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Thermal comfort in air-conditioned mosques in the dry desert climate

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ABSTRACT

In Kuwait, as in most countries with a typical dry desert climate, the summer season is long with a mean daily maximum temperature of 45 °C. Centralized air-conditioning, which is generally deployed from the beginning of April to the end of October, can have tremendous impact on the amount of electrical energy utilized to mechanically control the internal environment in mosque buildings. The indoor air temperature settings for all types of air-conditioned buildings and mosque buildings in particular, are often calculated based on the analytical model of ASHRAE 55-2004 and ISO 7730. However, a field study was conducted in six air-conditioned mosque buildings during the summers of 2007 to investigate indoor climate and prayers thermal comfort in state of Kuwait. The paper presents statistical data about the indoor environmental conditions in Kuwait mosque buildings, together with an analysis of prayer thermal comfort sensations for a total of 140 subjects providing 140 sets of physical measurements and subjective questionnaires were used to collect data. Results show that the neutral temperature (T_n) of the prayers is found to be 26.1 °C, while that for PMV is 23.3 °C. Discrepancy of these values is in fact about 2.8 °C higher than those predicted by PMV model. Therefore, thermal comfort temperature in Kuwait cannot directly correlate with ISO 7730 and ASHRAE 55-2004 standards. Findings from this study should be considered when designing air conditioning for mosque buildings. This knowledge can contribute towards the development of future energy-related design codes for Kuwait.

1. Introduction

Buildings are constructed in most cases to protect the occupants from the extreme outdoor environmental conditions (i.e. extreme temperatures, humidity, radiation, rain, wind, etc.), thus, providing comfortable indoor environment conditions. Such environment condition can vary considerably from the values adopted by national energy codes, which in turn can impact upon space energy consumption in buildings with air-conditioning systems, such as Kuwaiti mosque buildings. Kuwait, as in most Arabian Gulf states[1] with a dry-desert climate, has a long summer season with a mean daily maximum temperature of 45 °C [4].

Centralized air-conditioning, which is generally deployed from the beginning of April to the end of October [5]. This can have tremendous impact on the amount of electrical energy utilized to mechanically control the internal environment in mosque buildings. However, increasing the thermostat temperature setting in the summer season can potentially save significant electrical energy, which would, in turn, decrease energy expenditure, fossil fuel usage for generating electricity and consequently carbon dioxide emissions.

The indoor air temperature (or thermostat temperature) settings for all types of air-conditioned buildings and mosque buildings in particular, are often calculated based on the analytical model developed by Fanger [6]. This model, where comfort sensation is predicted via the Predicted Mean Vote (PMV), has been adopted by the ISO 7730 [1], as the standard approach for thermal comfort evaluation. The Predicted Mean Vote (PMV) value is a function of a set of environmental conditions that include: air temperature, mean radiant temperature, relative humidity, air velocity, and the personal variables of clothing insulation, and rate of production of metabolic heat.

In dry desert climate, Occupants thermal sensation of domestics and offices can adjust their clothing and their activity substantially in response to any level of thermal stress in their environment. While that for prayers in the mosque buildings are, to a certain extent, limited. This because congregation inside mosques are often of diverse age, clothing, activity, regions, ethnics, colour, etc, which therefore may have an adverse impact on prayers indoor thermal sensation. However, According to ANSI/ASHRAE-55 [2] and ISO 7730 [1], thermal comfort is as "That condition of mind which expresses satisfaction with the thermal environment". An understanding of indoor thermal comfort is required to assist building designers in providing an environment that is acceptable to users and that does not impair the health and performance of the prayers in the mosque buildings.

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[1] Arabian Gulf States are: Kuwait, Bahrain, Saudi Arabia, Qatar and Oman.

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Investigation of indoor thermal comfort in mosque buildings for countries located in dry desert climates is limited, although a study can be mentioned. Saeed [7] conducted research in the dry desert region in Riyadh, Saudi Arabia and measured thermal comfort in one mosque at Friday prayers during the hot season. The results indicate a fairly good agreement with Fanger's model in both studies, whilst subjects attending Friday prayer would prefer a cooler climate than the one recorded in his survey. In Saeed [7], clothing insulation (clo values) in both studies was estimated with disregard to the assessment methods of ISO 9920 [8] (i.e. estimation of clothing properties). In the study reported here, however, field experiments were conducted in six air-conditioned mosque buildings using survey questionnaires and physical measurements to collect data during the summers of 2007. This study also takes into account the clothing insulation values that were calculated by Al-ajmi et al. [9].

The main objective of this paper is to investigate the indoor climate and thermal conditions in air-conditioned mosque buildings situated in the dry desert climate of Kuwait. This will provide information that can assist future policy aimed at enhancing energy conservation and reducing carbon emissions.

