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Thermal Comfort in air-conditioned Campus Buildings in Kuwait

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Abstract A field study on the environmental conditions and thermal comfort was carried out in seven educational buildings in College of Technological Studies (CST) at the capital of state of Kuwait. These buildings were mechanically air-conditioned to assess their indoor thermal comfort during summer season. The study was made in summer 2017 to collect a full set of 136 subjects providing 136 sets of physical measurements and subjective assessments through questionnaires. The measured environmental parameters were air temperature, relative humidity air velocity. The subjective responses concern the judgment of the respondents about the thermal environment at the moment of measurements. By using linear regression analysis of responses on the ASHRAE seven-point thermal sensation scale, the neutral operative temperatures based on Actual Mean Vote (AMV) and Predicted Mean Vote (PMV) were found to be 22.9°C and 18.9°C, respectively. However, PMV predictions underestimated observed neutrality by less than AMV of about 4°C. This may indicate that ISO 7730 standard method for calculating PMV of the sensation underestimate the individual's actual sensation in dry desert climate like that of Kuwait. Findings from this study should be considered when designing air conditioning for educational buildings. This knowledge can contribute towards the development of future energy-related design codes for Kuwait.

Keywords: *thermal comfort, indoor environments, indoor air quality, classroom, educational buildings, energy consumption, predicted mean vote, dry desert climates*

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1. Introduction

People in different climates feel comfortable at different indoor air temperatures. Such temperatures can differ 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 educational 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 [4,5]. Centralized air-conditioning, which is generally deployed from the beginning of April to the end of October [4]. This can have tremendous impact on the amount of electrical energy utilized to mechanically control the internal environment in educational buildings. However, the indoor air temperature (or thermostat temperature) settings for all types of air-conditioned buildings and educational 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 educational buildings can adjust their clothing and their activity substantially in response to any level of thermal stress in their environment.

While that for students in the campus are, to a certain extent, limited. This because congregation inside classrooms are often of diverse age, genders, clothing, activity, regions, ethnics, colour, etc, which therefore may have an adverse impact on classrooms 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 students in the educational buildings.

Investigation of indoor thermal comfort in educational buildings for countries located in dry desert climates is very limited, although most of the recent studies have been conducted on adaptive comfort approach [7,13]. In

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

the study reported here, however, field experiments were conducted in seven air-conditioned educational buildings using survey questionnaires and physical measurements to collect data during the summers of 2017. This study also takes into account the clothing insulation values that were calculated by Al-ajmi et al. [9,10].

The main objective of this paper is to investigate the indoor climate and thermal conditions in air-conditioned educational 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 14–42% 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 290 13' North and longitude 470 58' East at an elevation above mean sea level (m.s.l.) of 45 m. Figure 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. Buildings Surveyed

Seven educational buildings were selected to be surveyed in Kuwait. Educational buildings were selected amongst the buildings of colleges of technological studies campus in Shuwaik city. In Each educational building, one classroom was selected for survey.

The selected classrooms in each educational building are within the size of 120 to 150m^2, which occupied number of students range between of 16 to 27 students, see Table 1. The location of classroom is similar direction, towards north. In addition, selected buildings were considered from the perspective of the following specific criteria:

- Centralized air-conditioning with similar cooling size.
- Selected classrooms of educational buildings are similar in size, location and construction materials.
- Selected classrooms of educational buildings are similar in age; not older than 10 years.

