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Indoor Environmental Quality in Air-conditioned Mosque Buildings in Kuwait

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Abstract In this study, the indoor environmental quality (IEQ) of air-conditioned mosque buildings in an extremely dry desert climate is examined from the perspective of the occupants via two aspects: thermal comfort and indoor air quality. The study presents statistical data about the worshiper thermal comfort together with data describing the indoor air quality in Kuwaiti mosque buildings. With respect to the latter, the overall IEQ acceptance using two measurements, namely, physical measurements and subjective information collected via questionnaires, was used to evaluate 140 worshipers visiting six air-conditioned mosque buildings in the state of Kuwait. The operative temperature based on actual mean vote (AMV) and predicted mean vote (PMV) was identified using a linear regression analysis of the responses on the ASHRAE seven-point thermal sensation scale and was found to be 26.1°C in the summer season .The indoor air quality (IAQ) with respect to the carbon dioxide concentration levels was compared with the acceptable limits of international standards, i.e., the ASHRAE Standard 62.1 [1]. The proposed overall IEQ acceptance findings in the mosque buildings show CO_2 concentrations between 730 and 1220 ppm. However, this is considered a slightly higher than the ideal CO_2 concentrations, which may require increasing ventilation rates by opening windows and, doors or by mechanical ventilation.

Keywords: *mosque buildings, Kuwait mosques indoor environments, prayer thermal comfort, dry desert climates*

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1. Introduction

In typical dry desert climates, the summer season is long, and the mean daily maximum temperature is 45°C. Air-conditioning in desert climate area is usually deployed from the beginning of April to the end of October, which may have tremendous impact on the amount of electrical energy utilized to mechanically control the internal environment in mosques buildings.

The work described here is the second stage of a project funded by the Kuwait Foundation for Advancement of Science (KFAS) that will include an investigation of the indoor environmental conditions of mosque buildings in Kuwait and an analysis of worshiper thermal comfort sensations. An earlier paper by Al-ajmi et al. [2] describes the first stage of the project, whereas the authors have investigated the indoor environment conditions and thermal comfort of air-conditioned domestic buildings. The main results of the previous work have provided information about the indoor domestic thermal environment in Kuwait, together with the occupant thermal comfort sensations.

People in different climates feel comfortable at different indoor air temperatures. These temperatures can differ considerably from the values adopted by national energy codes, which can impact the energy consumption in buildings with air conditioning systems, such as in Kuwaiti mosque buildings. Kuwait, like most Arabian Gulf states[1] with dry-desert climates, has a long summer season with a mean daily maximum temperature of 45°C [3]. Centralized air-conditioning is generally deployed from the beginning of April to the end of October [2]. This can have a tremendous impact on the amount of electrical energy utilized to mechanically control the indoor environments of mosque buildings. However, increasing the thermostat temperature setting in the summer can potentially save significant electrical energy, which would decrease the total energy expenditure, fossil fuel usage for generating electricity and 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 [4]. This model, where comfort sensation is predicted via the predicted mean vote (PMV), has been adopted by the ISO 7730 [4], 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 individual-related variables of clothing insulation and rate of production of metabolic heat.

In a dry desert climate,the thermal sensations of occupants domestic buildings and offices can adjust

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

their clothing and their activity substantially in response to any level of thermal stress in their environment. However, worshipers in the mosque buildings are, to a certain extent, limited because congregations inside mosques often differ in terms of age, clothing, activity, region, ethnicity, color, etc, which therefore may have an adverse impact on the indoor thermal sensation of the occupants. However, according to ANSI/ASHRAE-55 [5] and ISO-7730 [6], thermal comfort is described 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 worshiper in mosque buildings.

Investigation of the indoor thermal comfort in mosque buildings for countries located in dry desert climates is limited, although one such study can be mentioned. Saeed [7] conducted research in the dry desert region in Riyadh, Saudi Arabia, and measured the 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, except that the worshipers attending Friday prayer would prefer a cooler climate than the ones recorded in his survey. In later studies, the clothing insulations (clo values) in both studies were estimated with regard to the assessment methods of ISO 9920 [8] (i.e., estimation of clothing properties). In the study reported here, however, the field experiments were conducted in six air-conditioned mosque buildings using survey questionnaires and physical measurements to collect data during the summers of 2015 and 2016. This study also takes into account the clothing insulation values that were calculated by Al-ajmi et al. [9].

