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Thermal Comfort Assessment to Building Envelope: A Case Study for New Mosque Design in Baghdad

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ABSTRACT

The work is carried out with an objective of first, evaluating: the thermal characteristics of opaque and transparent parts of the building envelope in hot dry climate of case study "new mosque" building in Baghdad, the impact of sol-air temperatures, heat gain factors and the u-value of envelope section components. Second, it aims to assess the architectural criteria for appropriate passive design of new mosques in hot dry climates. Architectural design and construction of the new mosque (*musalla)* envelope in Baghdad are thermally inefficient in protecting the indoor space from climatic fluctuations. Therefore, the existing new mosques are not within thermal comfort level. To achieve and maintain that, applying architectural and construction alternatives on the mosque envelope contributes to controlling heat exchange through it as well as enhancing its thermal behaviors that contribute to getting internal thermal balance. The research covers survey of design, construction features, comfort levels in new mosques, and definition of the "model mosque", as well as identification and thermal assessment of the typical "model mosque". Computer simulations for building thermal behavior and design modification of building construction components also covered by the research. The findings and conclusion of the impact of simulation changes stated as well as recommendations for possible future mosque and design strategy. The findings show that HVAC systems entail capital, functional and maintenance costs whereas the passive mosque (*musallas*) building consumes less energy as well as being more likely to be in sympathy with the environment.

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1. Introduction

Architectural design is influenced by the actual thermal behavior of building components, and this depends not only on their steady and periodic thermal characteristics but also on exposure effects, orientation, surface features and the climate parameters of the location.

The main issue of this research is “the thermal comfort for internal space of the modern mosque in Baghdad”. The mechanical and electrical systems of heating and cooling encourage architects to implement new construction techniques and using wide openings in buildings' facades as well as employing new constructional materials, which are not suit local hot climate. All this makes people depends on HVAC systems, which consume high amounts of energy annually in an attempt to provide a comfortable indoor environment. The mosque buildings are affected by the adoption of new materials and new urban planning as well as new architectural designs, which are not sensitive to the environment, the actual needs of occupants, and the building function or comfort criteria. (Tappuni, 1973).

The new city of Baghdad nowadays includes individual multi-storey buildings. Wide streets and open spaces expose those buildings more to solar radiation and other types of climatic impact more than the other traditional buildings, which are surrounded by narrow alleyways. It can be concluded that for buildings in a hot-dry climate, minimizing the external heat gain through the building envelope would be a good strategy to reduce the dependence on energy in conditions of necessity. That can be achieved by means of appropriate design for the building envelope.

The research is carried out with the objectives of evaluating thermal characteristics of the new mosque “*musalla*” envelope in Baghdad, the impact of sol-air temperatures, heat gain factors and the U-value of envelope section in aims to assess the generational architectural criteria for appropriate passive design of mosques.

The research discusses the thermal comfort in the new “*musalla*” in Baghdad, which is effected by heat exchange that influenced by its orientation, envelope design, structural and constructional components as well as the specifications and use of materials in order to:

i. Investigate the impact of envelope components on the heat exchange and thermal comfort of the users of inner environment of the new mosque *(musalla)*.
ii. Investigate the thermal efficiency of the present new mosque envelope in Baghdad.

iii. Study how to minimize the "environmental impact" by revising the design and materials of the envelope.

iv. Identify the optimum thermal design "passive design" and construction materials specifications and details for the new mosque envelope.

v. Propose other suitable treatments, which affect thermal design for the mosque that provides thermal comfort for the occupants and reduces energy consumption at the same time.

vi. Optimize comfort level for occupants for five prayer times.

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2. Background of the Research

2.1 Baghdad Climate

Generally, the climate of Iraq is characterized by a large diurnal air temperature range coupled with a high intensity of incident solar radiation as shown in Figure 1 On the other hand, in such widely fluctuating climates, building envelope has great potential in providing thermal comfort and reducing energy consumption. An efficient thermal design of a building envelope should consider three main parameters which are; First the form and orientation of the building, Second; the fenestration, which relate to the size, orientation and exposure of the windows to the sun and the type of glazing and Third; the thermal properties of the opaque elements. This includes the solar absorptance of the external surfaces and the thermal capacity and conductance of the elements as well.

Climatic information, including air temperature and solar intensity in the Baghdad region, as well as thermal air rates, humidity and other parameters were obtained from the Iraq Forecast Directory-Baghdad. It has been arranged with the Building Research Center in Baghdad to get the outputs of some tests carried out by the center's instruments, which help in furnishing this research with some important information.

2.2 Problem Statement

Due to the defined daily uses of mosques, the problem facing architects and engineers is how to achieve thermal comfort during prayer times when the mosque building is occupied. The short time of each of the five daily prayers (almost 30 minutes per prayer) gives rise to

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serious problems in terms of providing comfort. It is noticed that it is not enough to reach comfort level even though an HVAC system is used and just operates before each prayer time. It would be too costly also to operate it for a long period before prayer times to provide comfort for very short periods of prayer.