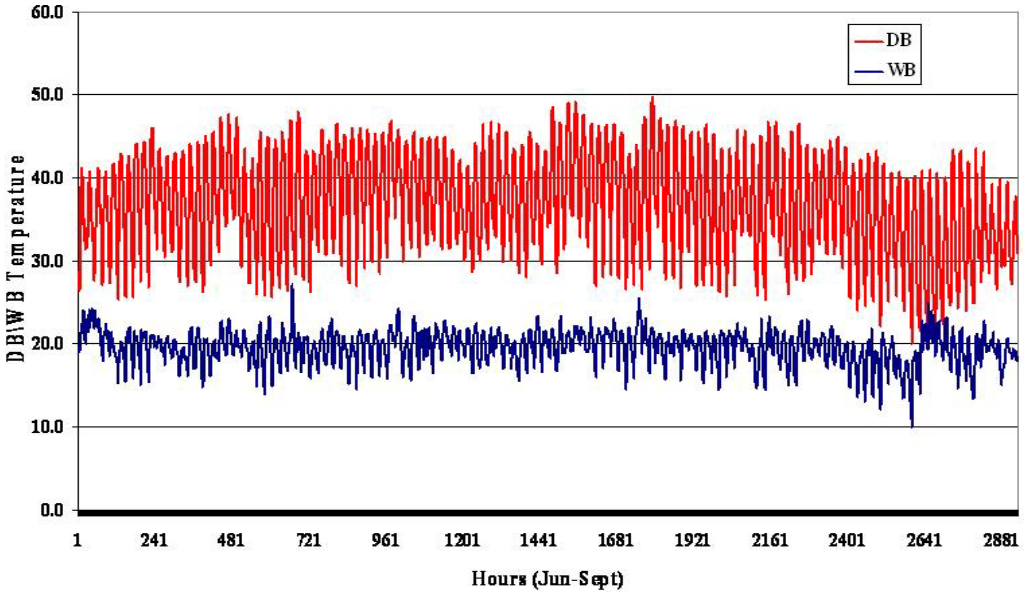

Figure 1. Hourly dry and wet bulb temperature for period between beginning of June to the end of September in state of Kuwait

Table 1. Area of classroom and students numbers of educational buildings

Classroom No.	Number of students	Area	Height
1	25	15X10	4m
2	14	15X10	4m
3	22	12X12	3.5m
4	16	12X10	3.5m
5	16	15X10	4m
6	18	12X12	3.5m
7	27	12X10	3.5m

3. Results and Analyses

3.1. Field Survey

A thermal comfort survey was carried in seven classrooms in seven educational buildings in colleges of technological studies campus in state of Kuwait, see Figure 2. A total of 136 subjects providing 136 sets of physical measurements and subjective questionnaires were used to collect data.

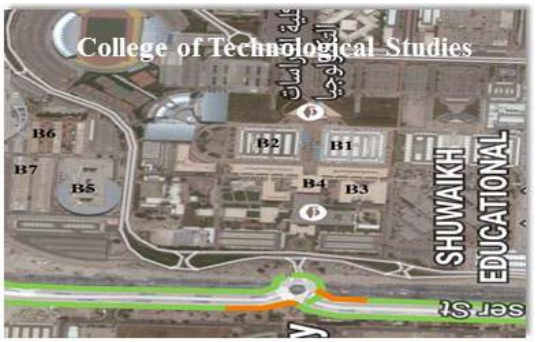

Figure 2. Seven air conditioned educational buildings at CTS, B1-B7

The subjects consist of 97 (71.3%) male and 39 (28.7%) female. The age of the inhabitants is ranged between 17 and 29.5 years, with a mean of 21.64 years. The mean height of was about 169cm and their mean weight was about 72.5 kg, see Table 2. The fieldworks were carried out in state of Kuwait during summer season 2017 using two kinds of surveys; subjective surveys (measurements) and physical surveys (measurements). Later surveys were explained in the forthcoming sections.

3.1.1. 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 classroom of educational buildings. The subjective questionnaires and a description of the experimental work procedure had been translated carefully into the Arabic language in order that the students 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 Vote, or AMV) based on the ASHRAE-seven point scale and consisting of: (-3) cold, (-2) cool, (-1) slightly cool, (0) neutral, (+1) slightly warm, (+2) warm, and (+3) hot); (iv) 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. (v) Air movements' 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.

3.1.2. Physical Measurements

In addition to the subjective data collection, physical measurements were carried out in the seven air-conditioned educational buildings using a Bruel & Kjaer Indoor Climate Analyser Type 1221; see Figure 3. The physical measurements included transducers to measure 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 0.6m above the floor, as specified by ASHRAE 55/2004 [2] and ISO 7726 (2005) [1] 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 classroom. This contributed to allowing the subjects to achieve a steady state thermal balance with their surroundings. The data collection period lasted for 75 minutes in each classroom. During this period, occupants (i.e. students) were asked to sit in the classroom, and were limited to light activity movement, such as body parts movements of hands, feet, neck etc. The metabolic rate value used in this study was estimated to be 1.3 met as recommended by ISO-7730 [1] for near sedentary physical activity. Five sets of measurements were taken each at 15-minute intervals.