2. Description of the Selected Mosque Buildings

Most mosque buildings or, as they are commonly called in Arabic "Masjid" (i.e., house of prayer in Islam) have centralized air conditioning. Mosque buildings are constructed using thermally heavy weight construction materials with exterior walls of autoclaved aerated concrete blocks (AAC blocks) or what is locally called "Azel" Block [2]. The mosque buildings generally consist of a large space for the hall prayer area , which has a high ceiling. The prayer halls of selected mosque buildings have what is called a "mihrab" as a common feature. A mihrab is a niche in the front wall of the mosque or Masjid that indicates the qibla, (i.e., the direction of the Kaaba in Makkah). The wall in which the mihrab appears is thus the "qibla wall". The Minbar, is the pulpit from which an Imam (the leader of prayer) addresses the congregation.The minbar is usually located on the right side, adjacent to the Mihrab, see Figure 1 (a,b). The mean area of the selected mosques is approximately 750m^2 with mean payer hall area dimensions of approximately 28 * 23m^2 and mean height of 8.5 m. The areas and heights of the prayer halls for the selected mosque buildings are shown in Table 1. The number of entrances (leading outdoors) of each the surveyed mosque buildings are in the range of 3 to 4 doors. The surveyed mosques or Masjids have large domes residing at the center of the top ceiling of the prayer hall, and each mosque has a a tall minaret which is usually situated at one of the corners of the mosque structure. The top of the minaret is always the highest point of the mosques and is, often the highest point of the immediate area; see Figure 1(c).

