Energy and Buildings 41 (2009) 607–614

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Assessment of monitored energy use and thermal comfort conditions in mosques in hot-humid climates

Mohammad S. Al-Homoud *, Adel A. Abdou, Ismail M. Budaiwi

Architectural Engineering Department, KFUPM, Dhahran 31261, Saudi Arabia

ARTICLE INFO

Article history:
Received 9 November 2008
Accepted 12 December 2008

Keywords:
Thermal comfort
Energy use
Mosques
Intermittent operation
Hot-humid climate
Saudi Arabia

ABSTRACT

In harsh climatic regions, buildings require air-conditioning in order to provide an acceptable level of thermal comfort. In many situations buildings are over cooled or the HVAC system is kept running for a much longer time than needed. In some other situations thermal comfort is not achieved due to improper operation practices coupled with poor maintenance and even lack it, and consequently inefficient air-conditioning systems. Mosques represent one type of building that is characterized by their unique intermittent operating schedule determined by prayer times, which vary continuously according to the local solar time. This paper presents the results of a study designed to monitor energy use and thermal comfort conditions of a number of mosques in a hot-humid climate so that both energy efficiency and the quality of thermal comfort conditions especially during occupancy periods in such intermittently operated buildings can be assessed accurately.

1. Introduction

Mosques represent a place of great importance and unique function and operation as worshipers using the mosque need to feel comfortable and calm, and be able to leave with a feeling of tranquility and peace. Consequently, they need to be carefully evaluated in terms of thermal comfort and energy requirements. However, only a limited number of studies have dealt with these requirements of mosques. A study on thermal comfort requirements for *Friday* prayer during the hot season in *Riyadh* [1] indicated that most people are comfortable and few prefer cooler conditions.

Thermal comfort considerations are usually paramount in most buildings involving people occupancy. This requires the addition or extraction of heat from the space depending mainly on the season and type of activities performed indoors. The thermal environment parameters involved are all those affecting body heat gains and losses. Air temperature, air humidity, air velocity, mean radiant temperature as well as human clothing and activity levels are factors that determine the heat balance of a human body in a given thermal environment. Several models are available in the literature to relate the human sensation of comfort to those factors. Prediction of thermal comfort has been of substantial interest to ASHRAE which developed the original comfort index based on effective temperature which is still in use [2]. Later, a new effective temperature was defined at 50% relative humidity, which describes the uniform temperature of a radiantly black enclosure at 50% relative humidity in which the occupant would experience the same comfort, physiological strain and heat exchange as in the actual environment with the same air motion [2].

A more elaborate prediction of thermal comfort at steady state conditions has been carried out by Fanger [3]. Considering the variability of thermal sensation under the same conditions, Fanger devised a means of estimating a predicted mean vote (PMV) of the subjects in a space in which there are deviations from optimal in the thermal sensation. Using the PMV, the percentage of people dissatisfied (PPD) can be predicted.

The impact of air movement and the effect of its flow patterns on thermal comfort have been the subject of many theoretical and experimental studies [4–7]. Results from those studies have emphasized the role of air velocity and air distribution patterns as a determinant factor of thermal comfort. Furthermore, models for predicting comfort at different flow regimes and air distribution patterns have been suggested. Charles [8] reviewed and assessed the validity of Fanger's Predicted Mean Vote (PMV) Model, and Fanger's Draught Model. The review also suggested that the bias in PMV predictions varies by context. The model was a better predictor in air-conditioned buildings than naturally ventilated ones, in part because of the influence of outdoor temperature, and opportunities for adaptation. Ji et al. [9] examined the thermal comfort of people in naturally ventilated environments in a field study in Shanghai, China. The study suggested that people residing

* Corresponding author. Tel.: +966 3 8603200; fax: +966 3 8603292.
E-mail addresses: alhomoud@kfupm.edu.sa (M.S. Al-Homoud), adel@kfupm.edu.sa (A.A. Abdou), ibudaiwi@kfupm.edu.sa (I.M. Budaiwi).

0378-7788/$ – see front matter © 2009 Published by Elsevier B.V.
doi:10.1016/j.enbuild.2008.12.005

in such hot area have adapted to its climate and their expectations for comfort allow them to endure heat better than expected.

de Dear and Brager [10] summarized earlier adaptive comfort research, presented some of its findings for naturally ventilated buildings, and discussed the process of getting the adaptive comfort incorporated into Standard 55. Adaptive models include in some way the variations in outdoor climate for determining thermal preferences indoors. Cheng and Ng [11] discussed in a recent study the adaptive model in thermal comfort, which has been included in the new revision of ASHRAE Standard 55-2004. Furthermore, it demonstrated the development of a comfort temperature chart for naturally ventilated buildings in Hong Kong. Van Hoof and Hensen Jan [12] discussed two implementations of the adaptive comfort model in terms of usability and energy use for moderate maritime climate zones by means of literature study, a case study comprising temperature measurements, and building performance simulation. The study concluded that for moderate climate zones the adaptive model is only applicable during summer months, and can reduce energy for naturally conditioned buildings.