Figure 3. Thermal comfort conditions transducers used with Bruel & Kjaer Air Tech. Instruments, thermal data logger 1221, were all fitted into a trolley

3.2. Clothing Description and Activities

Kuwaiti male and female clothing ensembles for college students are similar of those of outdoor ensembles in terms of their outlook, thickness and colures. Most of Male Kuwaiti college students wear usually dishdasha with underwear consists of T-shirt, underpants and a long Serwal. This uniform is usually addressed without headdress (i.e. Ghtutra, Taqia and Eqal), meanwhile some Kuwaiti college students still wear headdress with dishdasha. Kuwaiti male college students in educational building may wear some of western clothing such as that described in ISO 9920(2006) [8], see Figure 4.

Kuwaiti female clothing ensembles of college students consist of three types; these are Islamic, tradition and western clothing. This may be looked up in Al-ajmi et al. 2007 [9,10] and ISO9920 (2006) [8]. Nevertheless, a checklist of Kuwaiti male and female garments photos and descriptive schemes of ensembles were provided at the

time of completing questionnaire survey for subject to choose from, see Figure 5. However, the overall averaged clothing insulation values used for air conditioned educational buildings field experiments were estimated to be between 0.75clo-1.35clo (i.e. western ensembles with value of 0.75clo and traditional ensembles with value of 1.35clo), Table 2. The mean clothing insulation value is 1.01clo, see Table 2. Thus, the clo values of student's conduction with chair were taken into account in this study, by adding a value of 0.15 clo to that of student clothing ensembles [1,2,3,9]. The final value obtained was then used in PMV calculations.

Table 2. Summary of a collected data of student's personal data for each classroom building

Institute	1	2	3	4	5	6	7	All Mean
Age								
Mean	20.68	21.61	20	22.6	23.13	21.94	21.5	21.64
STD D	1.11	2.27	0	3.43	3.8	2.75	2.48	2.26
Min.	17	21	20	21	21	21	17	**17**
Max.	21	29.5	20	29.5	29.5	29.5	29.5	29.5
Height								
Mean	158.84	158.8	174.4	172.2	172.6	174.6	171.9	**169**
STD	5.49	5.59	4.48	8.98	7.68	5.9	10.88	7
Min	152	153	167	154	157	162	130	130
Max	172	172	183	188	185	184	191	191
Weight								
Mean	66.12	60.5	81.05	69.63	80	72.78	77.7	72.54
STD	18.45	12.62	22.19	16.29	16.68	12.61	21.33	17.17
Min	41	44	50	50	55	52	53	41
Max	115	85	125	102	120	100	120	125
Clothing insulation								
Mean	1.14	1.3	0.95	0.88	0.99	0.97	0.86	1.01
STD	0.23	0.1	0.14	0.11	0.13	0.14	0.1	0.14
Min	0.75	1	0.8	0.8	0.8	0.75	0.75	0.75
Max	1.35	1.35	1.15	1.1	1.15	1.05	1.05	1.35