One of the important characteristics of the mosque design is the orientation of Mecca (*Qibla* direction), which considered as a constant design parameter for the mosque.

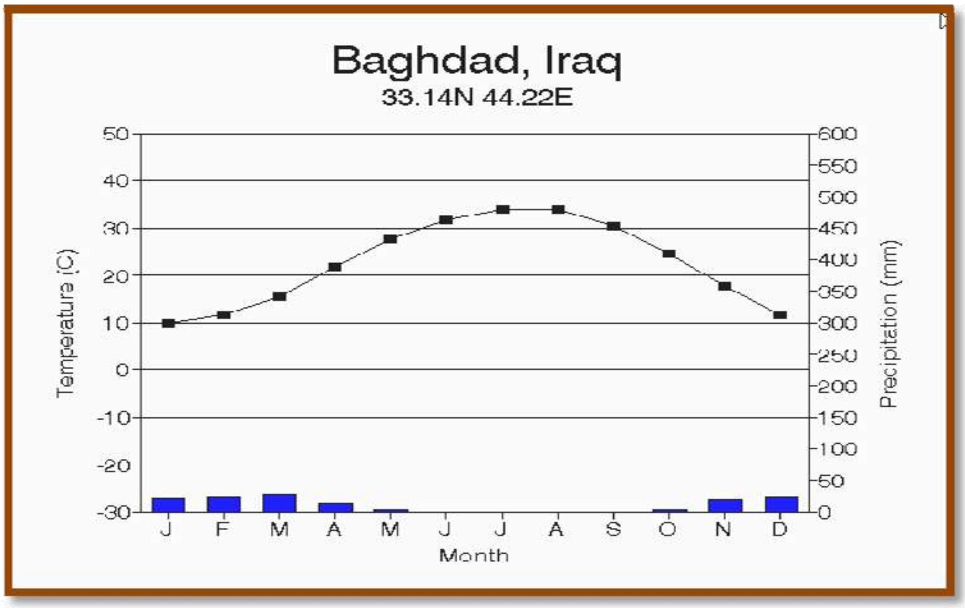

Figure 1: Annual Temperature in Baghdad, Source: Baghdad Metrological Dept.2000.

The thermal properties of the envelope are determined by the combination of wall mass, thermal resistance; insulation location, external surface colour and texture, and the size and location of glazing. All of those affect energy consumption differently according to weather conditions. The design of the building envelope can also greatly affect infiltration rates.

Based on the previous highlighted design features and specific climate parameters, the problems of the new mosque in Baghdad may be summarized as following:

i. Lack of optimum passive design guidelines for the mosque's envelope which influence the comfort level of the inner environment and contribute for energy conservation.

ii. Ignoring comfort level requirements for occupants which influenced by construction materials and details used in buildings as well as the suitable architectural treatments in the new mosques building design in Baghdad.

3. Research Method

The research has considered the following steps:

i. Achieving specific survey to ascertain whether it is true or not that the new mosque building in Baghdad is not comfortable thermally for occupants.

ii. Defining the weaknesses in the design and construction components of the mosque through the following strategy:

a. Collecting data from 50 new mosques in Baghdad that represent 65% of the new mosques in the Baghdad vicinity in July 2008.

b. Identification of the typical new mosque, "Model Mosque", in Baghdad.

ii. Applying an analytic study and assessment for architectural and construction components relating to heat exchange through the envelope of the "Model Mosque" in Baghdad, which is determined according to the common architectural and constructional elements in fifty new mosques in Baghdad, using heat balance equation.

iv. Assessment for the "Model Mosque" using a computer simulation program (BLAST program) before and after introducing changes to the total transparent area of its envelope and the construction features.

The BLAST (Building Loads Analysis and System Thermodynamics) system is a set of computer programs for predicting heating and cooling energy consumption in building.

One of the BLAST processors, Heat Balance Loads Calculator (HBLC), is used to interactively create BLAST input files with a minimum of input required from the user.

4. Definition of "Model Mosque"

A survey to define the "Model mosque "*musalla*" and determine the architectural and constructional features of the new mosque envelope as well as thermal comfort response for the praying people in those fifty new mosques is the main aim before starting thermal assessment.

The conclusion of the survey output gave the architectural characteristics and other constructional details of the typical new mosque in the Baghdad vicinity the "Model *Musalla*", which is considered as representative the typical design of new mosques for use in the computer simulations.

The typical "*musalla*" or "praying area hall" within mosque "complex" that has other facilities", has the same specifications as all the modern types in Baghdad. It was found that

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these specifications are the following:

i. The *musalla* has a detached rectangular form with inside net-dimensions in general 22mx11mx6m in height. It includes a central dome at the roof, the diameter of which is 7.0m and the height of which from the base to the top of the cone is 6.5m. This rectangular shape has one attached arcade laid at the same longitudinal wall, which is parallel to that which faces the "*qibla*" or Mecca (the holy city in Saudi Arabia) see Figure 3.

ii. The main feature of the *musalla* mass is the dome which lies in the center of the roof. The dome has three levels from bottom to top. The first part is the drum (dome base). Its height is 2.00m. Above it there is a spherical part and the upper part is the cone.

