vary from P=1, representing square shape, to P=3 representing a rectangular plan, at an increment ratio of P=0.5. Plan elongation is performed along the Qibla facade in accordance with expressed preference.

Height Variability: This is adjusted by three main height variations of 4, 5 and 6 m.

Glazing area: It is expressed as a ratio of glazing area to floor area, and taken to range from 6%, 8% to 10%. Glazing areas are proportionally allocated to facades, in accordance with length of facade and plan proportion.

Construction Variables

The parametric studies considers a range of construction materials for the main envelope components, in accordance with local construction practice:

Wall Construction:

- Exterior finish, lime stone brick / marble
- Clay block,
- Light weight concrete block,
- Lime stone block, and
- 5cm polystyrene insulation with standard wall block construction.

Roof Construction:

- Hordi, with concrete block,
- Hordi, with clay block,

- 5cm polystyrene insulation with standard roof construction, and
- Roof shading by double roofing.

Glazing Type:

- Bronze single glazing,
- Bronze reflective single glazing, and
- Bronze double-glazing.

Result Analyses

Energy performance of mosques is evaluated for the two sets of geometrical and constructional parametric combinations, in terms of electrical consumption index. Analyses of index variations highlight the impact of the different variables considered and gauge their energy saving potentials. Computed values for electrical energy performance index obtained from simulated studies, for the different geometrical configurations, vary markedly from the estimated value obtained from survey analysis. This can be attributed to the geometrical design, but mainly due to variable A/C operations, which is being considered for further future detailed studies.

The Effect of Geometrical Parameters

The parametric geometrical studies are conducted for the standard construction specification. Each parameter is taken at a time varied over its selected range, and for a set of parametric combinations. A reference geometrical combination assumes a 4m high and 8% glazing ratio.

Effect of floor area variability

The variation of floor area evidently affects the overall energy performance of mosques. However, electrical energy index shows inverse variation with floor area. This can be explained as due to corresponding inverse variation of facade to floor area ratio with area variation and the subsequent relative reduction of wall contribution to cooling load.

Electrical performance index shows an average variation rate of 0.6% per 10% of floor area variation, for a reference height of 4 m. Thus, doubling the floor area can cause up to 6% reduction of index performance. This rate remains consistent for plan proportion and glazing area variations, but marginally influenced by height variation. (Fig. 3) illustrates the effects of area variation on the electrical energy index.

Effect of plan proportion

The effect of plan proportion on electrical energy performance of mosques is generally marginal. It is shown to increase slightly with plan elongation, by an average rate of about 1.3% per unit increase of P (Fig. 3). Area and height variations cause negligible effects on this rate. This limited effect due to plan proportion can be explained as mainly due to the elongated westerly and easterly facades.

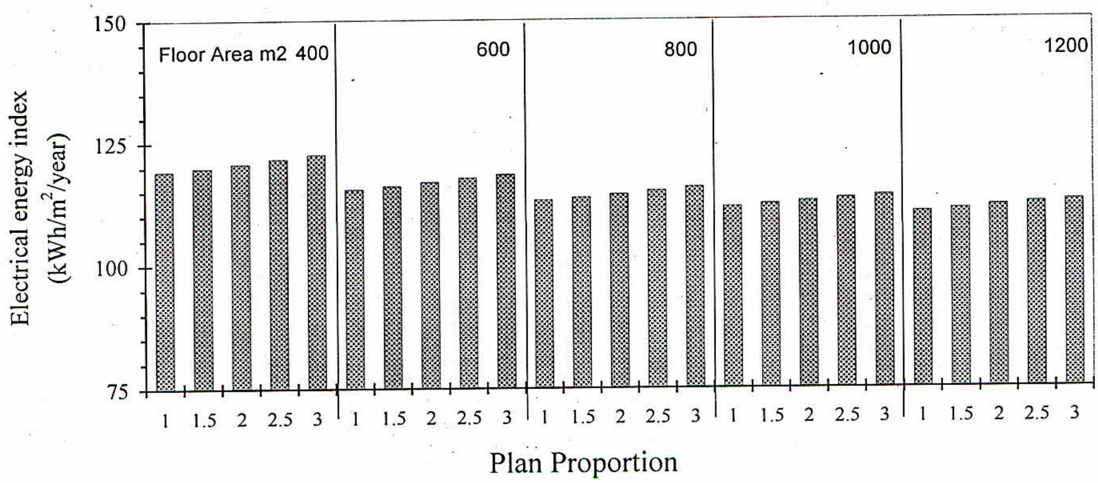


Fig. 3: The effect of floor area and plan proportion variations on electrical energy consumption index, for 4m height and 8% glazing ratio.