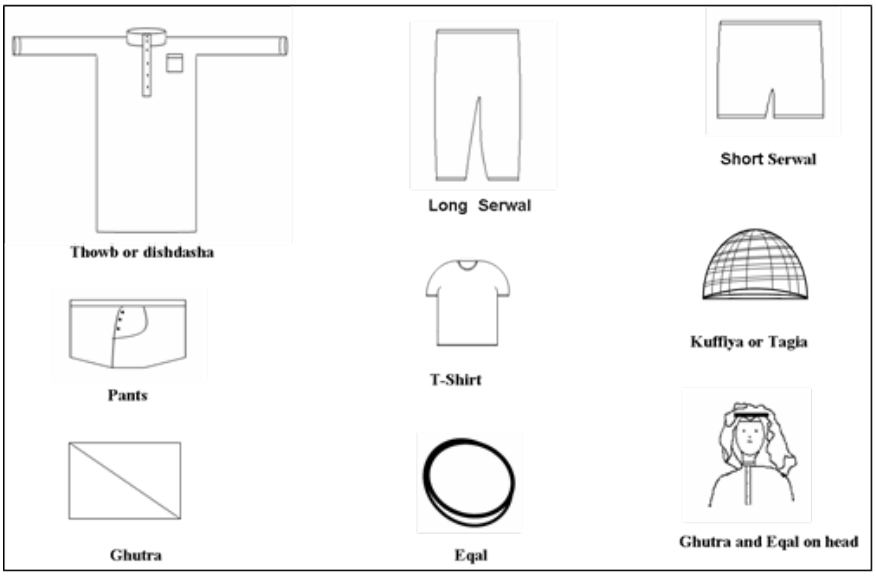

Figure 4. Descriptive of Students male traditional garments

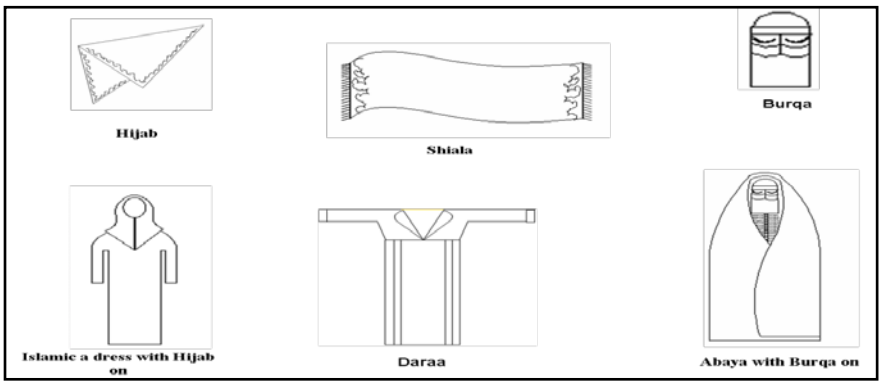

Figure 5. Descriptive of students Female traditional garments

Table 3. Summary of statistical results of indoor environments parameters for each air-conditioned classroom building

Institute	1	2	3	4	5	6	7	All Mean
Air temperature								
Mean	21.46	18.94	20.82	22.8	26.12	25.08	24.6	22.83
STD D	0.93	12.	0.05	0.19	0.25	0.14	0.77	0.35
Min.	19.9	18.8	20.7	22.6	25.7	24.5	23.3	18.8
Max.	22.3	19.1	20.9	23	26.3	25.2	25.1	26.3
Relative Humidity								
Mean	44.08	49.53	62.59	45.63	39.5	45.61	35.08	**46**
STD	1.9	0.25	0.93	0.34	0.66	1.14	1.33	0.94
Min	43.05	49.18	61	44.78	38.82	43.75	33.66	33.66
Max	47.44	49.77	63.38	46.33	40.45	46.52	36.99	63.38
Air Velocity								
Mean	0.19	0.16	0.14	0.02	0.01	0.1	0.01	0.09
STD	0.3	0.1	0.01	0.02	0.02	0.03	0.01	0.07
Min	0.16	0	0.12	0.01	0	0.06	0	0.01
Max	0.22	0.21	0.15	0.04	0.04	0.16	0.02	0.22
Operative Temp.(C)								
Mean	21.98	19.76	21.52	23.16	26.42	25.62	25.14	23.37
STD D	0.73	0.05	0.04	0.2	0.13	0.34	0.85	0.33
Min.	20.8	19.7	21.5	22.9	26.2	25.1	23.8	19.7
Max.	22.7	19.8	21.6	23.4	26.5	26	25.8	26.5
Actual Mean Vote (AMV)								
Mean	0.09	-0.46	-0.46	0.08	0.56	0.34	0.68	**0.11**
STD D	0.7	0.59	0.78	0.39	0.67	0.67	0.77	**0.65**
Min.	-1.2	-1.8	-1.6	-0.4	-0.8	-0.6	-0.6	**-1.8**
Max.	1.4	0.6	1	1	1.6	1.2	2	2
P P D	5.2	9.4	9.4	5.1	11.6	7.5	14.7	**9**
Predicted Mean Vote (PMV)								
Mean	0.42	0.24	0.1	0.47	0.99	0.75	0.61	0.51
STD D	0.15	0.02	0.02	0.05	0.04	0.12	0.19	0.08
Min.	0.18	0.23	0.08	0.42	0.93	0.57	0.31	0.08
Max.	0.55	0.27	0.13	0.52	1.01	0.86	0.76	1.01
P P D	8.7	6.2	5.2	9.6	25.6	16.8	12.9	**12.14**