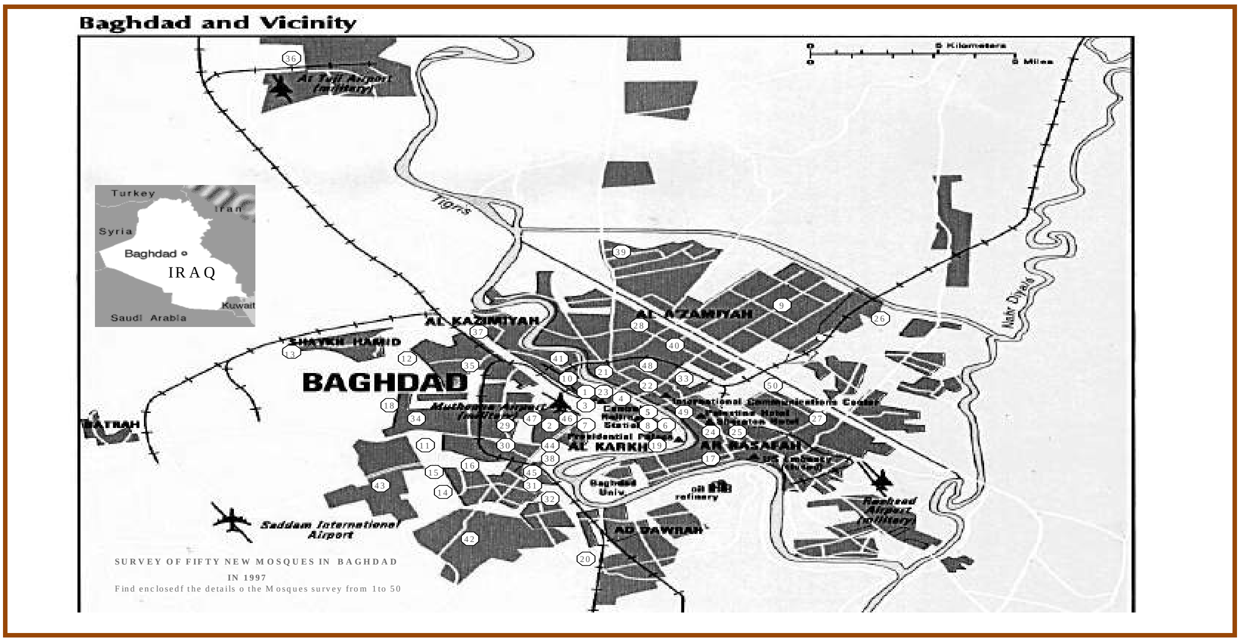

Figure 2: Location of fifty surveyed new mosques in Baghdad.

All these components are usually found in the typical Baghdadi mosque's dome. Four columns support the dome from inside praying hall; the average thickness of its concrete slab is 0.15m and includes eight small arcade windows normally situated on the drum part of the dome.

iii. The *musalla* is usually constructed from a reinforced concrete skeleton structure with brick wall partitions. The roofing slab thickness is 0.15m, and the brick wall is 0.24m thick. Above the concrete slab of the roof there are many layers which consist of the waterproof layer (0.07m), natural clean sand (0.15m) and rough sand (0.05m) and cement tiles (0.03m). The dimensions of each cement tile are 0.80mx0.80m. The interior finishing of the dome and the walls is fine gypsum, and its thickness is 0.025m.

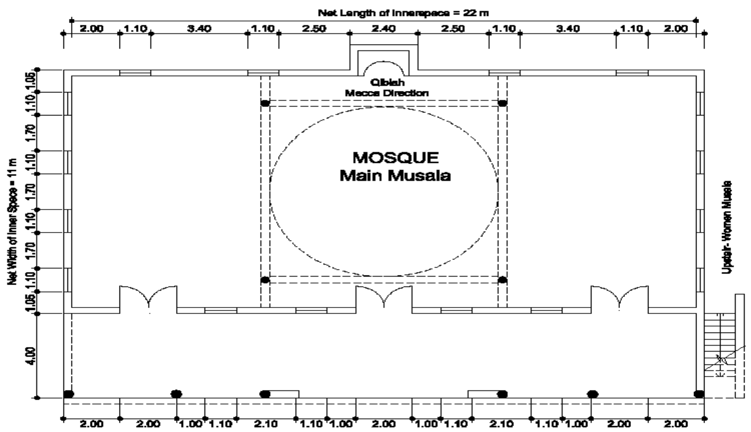

Figure 2a: Plan for the Model Mosque *"Musalla"*.