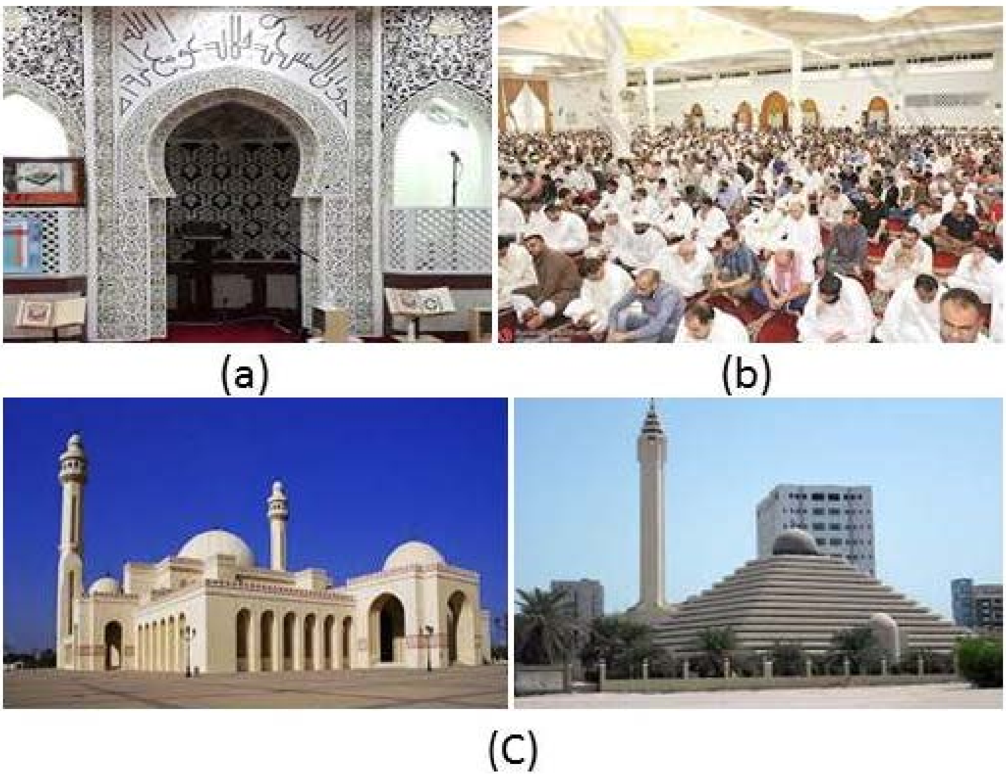

Figure 1. Internal and external features of the mosque are shown; (b) prayer hall space, high ceiling, (a) Mihrab, Minbar on the right side and adjacent to Mihrab (a,b),while the minaret, which is the highest point in the mosque and the dome are shown (c)

Table 1. Each mosque hall prayer area and height

Prayer hall no.	Area (m^2)	Height (m)	Volume (m^3)
1	21×19	9	3591
2	22×22	10	4840
3	50×25	9	11250
4	27×25	6	4050
5	25×20	8	4000
6	24×26	10	6240

3. Field Survey

Six mosque buildings were selected to be surveyed in Kuwait. The 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 start from one floor with a plot area of 750 m^2. While it was impossible to cover all the mosque building types in Kuwait in this study, those buildings selected were selected if they met the following specific criteria:

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

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

3.1. Thermal Environment

The thermal environment and comfort survey s were 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 were all male. The ages of the subjects ranged from 12 to 65 years, with a mean age of 32.6 years. The subjects' mean height was approximately 162.cm , and their mean weight was 70.8 kg ; see Table 2. The fieldwork was carried out in the state of Kuwait during the summer seasons of 2015 and 2016 using the following survey procedures.

3.2. Subjective Measurements

The subjective study involved collecting data using questionnaires which were given to each subject to complete simultaneously with the 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 Arabic so that the worshipers could follow and understand. The questionnaire addressed the following areas: (i) background and personal information; (ii) current clothing garments; the (iii) subjective thermal sensation vote (the actual mean vote, or AMV) based on the ASHRAE-seven -point scale , which consists of: (-3) cold, (-2) cool, (-1) slightly cool, (0) neutral, (+1) slightly warm, (+2) warm, and (+3) hot); (iv) the humidity sensation, scaled as: (-3) very humid, (-2) humid, (-1) slightly humid, (0) neither humid nor dry, (+1) slightly dry, (+2) dry, and (+3) very dry; and (v) the air movement, which was sensation scaled as (-3) very low, (-2) low, (-1) slightly low, (0) neither high nor low, (+1) slightly high, (+2) high, and (+3) very high. The subjects were required to make only one choice from the scale for each question.

3.3. Physical Measurements

In addition to the subjective data collection, physical measurements were carried out in the sex air-conditioned mosque buildings using a Bruel & Kjaer Indoor Climate Analyser Type 1212. The physical measurements included transducers to measure the dry bulb and wet bulb air temperatures, relative humidity, air velocity, and operative temperature. The transducers and data logging system were fitted into a trolley arrangement to collect indoor climatic data at a height of 0.6 m above the floor, as specified by ISO 7730 (2009) [4] for a seated person. This was performed while respondents completed the questionnaires. A period of fifteen minutes was taken prior to the measurements survey to explain and demonstrate the procedure of the field experiments to the subjects in each building. This allowed the subjects to achieve a steady state thermal balance with their surroundings. The data collection period lasted for 75 minutes in each mosque building. During this period, occupants (i.e., worshipers) were asked to sit in the prayer hall, and were limited to light activity, such as movements of the hands, feet, neck, etc. The metabolic rate value used in this study was estimated to be 1.3 met, as recommended by ISO 7730 [10] for near sedentary physical activity. Five sets of measurements were taken at 15-min intervals [11].