The index is shown to vary directly with height by an average rate of 6.5% per unit meter height, above the 4 m reference height. This rate of index performance variation with height is marginally influenced by area and plan proportion, where it varies directly with plan proportion and inversely with area variation. (Fig. 4) illustrates the effect of building height on the electrical energy consumption index.

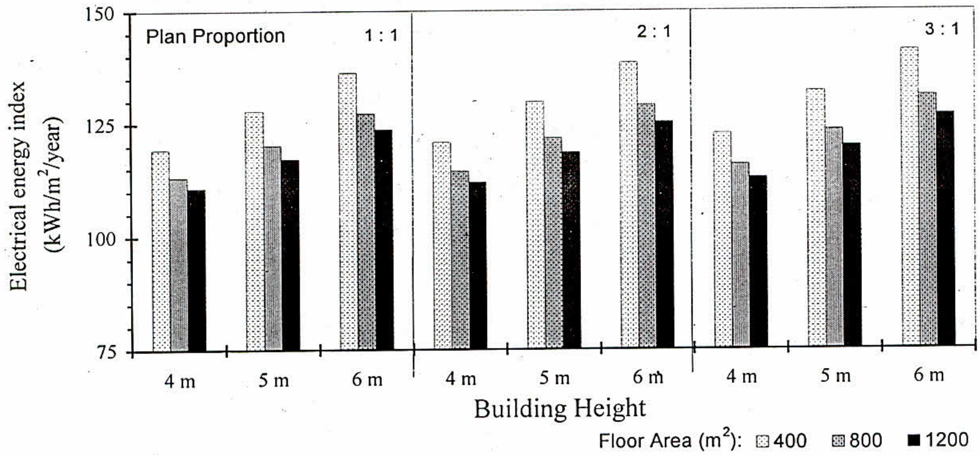


Fig. 4: The effect of building height variation on the electrical energy consumption index, for different floor area and plan proportion and 8 % glazing ratio.

Effect of glazing area

Electrical energy consumption is shown to vary directly with glazing area. An average rate of electrical index variation with glazing is established at about 1.5% per 1% of glazing area ratio. This is equivalent to about 1% of performance variation per 10% of glazing area variation. This rate of index variation is generally consistent for different floor area and plan proportion variations, as illustrated in (Fig. 5).

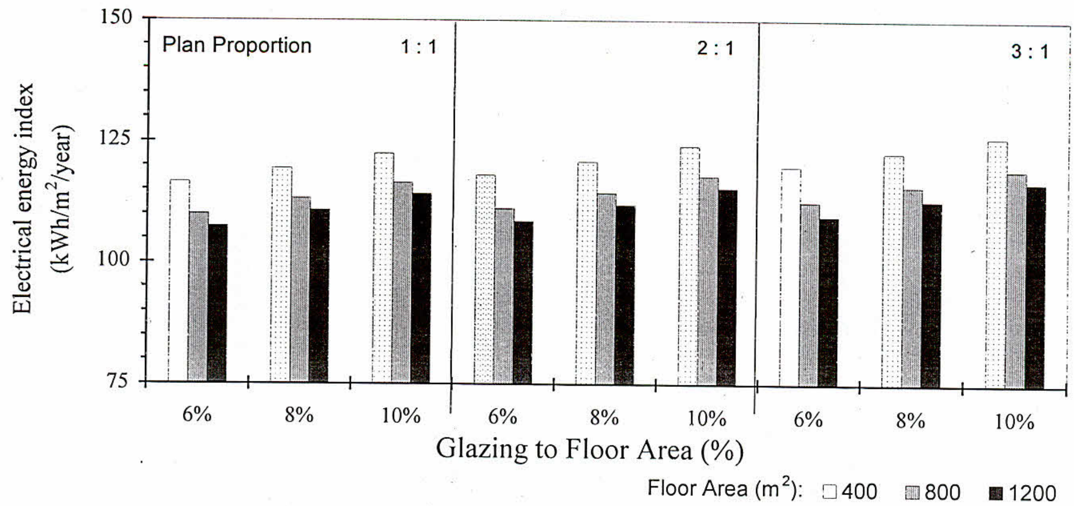


Fig. 5: The effect of glazing area variation on the electrical energy consumption index, for different floor area and plan proportion and 4m height.