5. Research Considerations

Fundamental research considerations for the "Model Mosque" features are:

1. *musalla* envelope is one piece.
2. The collected data did not refer to the existence of any space beneath the *musalla.*
3. The *musalla* envelope consists of just external Walls, Roof and Floor.
4. Sub-parameters, windows, and doors "Transparent Part" are represented as part of the envelope.
5. Air vents, as uncontrolled openings do not exist.
6. The *minaret* "the tower" still has no role in the thermal behavior of the new *musalla* envelope.
7. Average number of praying persons per prayer time for the five daily prayers is 30, becoming sometimes 45 at peak time at sunset prayer "*maghrib* prayer".
8. Air cubage is represented by the human comfort zone that is within 8 feet in height and the remaining volume of the internal space of the *musalla.*
9. It is proposed that the inner environment of the "Model *musalla"* is in thermal balance to estimate the actual ability of the *musalla* envelope to maintain that balance. The present research discussed, by means of geometrical analytical study, all parts of the *musalla* envelope to highlight the role of each, area of opaque and transparent parts, and

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study for the dome parts as well as defining the air cubage.

10. Heat exchange estimate by heat flow mean per sq.m through walls, windows and roof as well as heat flow mean by ventilation per m^3 owing to the successful results from thermal computer simulations and approach, which have been considered.

The new mosque type in Baghdad is representative of the mosques built after World War II and shares the following characteristics:

1. Located in the Baghdad vicinity.
2. Used usually on five short occasions daily.
3. Its building is passive designed.

6. Results

6.1 Computer Simulation

The "Model *musalla*" building as shown in Figure 3 has been simulated for the four different roof and five different walls structures. To make the simulations comparable, the size of one huge space or praying hall (*musalla*) and its direction to Mecca at 10 degree southwest has been treated as a constant.

6.2 Simulation Alternatives Applications

6.2.1 Walls Simulation Analysis

a. The computer simulation proved that the massive envelope behaves as a "Thermos Flask". So, there is no an actual enhancement for thermal comfort level of the inner environment after increasing wall thickness more than 36cm or even using cavity walls with the same specifications of the "Model *Musalla*" envelope, Figures 4, 5, and 7.

b. It appears that the *musalla* building is dialectically balanced with the outside climate for a wall thickness of 36 cm because as the wall thickness decreases below 36cm its effectiveness in damping outside temperature fluctuations also decreases. On the other hand, for wall thickness more than 36cm, the heat received during the long summer day cannot be released during the shorter nighttime according to expected long "Time Lag", which causes bad envelope behaviors in terms of "Thermos Flask" manner. In this case, there is overlapping heat gain occurrence which a raises the inner air temperature.

c. The inner environment of the *musalla's* building is balanced with the outside climate when the wall thickness is 36cm, but it is influenced more by climatic fluctuations when there is a thin envelope of 12cm thickness.

6.2.2 Roof Simulation Analysis

The computer simulation also indicates, that the traditional RC (Reinforced Concrete) flat roof still perform the best thermally, and has positive heat exchange after the applying of additional insulation material (15cm)**,** Figures 6, 8 and 9.

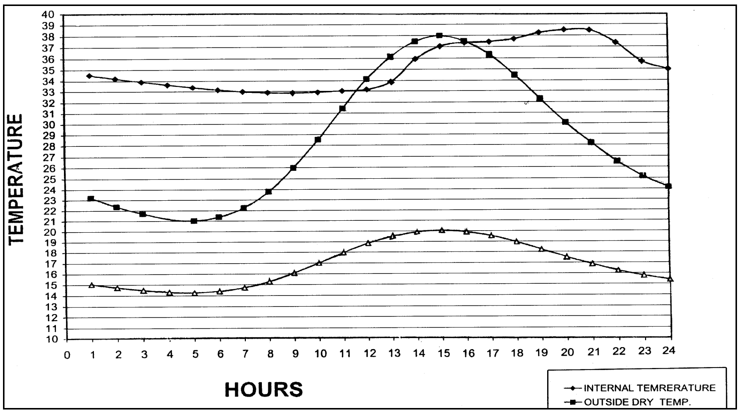

Figure 3 This graph shows that the radiation peak time in Baghdad starts at 10.30 am and increases gradually to reach a maximum at 3.00 pm, and reduces gradually after that to reach starting point at 7.00pm. However, the inner temperature increases from 1.00 pm gradually till 10.00 pm, that indicates the important role of the envelope in delaying the heat gain from reaching the inner space, or what is called –Time lag period–which depends on the envelope section in terms of the specifications of material and constructional details. The lowest curve indicating the comfort level ranges