3.3. Indoor Climate

Table 3 provides the indoor climate measurements for students in selected classroom building. The indoor air temperature and relative humidity averaged between 18.8 to 26.3°C with mean of 22.83°C and 33.7 to 63.4 % with mean of 46 %, respectively. The average indoor air movements varied between 0.01 to 0.22 m/s. Table 3 also provides statistical summaries of thermal environments and thermal indices of occupants. Operative temperature fell within 19.7-26.5°C range with mean of 23.4°C; while the actual mean vote (AMV) fell within -1.8 to 2 ranges with occupants mean thermal sensation of 0.11.

3.4. Actual Mean Vote of Subjects

The actual mean vote (or may be called thermal sensation vote) of students was collected for seven air-conditioned classrooms, representing a total of 136 subjects. The fieldworks were carried out during summer season, (May-October) in State of Kuwait. Figure 6 shows the students overall actual mean vote (or over thermal comfort sensation) for the selected classrooms. It can be seen that 38.97% of the respondent are feeling neutral (0), whilst 23.09% are feeling slightly cool. In addition, 2.21% of students are feeling cool (-2), while 28.24% of the respondent are being warm. Furthermore, preferred scale as may be seen in Table 4, showed that 43% of students did not want to a change their indoor environments, while 12.25 % wanted to be warmer, and 44.8% want to be cooler.

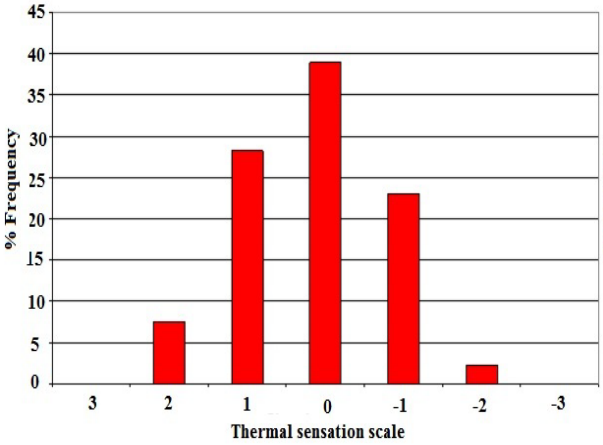

Figure 6. Percentage of acceptable overall thermal sensation of selected classroom of educational buildings

Table 4. Thermal acceptability of all subjects occupied in the selected educational buildings.

Thermal Sensation Scales	Thermal preference scales		
	Warmer	No change	Cooler
-3,-2	14.6%	6.25%	79.17%
-1,0,+1	12.25%	43%	44.8%
+3,+2	15%	15%	70%

The actual mean vote (AMV) of the students (male and female) in air-conditioned classroom in educational

buildings on ASHRAE seven-point scale were marginally slightly warm (i.e. 0.11), which correspond to predicted percentage dissatisfaction (PPD) equal to 9 %, while that for predicted mean vote (PMV) were marginally slightly warm (i.e. 0.51), which correspond to (PPD) equal to 12.14%. Both findings of AMV and PMV are very close to neutral vote, see Table 3. Further analysis for finding indoor optimum thermal comfort range maybe followed as:

- Operative temperatures of selected air conditioned buildings were binned into 0.5°C interval and analyzed the bin's mean thermal sensation of students. Linear regression analysis for actual mean vote (AMV) and predicted mean vote (PMV) = a + b* (to) and operative temperature (to) were applied.
- Regression analysis were solved for neutrality (actual mean vote =0) to configure operative temperature range of the occupants in selected buildings.