3.4. Clothing Descriptions

Worshiper outfits inside the mosques are similar to outdoor outfits in terms of their outwards looks, thicknesses and colors. This is because Muslims are commanded by Allah to attend the mosque while clean and wearing nice and attractive clothes. However, once a Muslim hears the voice of Adhan (i.e., the Islamic call to Prayer five time a day) he should leave all his work at once (while he is clean and wearing his nice and attractive clothes) to attend and perform his Salah in the mosques. People attending mosques in Kuwait wear different outfitsdepending on the locations of the mosques. Mostly, in the mosques that are near markets and mall areas, the worshipers wear outfits that are a mix of between western and Arabian Gulf fashions (or Kuwaiti clothing). The Western outfits of the worshipers are similar to those described in ISO 9920 [12]. Those that are Kuwaiti include dishdasha with headdresses, (i.e., Ghutra, Taqia and Eqal), while others wear dishdasha without headdresses. This outer garment is usually worn with underwear that consists of a T-shirt, underpants and a long or short Serwal. However, in mosques that are surrounded by Kuwaiti houses (community), worshipers usually wear typically tradition Kuwaiti male garments and ensembles. The overall average clothing insulation values used in this fieldwork study were estimated to be between 0.75 and

1.2 clo, with a mean value of 0.9 clo; see Table 2. Worshipers were allowed to worship in the mosques during Salah or prayer time. Salah is limited to precise body postures and light activity movements, such as standing, bowing, prostrating and sitting. The posture of Salah or prayer is an indication of a man's relation to his Creator a relation of reverent submission and gratitude. The metabolic rate value used for worshipers in this study were estimated to be 1.3 met. A checklist of Kuwaiti male garments , shown as photographs and descriptive schemes of ensembles , was provided to the worshipers at the time of completing the questionnaire survey. A full description of the male clothing ensembles and clothing insulation values were published in ASHRAE Transactions 2006 [7] and were coded in ISO 9920 [12]. The overall average clothing insulation values used in this study were estimated to be between 0.75 and 1.2 clo, with a mean value of 0.93 clo; see Table 2. worshipers in mosques are usually seated ion floor that is fitted with carpets; see Figure 1(a, b). Thus, the clo values of worshipers' conduction with floor fabrics taken into account were used in this study, which was achieved by adding a value of 0.15 clo to that of prayer clothing ensembles [2]. The final value obtained was then used in the PMV calculations.

4. Indoor Thermal Conditions

Table 2 provides a summary of the personal data from the 140 worshipers in the survey, including their clothing insulation values. The data are presented for the mean of the worshipers in each of the six Mosque occupants. The indoor climate measurements for the six mosque buildings are presented in Table 4. The indoor air temperature values ranged between 18.5 and 28.6°C, with a mean value of 23°C and a standard deviation of 0.53, However the recorded indoor relative humidities ranged from 33.76 to 56.29%, with a mean value of 44.19% and a standard deviation of 0.85. The average indoor air movements varied between 0.11 and 0.39 m/s, with a mean value of 0.23m/s and a standard deviation of 0.08, and the operative temperatures were in the range of 19.5-29.3°C, with a mean of 23.98°C and a standard deviation of 0.51. Table 3 also provides statistical summaries of the thermal environments and thermal indices of the worshipers, with actual mean votes (AMVs) ranging from -2.67 to +2.33 with a mean of -0.26 and a standard deviation of 0.73.

Further analysis was conducted to find the indoor neutral temperatures and thermal acceptability for the air-conditioned mosque buildings, as shown in [13].

Table 2. Personal factors of the selected mosques

	Mosque-(Masjid)						
locations	**1**	**2**	**3**	**4**	**5**	**6**	**All**
Age							
Mean	31.82	38	34.59	39.85	17.31	34.11	32.61
STD D	18.96	20.42	7.73	9.06	9.92	7.47	12.26
Min.	12	12	21	29.5	12	21	**12**
Max.	65	65	49.5	59.5	49.5	59.45	65
Height							
Mean	162.4	161	172.25	172.6	138.59	165.39	**162.04**
STD	14.49	18.74	5.73	7	29.2	12.57	14.62
Min	125	110	165	160	92	125	92
Max	180	182	179	186	180	181	186
Weight							
Mean	68	72.67	82.75	78.38	51.79	71.13	70.79
STD	21.22	24.26	13.21	13.59	20.59	13.22	17.68
Min	32	25	65	60	20	32	20
Max	112	125	110	115	120	100	125
Clothing insulation							
Mean	0.94	1.05	0.92	0.88	0.94	0.85	0.93
STD	0.18	0.12	0.17	0.17	0.09	0.14	0.15
Min	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Max	1.1	1.2	1.1	1.1	1.1	1.1	1.2