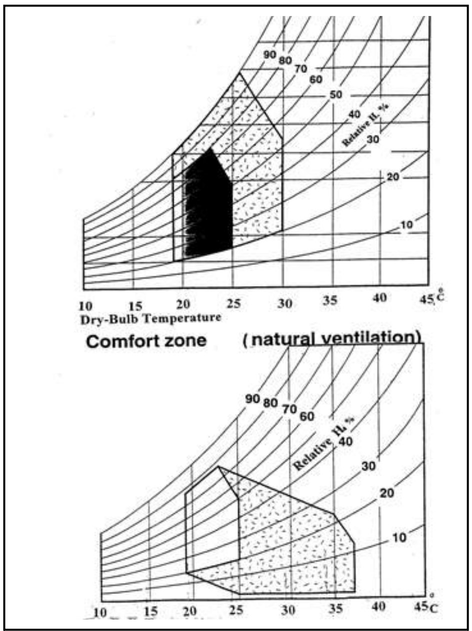

Figure 4 Range of Comfort Level in Iraq

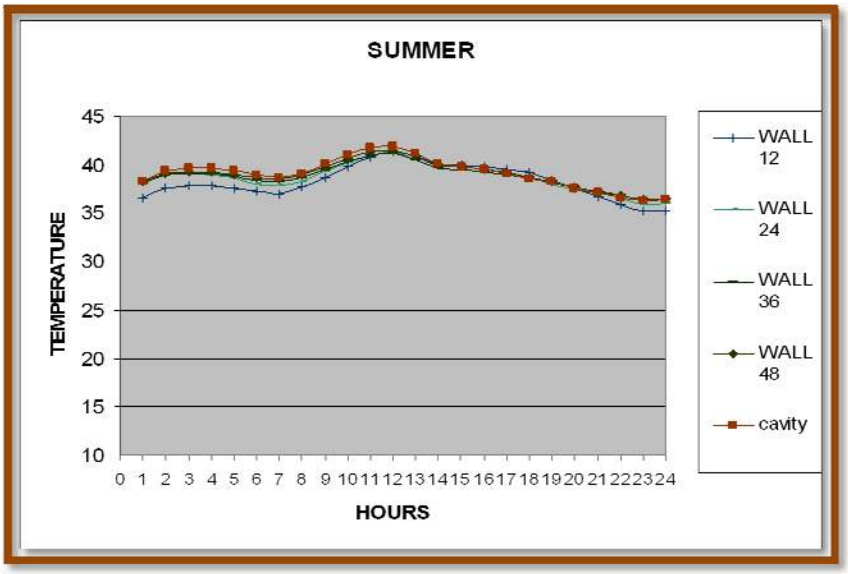

Figure 4a: Building envelope behavior before applying simulation.

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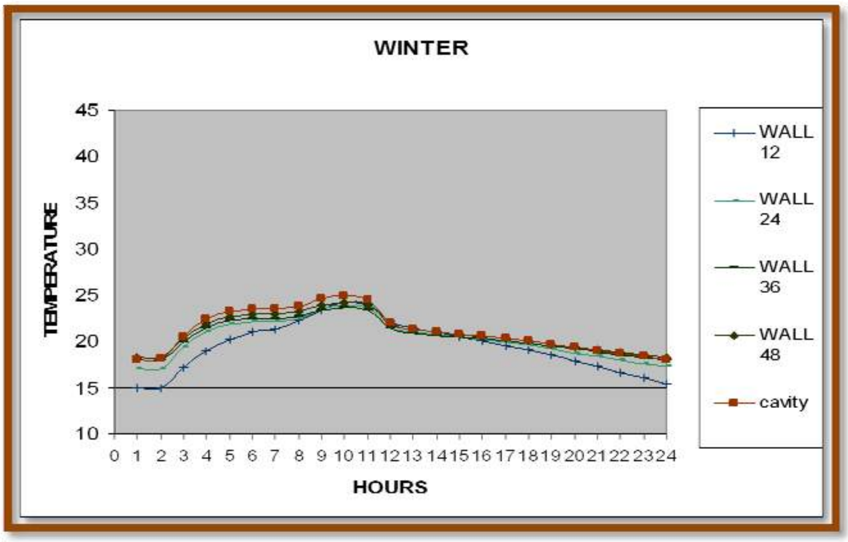

Figure 4b: Building envelope behavior before applying simulation.

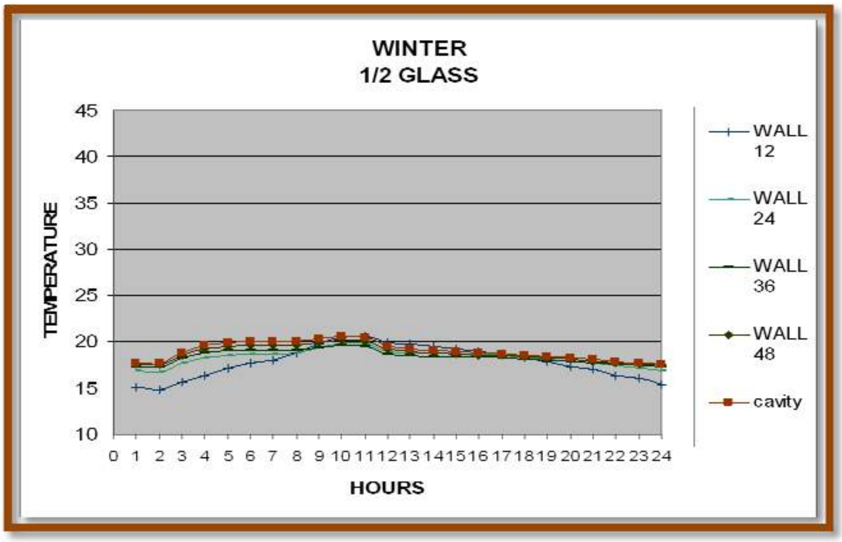

Figure 5: Building envelope behavior after reducing glazing area to half.