Effect of Construction Parameters

Parametric studies for the effects of different construction applications on electrical energy consumption are conducted with reference to the standard geometrical designs of the two typified mosques, for a range of common construction materials of main envelope components. The impact of different construction applications are comparatively assessed with regard to corresponding performance of the standard construction of typified mosques, as specified in (Table 1).

The effect of wall construction

The effects of different wall constructions indicate consistent performance variations for the two types of mosque designs. Wall construction, evidently, provides advantageous potentials for performance improvements, as wall contribution to cooling load is relatively high.

Exterior wall finish materials generally show marginal performance improvement benefits of less than 2%. Common block wall filling materials indicate comparable reductions of electrical energy consumption ranging up to 4%, as compared to standard wall construction of heavy weight concrete block, to indicate no particular preference. The use of perlite concrete block offers moderate performance improvement, ranging up to 7%. However, the application of wall insulation offers the most advantageous performance reduction of up to 10%. (Fig. 6) illustrates the effects of different wall construction materials on electrical energy index.

The effect of roof construction

The effects of different roof constructions indicate consistent performance variations for the two types of mosque designs (Fig. 7). Alternative Hordi roof slabs with clay and concrete block provided performance improvement ranging up to 10%, as compared to standard concrete slab construction. However, the performance of Hordi clay block is slightly better, compared to concrete block.

Application of roof insulation provides substantial performance improvement, reducing the electrical energy consumption index by up to 19%. On the other hand, provision of roof shading by double roofing reduces electrical energy consumption index by up to 8%. The high effectiveness of different roof materials can be explained by the relatively high roof contribution to cooling load.

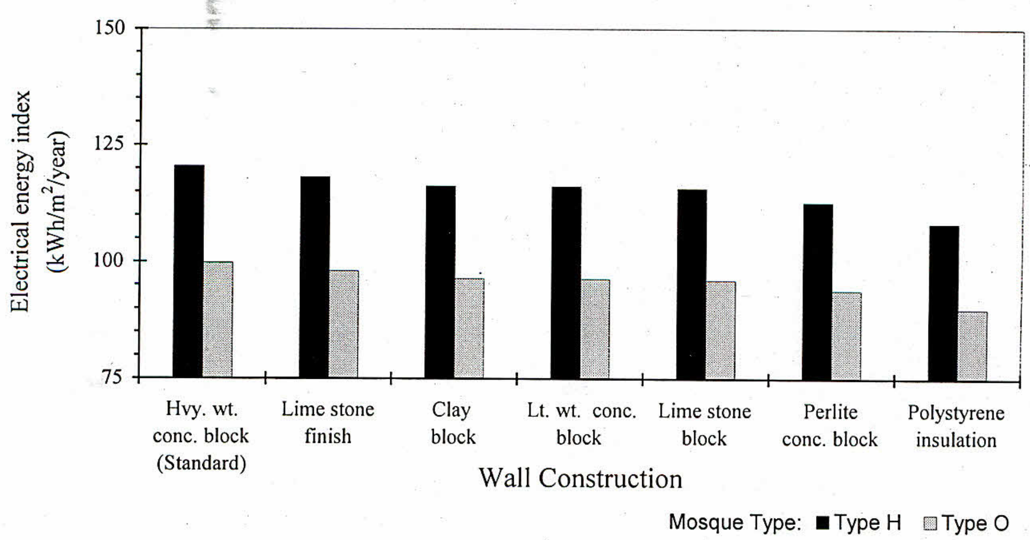


Fig. 6: Variation of electrical energy consumption index for different wall constructions.