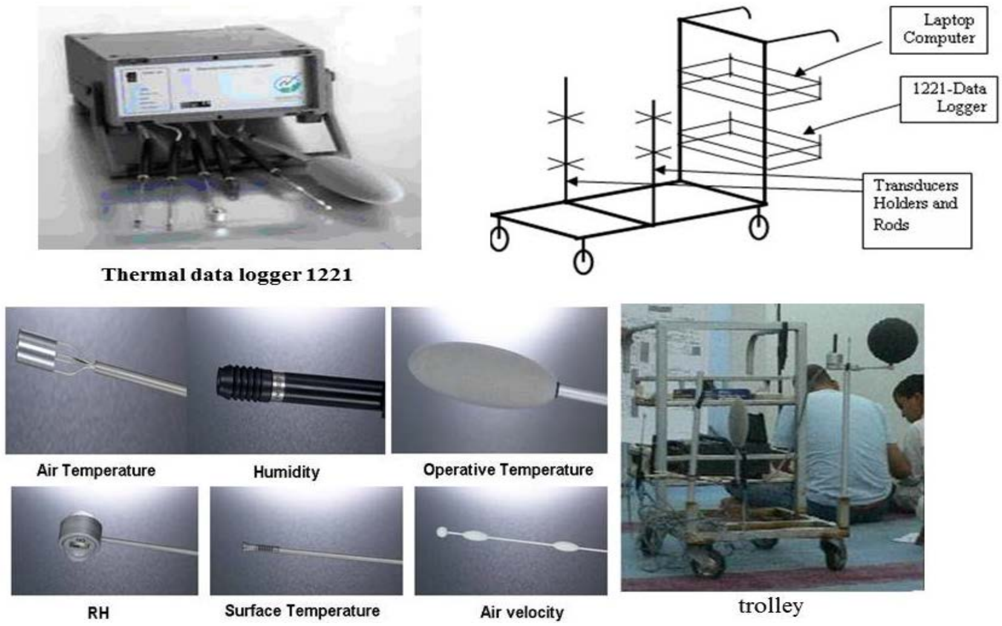

Figure 2. Thermal comfort conditions transducers used with Bruel & Kjaer Air Tech. The instruments and, thermal data logger 1221, were all fitted into a trolley

Table 3. Indoor environmental characteristics of the selected mosques

Masjid (Mosque)	**1**	**2**	**3**	**4**	**5**	**6**	**All**
Locations							**Mean**
Air temperature (°C)							
Mean	23.87	20.27	21.53	19.13	28	25.43	23.04
STD D	0.2	0.35	0.3	0.93	0.95	0.45	0.53
Min.	23.7	19.9	21.2	18.5	26.9	25	18.5
Max.	24.1	20.6	21.8	20.2	28.6	25.9	28.6
Air Velocity (m/s)							
Mean	0.22	0.23	0.22	0.16	0.21	0.32	**0.23**
STD	0.02	0.02	0.2	0.04	0.07	0.1	0.08
Min	0.21	0.21	0.21	0.11	0.14	0.22	0.11
Max	0.24	0.25	0.24	0.19	0.29	0.39	0.39
Relative Humidity (%)							
Mean	42.51	55.47	43.79	51.6	35.05	36.7	44.19
STD	0.35	0.71	1.3	0.57	1.27	0.87	0.85
Min	42.18	55.01	42.5	49.69	33.76	35.76	33.76
Max	42.87	56.29	45.1	53.28	36.3	37.49	56.29
Operative Temp. (°C)							
Mean	24.7	21.27	22.63	20.23	28.6	26.43	23.98
STD D	0.2	0.48	0.21	0.94	0.75	0.49	0.51
Min.	24.5	20.9	22.4	19.5	27.8	26.1	19.5
Max.	24.9	21.8	22.8	21.3	29.3	27	29.3
Actual Mean Vote (AMV)							
Mean	0.06	-.49	-.08	-1.11	0.27	-.19	**-0.26**
STD D	1.01	1.02	0.45	0.61	0.87	0.44	**0.73**
Min.	-1	-2	-1	-2.67	-1	-1	**-2.67**
Max.	2.33	2	1	0	2	0.67	**2.33**
P P D	5	10	5.1	31	6.5	5.7	10.6
Predicted Mean Vote (PMV)							
Mean	0.59	-0.14	-0.39	-0.67	1.3	0.46	0.19
STD D	0.04	0.12	0.04	0.32	0.17	0.14	0.14
Min.	0.54	-0.005	-0.35	-0.3	1.1	0.34	**-0.005**
Max.	0.65	-0.25	-0.44	-0.9	1.43	0.61	**1.43**
P P D	12.3	5.4	8.2	14.4	40.3	9.4	**15**