2. Context

2.1. The outdoor condition

Kuwait is typical of a dry desert climate with the highest air temperature being recorded in July and August with an afternoon average maximum of 45 °C. Summer starts at the beginning of April and continues until the end of October, with a mean air temperature of 37 °C [4]. In addition, the air is generally dry with an average relative humidity ranging from 14 to 42% in the summer and 42–80% in the winter. In winter, the weather is comfortably cool, generally mild, with a monthly mean temperature of 10 °C, and a minimum temperature recorded as being occasionally below 5 °C. Precipitation is low and dust storms are common [4]. Kuwait is located between latitude 29° 13′ North and longitude 47° 58′ East at an elevation above mean sea level (m s l) of 45 m Fig. 1 gives the hourly values of dry and wet bulb temperatures for the summer harshest period, from the beginning of June to the end of September in the State of Kuwait.

2.2. Description of selected mosque buildings

Most of the mosque buildings, or may be as in common Arabic word called "Masjid" (i.e. house of prayer in Islam), have centralized air conditioning. Mosque buildings are constructed from thermally heavy weight construction; with exterior walls of Autoclaved Aerated concrete blocks (AAC block) or what is locally called "Azel" Block [5]. The mosque buildings in general consist of al large space of hall prayer area with a high ceiling. The prayer hall of selected mosque buildings has what is called "mihrab" as a common feature. Mihrab is a niche in the front wall of a mosque or Masjid that indicates the qibla, (i.e. the direction of the Kaaba in Makkah). The wall in which a mihrab appears is thus the "qibla wall". Minbar, which is the pulpit from which an Imam (leader of prayer) addresses the congregation. Minbar is usually located on the right side, adjacent to Mihrab, see Fig. 2 (a,b). The mean area of selected mosques is about 655 m^2 with mean payer hall area dimensions of about 28.5 $\times$ 23m^2 with mean height of 8.5m. Space area and height of prayer hall for selected mosque buildings are shown in Table 1. Number of entrance (outdoors) of the surveyed mosque buildings are in the range of 3–4 doors. Surveyed mosques or Masjids have a large size dome resides at the center of top ceiling of the prayer hall and a tall Minaret which, usually situated at one of the corners of the mosque structure. The top of the minaret is always the highest point in mosques that have one, and often the highest point in the immediate area, see Fig. 2(c).

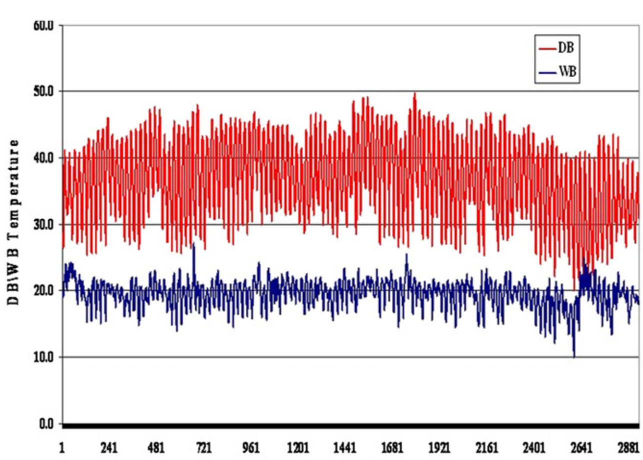

Fig. 1. Hourly dry and wet bulb temperature for period between beginning of June to the end of September in state of Kuwait.

2.3. Buildings surveyed

Six mosque buildings were selected to be surveyed in Kuwait. Buildings were selected evenly over the six provinces of Kuwait (i.e. Capital, Hawalli, Aljahra, Alahamidi, Alfarwaniya and Mobarak-Alkabeir). The sizes of the selected mosque buildings are from one floor with a mean plot area of 655 m^2. Whilst it was impossible to cover all mosque buildings types in Kuwait in this study, those buildings selected were considered from the perspective of the following specific criteria:

- Centralized air-conditioning with similar cooling size.
- Typical type, size and construction materials.
- Selected mosques are not older than 10 years and distributed evenly amongst the six provinces of Kuwait.

In this way, a reasonable sample of mosque types from the Kuwaiti building stock is covered by this investigation.

3. Field survey

The thermal environment and comfort survey was carried out in six mosque buildings across the six provinces of Kuwait. A total of 140 subjects providing 140 sets of physical measurements, and questionnaires were used to collect subjective data. The subjects consisted of 100% males. The age of the prayers ranged from 12 to 65 years, with a mean age of 32.6 years. Their mean height was bout 162.cm and their mean weight was 70.8 kg, see Table 2. The field-works were carried out in state of Kuwait during the summer season of year 2007 using the following survey procedure.

3.1. Subjective measurements

The subjective study involved collecting data using questionnaires which were given to each subject to complete simultaneously with collection of the physical measurements in each mosque building. The subjective questionnaires and a description of the experimental work procedure had been translated carefully into the Arabic language in order that the prayers could follow and understand. The questionnaire addressed the following areas: (i) background and personal information; (ii) current clothing garments; (iii) subjective thermal sensation vote (the Actual Mean