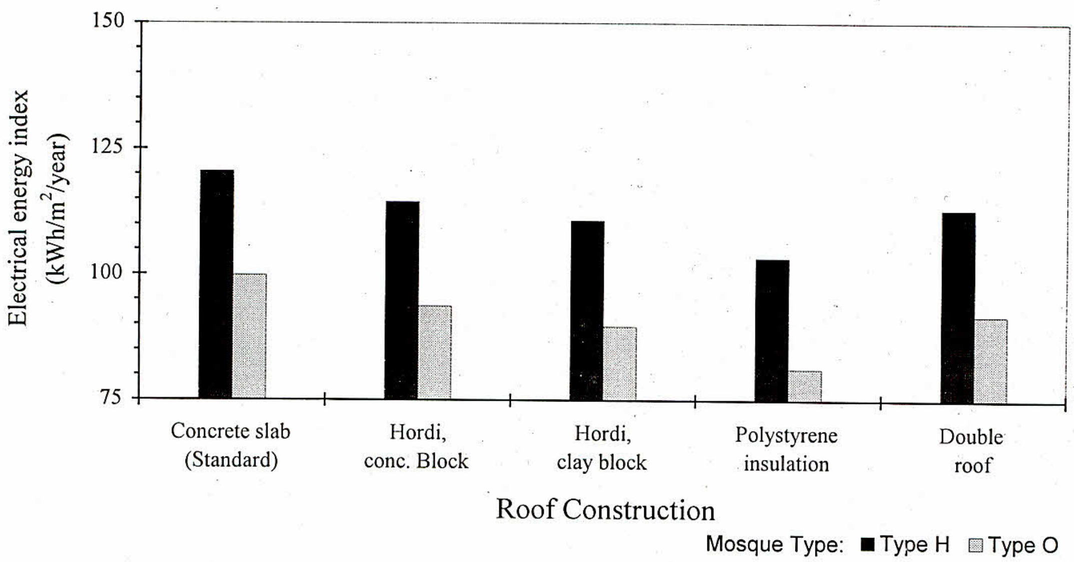
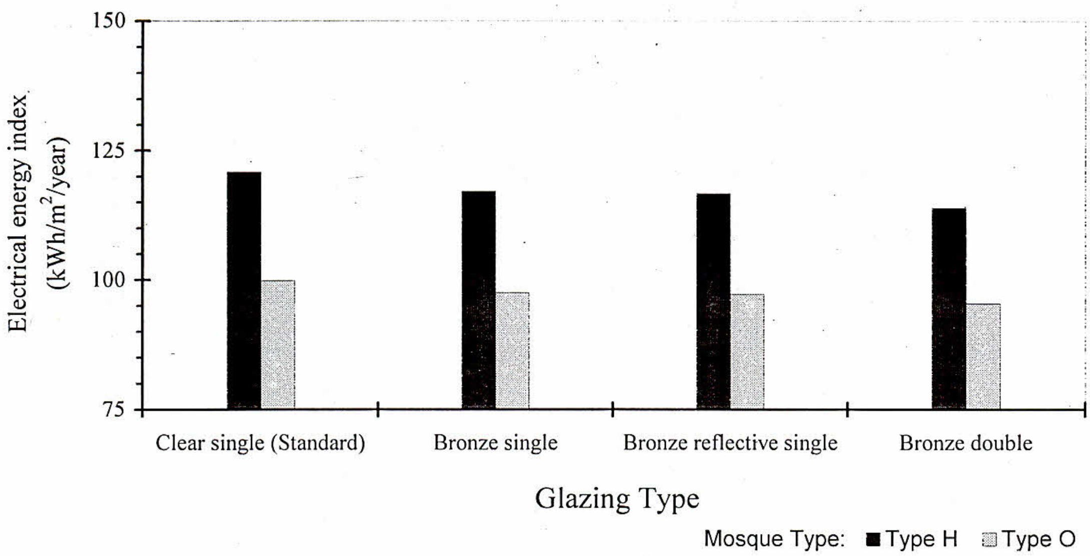


Fig. 7: Variation of electrical energy consumption index for different wall constructions.

The effect of glazing design

In addition to glazing area variability, the glazing design is alternatively assessed with consideration of different glazing types. Energy performance due to single glazing is generally consistent and marginal, irrespective of glazing type, providing only limited improvement of up to 3% with reflective glass, as compared to standard glazing design.