Table 4. CO_2 concentrations of the selected mosque buildings in Kuwait

Mosque No.	CO_2				CO_2 increase (%) $1-\frac{CO_2\ Mosque\ No.}{CO_2\ Mosque}$
	Min.	Max.	STD	Mean	
1	737	750	7.51	742.3	0%
2	943	955	6.03	949.3	21.8%
3	780	791	5.57	785	5.4%
4	1078	1220	76.22	1133	34.5%
5	868	906	19.14	885.8	16.2%
6	730	778	27.15	761.3	2.5%

5. Indoor Air Quality

Indoor air quality (IAQ) is not considered a direct thermal comfort parameter but is greatly related to this issue. For instance, odor, airborne dusts, suspended particles and high low relative humidities in a space can be sources of discomfort. Additionally, high relative humidities, i.e., above 70%, may encourage molds and fungi; on the other hand, relative humidity levels below 30% can be a cause of dryness of the air inside the indoor environments.

However, mosque buildings in Kuwait, where worshipers spend 40 minutes for each of the five daily prayers, are tightly enclosed spaces that avoid outdoor conditions. This type of case, with poorly ventilated and tight buildings, increases the problems of indoor air quality, which can have significant health impacts on and lead to the dissatisfaction of the worshipers due to unacceptable thermal comfort sensations. In addition, the poor indoor air quality has become a major concern in recent years, particularly due to the increasing number of reports of Sick-Building-Syndrome (SBS), which is associated with symptoms such as itchy eyes, skin irritation, etc. Additionally, order which is an indicator of poor indoor air quality and is often associated with the level of carbon dioxide (CO_2) [1,6]. However, in order to obtain more insight into IAQ and thermal comfort of the indoor environments of each mosque, three steps were developed to quantify these measures [1], which are, as follows:

- Step 1: Walkthrough step.
- Step 2: On-site data collections.
- Step 3: Data analysis and evaluation.

5.1. Walkthrough (step 1)

The first and most important step of an IAQ investigation for preparing the data analysis and evaluating (step 3) a building is the walkthrough inspections. This method can help to clarify the most important areas of the mosque design and may help to develop detailed on-site data collection (step 2).

5.2. On-site Data Collections (step 2)

Measurements of CO_2 concentrations level were carried out at different locations in the occupied zone within each mosque during the worshipers' thermal comfort sensation measures. Three sampling points were selected in the occupied space and an additional point was selected in an outdoor location. These measurements were performed as the respondents completed the thermal comfort questionnaires and during the data collection period. In addition to carbon dioxide concentration measurements, the air temperature, relative humidity and air velocity were measured at 5min intervals over approximately 75 min for each mosque.