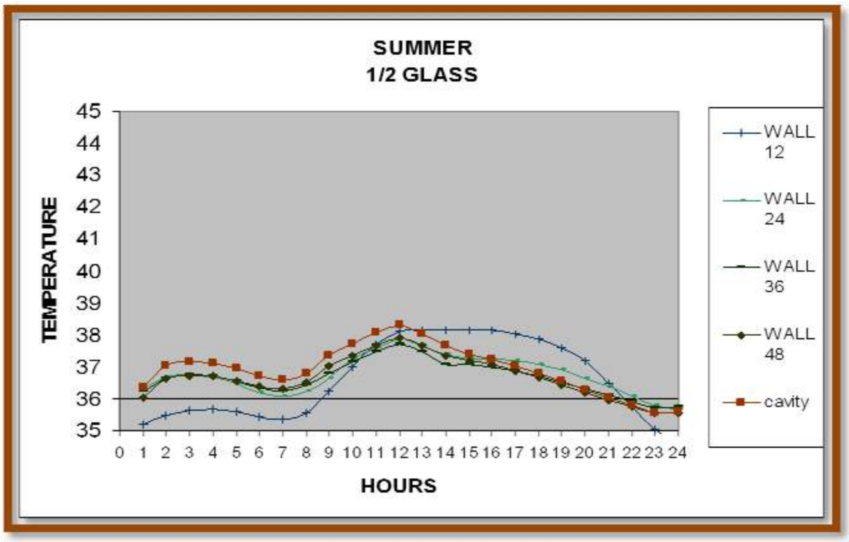

Figure 6: Building envelope behavior after reducing glazing area to half.

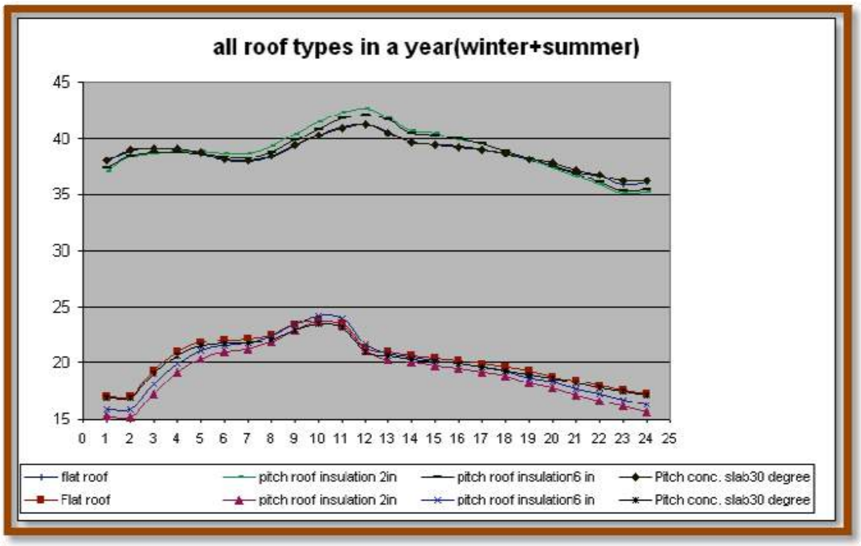

Figure 7: Building envelope behavior using different types of roof.

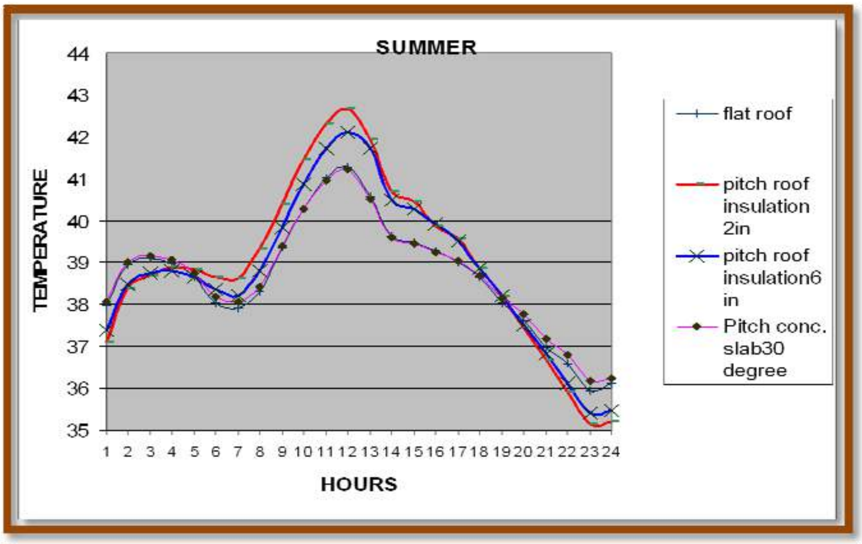

Figure 8: Building envelope behavior using different types of roof.