Double glazing, on the other hand, causes advantageous energy performance improvement. This arises from corresponding reduction of glazing heat gain. The overall reduction of electrical energy consumption comes to about 6%, as compared to standard clear single glazing application. These rates of variations are consistent for the two typified mosque designs as illustrated in (Fig. 8).



CONCLUSIONS

Comparative evaluations of the impact of main geometrical and constructional parameters on the energy performance of mosques reveal their effectiveness. Geometrical parameters are evidently as effective as construction parameters. The combined effectiveness of parameters can be advantageously exploited to provide significant performance improvement for energy efficient design of mosques.

Plan elongation is generally the least effective of the geometrical parameters in influencing mosque energy performance. Thus, the preference for elongating the Qibla façade and rows of prayer can be pursued without excessive energy penalties, even though the Qibla facade is of westerly orientation in the Gulf Region. Other main geometrical parameters of floor area, height and glazing area generally show comparable effects with performance variation rates for the electrical energy index ranging up to 6 %.

Most of wall block filling construction materials indicate comparable but limited performance improvement of up to 4 %, indicating no particular preference. However, greater advantages can be achieved with the use of wall insulation, which provides performance improvements of up to 10 %. On the other hand, single glazing materials are generally of marginal effectiveness, while double glazing can provide performance improvement of up to 6 %.

REFERENCES

[1] SCECO East. *Data provided by Department of Distribution*. 1998.

[2] Aba Al-Khil, I.A., ed. "The Mosque." *Al-Benna*, No.1, Feb-March, 1979.

[3] El-Bashir, A. and Al-Gunaimi, A. "Evaluation of Acoustical Performance of Mosques – A Case Study of a Typical Mosque in the Gulf Region." *The Fourth Saudi Engineering Conference.* Jeddah: King Abdulaziz University, Nov. 1995, pp. 169-176.

[4] Ismail, S., and Steel, J., ed. *Architecture of Contemporary Mosque.* Academy Group Ltd., 1996.

[5] Saeed, S. A. "Natural Light for Friday Mosque at Ad-deriya: Riyadh, Kingdom of Saudi Arabia." J. *King Saud University: Architecture and Planning*, Vol. 9, 1997, pp. 113-128.

[6] Shaviv, E, and Capeluto, I. G. "The Relative Importance of Various Geometrical Design Parameters in a Hot, Humid Climate." *ASHRAE Trans.*, Vol. 98, Pt.1, 1992, pp. 589-604.

[7] Numan, M.Y., and Al-Maziad, F.A. "The Use of PC-DOE for the Assessments of Energy Performance of Alternative Building Systems and Design Strategies Dealing with Envelope Constructions for Housing Application in Saudi Arabia." *J. of King Abdulaziz University, special issue of the 1st Saudi Symposium on Energy and its Utilization in S.A.,* 1993, pp. 346-354.

[8] The Ministry of Islamic Affairs, Endowment, Da'wa and Guidance, information provided by the Technical Department - Eastern Province.

تأثير محددات التصميم المعماري على أداء الطاقة في المساجد في الخليج العربي: دراسة لحالة مدينة الدمام

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ملخص البحث: تمثل الدراسة الخصائص الرئيسة لتصميم المسجد كقاعدة للتصنيف التفصيل للمعلومات والمحددات الخاصة بدراسة أداء الطاقة في المساجد بواسطة تمثيل المعلومات بالحاسوب. وقد أخذ في الاعتبار التشكيل الهندسي ومواد البناء الشائعة الاستخدام في عناصر الغلاف الخارجي كمحددات للدراسة. كما أعدت قائمة مبسطة لمقارنة تقدير استهلاك الكهرباء وقد بحثت هذه المحددات لمعرفة تأثيرها على توفير الطاقة. وأظهرت الدراسة المقارنة أن محدد التشكيل الهندسي كان له تأثير إيجابي بمقدار ٦٪. وإنشاء السطح فتأثيره الإيجابي كان بنسبة ١٠٪ وبعد استخدام المواد العازلة للحرارة في الجدران والسطح ارتفعت كفاءة الأداء بنسبة ١٠٪ و ٢٠٪ على التوالي.