5.3. Data Analysis and Assessment

The collected IAQ data are analyzed based on the concentrations of carbon dioxide (CO_2) measured. Measured values of the thermal comfort parameters are analyzed as in section 3 and are tabulated as shown in Table 2 and Table 3. In this section, the measurements of the CO_2 concentration levels can be considered indicators of the fresh air required in the space in terms of the ventilation rate [14]. Table 4 gives the mean concentrations of CO_2 as well as the minimum, maximum, and standard deviation of these concentrations for each mosque. The CO_2 monitoring shows that concentrations vary from mosque to mosque and may be changed according to the A/C type used, air tightness of the enclosed space, window operation, and building location. The concentration levels of CO_2 were measured using a GE Telaire 7001 CO_2/Temperature Monitor.

The results of the indoor CO_2 concentration levels measurements for the surveyed mosque buildings in the State of Kuwait are between 730 ppm and 1220 ppm. The average mean CO_2 concentration level value of all the surveyed mosque buildings show that mosque building No. 4 exhibits the highest CO_2 concentration, equal to 1133 ppm, while that for mosque building No.1 is the lowest , equal to 742.3ppm. However, the concentrations in the surveyed mosque buildings in Kuwait are between 730 ppm, and 1220 ppm. The averaged mean CO_2 concentration for all the surveyed Mosque buildings is 876 ppm. The increase in the CO_2 concentration of mosque building No.4 is equal to 34.5%, which is the highest CO_2-concentration of the surveyed mosque buildings; see Table 4.

However, the CO_2 concentrations of other air-conditioned mosque buildings in Kuwait during the summer season are within the criteria limits of 1000ppm, except that of mosque No. 4 (see Table 4), which was 133 ppm greater than the specified CO_2 concentration criteria limits. However, the slight increase in the CO_2, concentration in mosque building No. 4 is due to its height, which does not sufficiently correspond to the number of worshipers attending the mosque during the prayer times (see Table 1 and Table 4). The height of mosque building No. 4 is equal to that of 6, which is the lowest among the other mosques.

Therefore, this mosque may require an increase of the ventilation rate, either by mechanical means or naturally, i.e., by opening windows, door etc. Still, the volumetric sizes of the mosques should be proportional to the sizes of the community adjacent to the mosques in order to maintain CO_2, concentration within the limit of 1000 ppm.

6. Conclusion

The main objective of this study was to investigate the indoor environmental quality (IEQ) in air conditioned mosque buildings in a dry desert climate in terms of their thermal comforts and indoor air qualities. A total of 140 worshipers in six air-conditioned mosque buildings were surveyed during the summers of 2015 and 2016. The surveys involved recording the environmental parameters and human thermal comfort responses. The mosque buildings were evenly distributed across the five provinces of Kuwait. The main findings of this study may be used as a quantitative assessment criterion for indoor Kuwaiti mosque environments as well as for the development of future energy-related design codes. The main results of this study were as follows:

- The level of carbon dioxide monitoring shows that the CO_2 concentrations vary from mosque to mosque and may change according to A/C type, windows operation, air tightness within the building space and building location.
- The concentration levels of CO_2 for the surveyed mosque buildings are between 730ppm and 1220 ppm.
- Of all mosque buildings surveyed, the mean concentration level of CO_2 in the mosque building NO.4 is equal to 1133ppm. This shows a CO_2 concentration of 34.5%, which is higher than that of other the mosque buildings, which may be due to the lower ceiling height of this mosque. The height of mosque building No. 4 is equal to that of 6, which is the lowest of the other mosques. In this case, a mosque with a lower ceiling may require an engineer/architect to consider increasing the ventilation rate through window operation or using mechanical ventilation.
- Across all the mosque buildings, the mean indoor dry- bulb air temperature was found to be 23°C with a standard deviation of 0.53 and a mean relative humidity of 44.19% with a standard deviation of 0.85 and a mean air movement of 0.23 m/s, with a standard deviation of 0.03.

The neutral operative temperature for the worshipers was found to be 26°C. This was obtained by linear regression analysis of the actual mean vote on operative temperature.

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References

[1] Kuwait International Airport. Meteorological summaries year 1962-2014, State of Kuwait: *Meteorological Department Climatological Division* 2014.