The subject of thermal comfort in buildings is intimately related to the energy consumption/conservation issue as most of the time either heating or cooling is needed to maintain the space at a comfortable level. Many studies have been carried out to investigate this relationship and explore means and ways to conserve energy without compromising comfort [13,14]. A multidisciplinary approach for achieving energy saving and thermal comfort simultaneously was developed [15].

The impact of various energy conservation measures and HVAC system and component characteristics on building thermal performance including thermal comfort have been investigated. Results have indicated that adaptation of a higher temperature set point in summer can lead to a significant reduction in cooling energy without loss of thermal comfort [13]. The energy consumption by building heating, ventilating, and air-conditioning (HVAC) systems has evoked increasing attention to promote energy efficient control and operation of HVAC systems [16,17].

Many other measures related to the design and operation of the HVAC system can be considered for conserving energy. However, in no circumstances should the comfort of occupants be compromised. In hot and cold climates, thermal comfort in building is achieved by HVAC systems, resulting in considerable energy costs. In many situations, buildings are over cooled or the HVAC system is kept running for a much longer time than needed. This will allow considerable opportunities to conserve energy while achieving better comfort conditions or at least maintaining the desired comfort conditions at a reduced level of energy consumption. Recently, Budaiwi [18] proposed and implemented a multi-phase approach to investigate and remedy thermal comfort problems in buildings.

Although mosques are important buildings with a unique function and intermittent operation, evaluation of their thermal performance, problems and, subsequently, possible remedies did not receive adequate attention by researchers. This paper presents the results of a study monitoring energy use and indoor environmental conditions in a number of mosques in order to assess the quality of their thermal comfort conditions especially during occupancy periods in such intermittently operated buildings in hot-humid climates. This study is part of a comprehensive research conducted on mosque thermal performance [19].

In this part of the study, energy use and thermal indoor conditions for three mosques were monitored over a period of one year. These mosques were selected to represent the common types of a single-zone daily prayers mosque, a single-zone Friday (large) mosque, and a two-zone Friday mosque. The criteria of representative mosques selection as well as their physical and operational characteristics have been presented in previous work [20,21].

2. Common characteristics of mosques

Before presenting the energy use and thermal indoor conditions in the investigated mosques, it is essential to briefly describe the basic elements of typical mosque design as well as the activity modes occurring in a mosque.

2.1. Basic design elements of a typical mosque

The mosque is commonly a simple rectangular, walled enclosure with a roofed prayer hall. The long side of the rectangle is oriented toward the direction of the holy mosque in *Makkah* city. This wall is usually described as the *qibla* wall. The wall contains a recess in its center in the form of a wall niche called the *mihrab*. This wall also includes the *minbar* which is commonly an elevated floor, to the right of the *mihrab*, from which the *Imam* preaches or delivers the *Friday* speech, i.e. the *khutba*. These basic elements are the essentials of mosque design. Fig. 1 illustrates the plan and isometric of a simple, typical mosque design in which the basic design elements are emphasized. Though the functions of the mosque have remained unchanged, its architectural form, space, construction system, and building materials have evolved and developed to a significant and variable extent in different parts of the Islamic world, influenced by many factors.

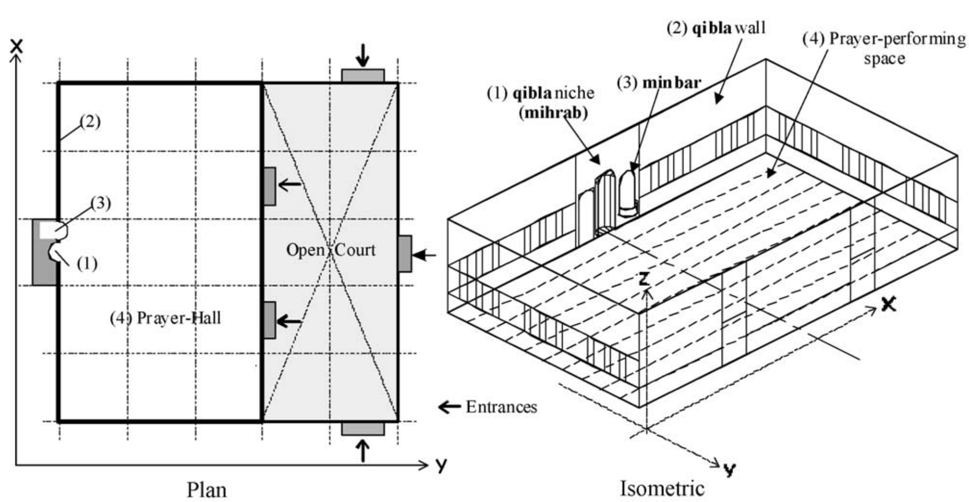

Fig. 1. The basic design elements of a simple mosque (a) plan, and (b) isometric [Reference: [22]].