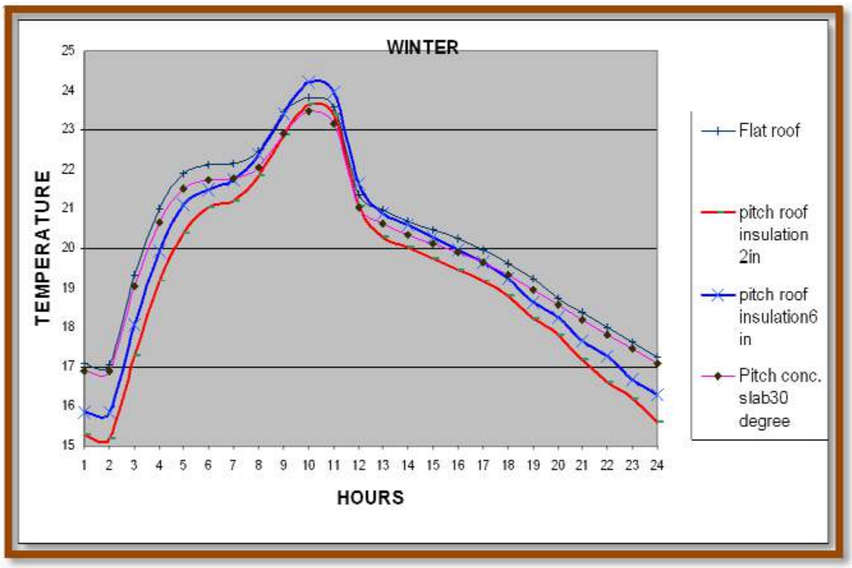

Figure 9: Building envelope behavior using different types of roof.

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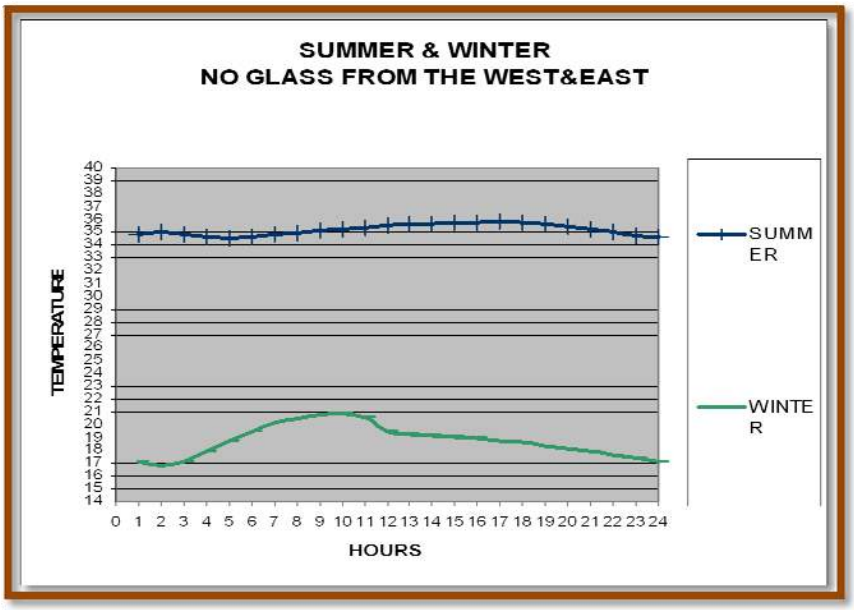

Figure 10 Building envelope behavior using no glass area at west& east

7. Discussion

Achieving and maintaining thermal comfort level for the indoor environment of the mosque “*musalla*” by applying architectural and construction alternatives on the *musalla* envelope will contribute controlling heat exchange through it as well as enhancing the thermal behaviors of its construction components.

The findings are showing that HVAC systems mean capital, functional and maintenance costs for passive *musalla* building consumes less energy. It is more likely to be in sympathy with the environment also.

The specific research findings are concluded as follows:

1. Architectural Design of the present new mosque “*musalla*” envelope in Baghdad is thermally inefficient according to the previous analytical assessment and computer simulation.

2. Materials used in the construction of the envelope of the new *musalla* are not thermally efficient in protecting the indoor environment from climatic fluctuations.

3. Then, the indoor environment of the present new *musalla* is not recently within thermal comfort level.

4. It appears that the indoor environment of the *musalla* building is thermally balanced with the local climate for a wall thickness of 36cm; highly insulated typical RC flat roof, avoid the transparent area at west and east as well as reducing it at South-west orientation to be half of transparent area of the “model *musalla*”.