[2] Al-ajmi F., Hanby V.I. Simulation of energy consumption for Kuwaiti domestic buildings. Energy and Buildings 2008, 40: 1101-1109.

[3] Al-Ajmi F. Loveday D.L. Havenith G. Thermal insulation of Arabian Gulf male clothing: “measurements using a thermal manikin”. *ASHRAE Transactions* 2006, pp. 112 (2).

[4] Fanger P.O. Thermal comfort: analysis and applications in environmental engineering. Copenhagen: Danish Technical Press, 1972.

[5] ANSI/ASHRAE, Standard 55. Thermal environmental conditions for human occupancy. American Society of Heating, Refrigerating and Air-conditioning Engineers, Inc.2009, Atlanta, Georgia.

[6] ISO 7730. Moderate thermal environments. Determination of the PMVand PPD indices and specification of the conditions for thermal comfort. 2nd ed. Gevena, Switzerland: International Organisation for Standardisation 2005.

[7] Saeed RAS. Thermal comfort requirements in hot dry region with special reference to Riyadh: part 1: for Friday prayers. International Journal of Ambient Energy 1996; 17(1): 17e21.

[8] ISO 9920. Ergonomics of the thermal environment-Estimation of the thermal insulation and evaporative resistance of clothing. International Standard Organization for Standardization (ISO) 2006.

[9] Al-ajmi F. Loveday D.L. Bedwell K.H. Havenith G. “Thermal insulation and clothing area factors of typical Arabian Gulf clothing ensembles for males and females: measurements using thermal manikins”.*Applied Ergonomics* 2008, 39(3), pp. 407-14.

[10] Sekhar C. Ching C.S. Indoor air quality and thermal comfort studies of an under-floor air-conditioning system in the tropics. Energy and Buildings, 2002; 34: (5), pp.431-44.

[11] Cena K. deDear R.J. Thermal comfort and behavioural strategies in office buildings located in a hot-arid climate. Journal of Thermal Biology 2001, 26(4-5), pp.409-14.

[12] de Dear R.J. Brager GS. Developing an adaptive model of thermal comfort and preference. ASHRAE Transactions, 1998, 104(1), pp.145-67.

[13] Farraj F. Al-ajmi., Thermal comfort in air-conditioned mosques in the dry desert climate, Building and environemnt 45 (2010). pp. 2407-2413.

[14] ANSI/ASHRAE Standard 62.1.Ventilation for Acceptable Indoor Air Quality. American Society of Heating, Refrigerating and Air-conditioning Engineers, Inc.2007, Atlanta, Georgia.

[15] Clerk Maxwell J. A Treatise on Electricity and Magnetism. 3rd ed. vol. 2. Oxford: Clarendon 1892, pp.68-73.

[16] Schiller G.E. A comparison of measured and predicted comfort in office buildings. ASHRAE Transactions 1990, 96(1), pp. 609-22.

[17] Benton C. Bauman F. and Fountain M. A field measurement system for the study of thermal comfort. ASHRAE Transactions, 1990, 96(1), pp. 623-33.

[18] deDear R.J. Fountain ME. Field experiments on occupant comfort and office thermal environments in a hot-humid climate. ASHRAE Transactions 1994, 100(2), pp.457-75.

[19] Mallick F.H. Thermal comfort and building design in the tropical climates. Energy and Buildings 1996, 23(3), pp.161-7.

[20] Howell W.C. Kennedy P.A. Field validation of the Fanger thermal comfort model. Human Factors 1979, 21(2), pp. 229-39.

[21] J.F. Busch, “Thermal responses to the THAI office environment,” ASHRAE Transactions 1990, 96(1), pp. 859-72.

[22] Mui K.W. Wong L.T. Neutral temperature in subtropical climatesd A field survey in air-conditioned offices. Building and Environment 2007, 42(2), pp.699-706.

[23] Al-ajmi Farraj F. Loveday D.L. Indoor thermal conditions and thermal comfort in air-conditioned domestic buildings in the dry-desert climate of Kuwait. Building and Environment 2010, 45, pp.704-710.