5. It is found also that the indoor environment of the *musalla’s* building is influenced more

by climatic fluctuations when there is a thin envelope (less than 30cm thickness), and the envelope's behaves as a “Thermos Flask” when there is a massive envelope (more than 36cm thickness).

6. During the past ten years it has not been economically feasible to invest in HVAC plant for mosques to meet the running costs. It is not likely that this economic situation in Iraq will change in the near future and undoubtedly many mosques will have to be built with these economic constraints. So, this study has not considered the totally dependence on centralized HVAC systems as part of any strategy to achieve thermal comfort.

7. Achieving as well as maintaining thermal comfort for the indoor environment of the present new *musalla* should come from controlling heat gain and enhancing external microclimate. *The following factors should be taken into consideration as recommendations and techniques to be applied:*

i. Selecting materials and construction system on the basis of low thermal transmittance (low U-value) and high thermal mass in addition to the implementation of constructional treatments and alternatives to get a desired time lag within 8 to 14 hours for walls, and 20 to 30 hours for the roof. Using well-insulated roofing materials to provide high time lag, low thermal transmittance and high thermal capacity (like local *fershi* brick 30cmx30cmx5cm) and 0.36m walls thickness to replace 0.24m walls, or foaming Portland cement mixture with a foaming agent such as aluminum dust to make insulated light concrete roof slab could be also more effective in controlling heat flow.

ii. Using the most common economical thermal insulation materials in Baghdad, that is, polystyrene (11 cm) thick for the roof; (7 cm) thick for south-facing walls;(8 cm) for southeast walls; and (10 cm) for other orientations. Insulation material should be located near the external layer of the walls, which should be smooth and painted externally in light colors.

iii. Designing well-shaded walls and windows, selecting suitable window insulating Low-e-glass and size for each orientation, these areas should be minimal on the east and west elevations.

v. Raising the roof enables cooling by ventilation; the best U-value for the whole roof and ceiling construction should be 0.8 W/sq.mc.

v. Using double roof, double walls skin and the early development ideas on "Filter" Architecture" to get high thermal protection will give an additional protection for indoor environment.

vi. Designing the *musalla* to be in thermal contact with the earth, the idea of (sub ground

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level–basement) enables benefits from the cooled humid space more than is possible at ground level.

vii. Additional ventilation is required in summer using fans. This can be beneficial, particularly at nighttime, and daytime in shaded spaces. Further research is needed on the optimal mix of natural ventilation, the simple mechanical fan, and water nozzle fan.

viii. Employment of an L-shape or U-shape *Riwaq* (semi-covered arcade area) attached to the *musalla* envelope gives it more shade, and enhances the microclimate. In addition, an increase in the numbers of domes is thermally desirable for more benefits from buoyancy phenomena occurrences that generate more passive ventilation through the dome and envelope openings.

ix. Employing of *minarets* as external breeze catchers (Air Scoop). The inlet openings of *minarets* should face the prevailing pleasant northwest wind in Baghdad to promote airflow into the *musalla*, using the convective and evaporative cooling techniques for elevating internal comfort level in such harsh summer in Baghdad.

x. Microclimate planning controls can have a major effect over the *musalla* design. In addition to providing shade, plants can assist cooling by evaportranspiration. Plants also enhance the visual environment and create pleasant filtered light.

xi. The study will be transferable for other parts of Iraq with certain limitations. For example, in the southern part of Iraq increase in temperature could be consummated either by introduction of some cooling or an increase in the thermal mass. In the north, which is generally cool, this may be consummated of some heating or an increase in insulation and a reduction in glazed area.

8. Conclusion

The existing *musalla* is effectively a passive building. Based on that, there is no consideration for HVAC systems. The *musalla* building will be dialectically balanced with the outside climate for a wall thickness 36 cm because as the wall thickness decrees below 36cm its effectiveness in damping outside temperature fluctuations also decreases.

For wall thickness more than 36cm, the heat received during the long summer day can not be released during the shorter nighttime that brings overlapping heat gain occurrence which raises the indoor air temperature. The computer simulation also indicates, that the traditional RC (Reinforced Concrete) flat roof still the best thermally in terms of cost, available labor skill in Baghdad, and positive heat exchange as well that will be more suitable after applying of additional insulation material (15 cm).

Passive Mosque *(Musalla)* building design must take into account the following;

i. Indoor Thermal comfort requirements.

ii. Limitations of local construction, climate, available materials and labor skills.

iii. Specific nature of activity.

v. Capability of building envelope for protecting the indoor environment of the *musalla* from climatic fluctuations.

vi. Consideration of high thermal mass envelope, insulation and other criteria that influence heat exchange and Time-Lag.

vii. Microclimate impacts as well the pattern of the surrounding urban fabric, vegetation and landscape.

viii. Construction capability that play direct role in heat flow.

ix. How all the previous criteria affect the economic factor that represents a major parameter in taking design decisions?

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