Thus, linear regression equation for students' sensation is highly significant and the surveyed fitted equations is

$$AMV = 0.1656t_o - 3.786. \quad (1)$$

In addition, the linear regression equation also applied to PMV model and operative temperature and fitted equation is:

$$PMV = 0.1098t_o - 2.0754. \quad (2)$$

The correction coefficient between the actual mean vote (AMV) and the operative temperature (to) for Eq. (1) is 0.8375, while predicted mean vote (PMV) and operative temperature for Eq. (2) is 0.8299. The slope of the regression line represent the sensitivity of the students with respect to the operative temperature index is 0.1656/°C. Interpreting the slope terms in Figure 7, it shows that when the regression line of AMV and PMV plotted on the graph, the mean neutral operative temperature is the point where regression line crosses the x-axis. Furthermore, Eq. (1) and Eq. (2) were solved for neutrality to derive neutral operative temperature. The operative temperatures were neutralities for AMV and PMV determined to be 22.9°C and 18.9°C, respectively.

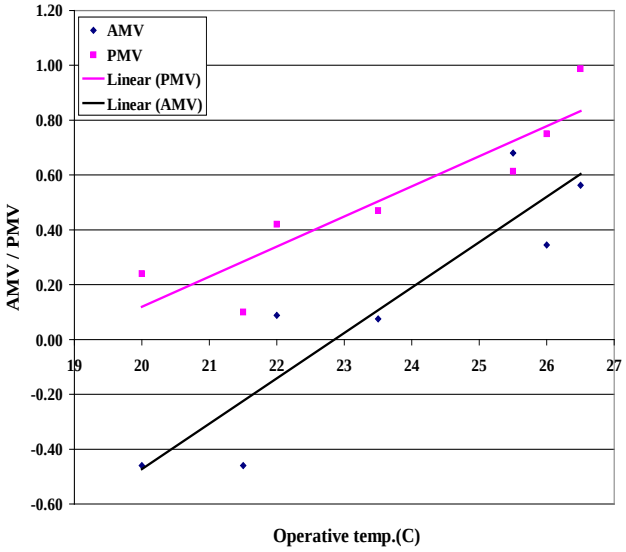

Figure 7. Linear regression calculation based on binned AMV and PMV against operative temperature

However, PMV predictions underestimated observed neutrality by less than AMV of about 4°C. This may indicate that ISO 7730 standard method for calculating PMV of the sensation underestimate the individual's actual sensation for occupied educational buildings (i.e students) in dry desert climate.

This may be explained that students in the air-conditioned educational buildings located in dry desert climate like that of Kuwait are in fact adapted to their indoor environments even if they are being overcooled. Further explanation of the discrepancies between actual mean vote (AMV) and predicted mean vote (PMV) were explained in the ref, Al-ajmi et al. [3].

For Kuwaiti students in educational buildings, we may conclude that, students do prefer lower indoor temperature compared to domestic buildings and mosques as may be mentioned in Al-ajmi et al. [3,11]. This may be explained that college students (male and female) wear thicker clothing ensemble and garments than that worn by inhabitants of houses or mosques.

However, from the above findings, optimum operative temperature equal to 22.9°C, was found to be optimum and may contribute to maintain pleasant indoor thermal environment for students. However, this new finding of operative temperature would lower thermostat set point to a level that much higher than the indoor air temperature (i.e. operative temperature) that is recommended by MEW (equal to 26°C) which may contribute to a slight increase of air-conditioning use in educational buildings.

However, disappointing results of optimum operative temperature equal to 22.9°C would rather be pessimistic in terms of reducing the use of energy cooling, as one might hope, but on the other hand, this may attribute to determine the best cooling load of HVAC system that would enhance a comfortable environmental indoor condition in classrooms in educational buildings.

4. Indoor Air Quality

The results of indoor CO2 concentration levels for the surveyed classroom in educational buildings (in colleges of technological studies campus) in state of Kuwait are between 722ppm, as the lowest value and 1121ppm as a highest value, see Table 5.

The averaged mean CO2 concentration level values of all surveyed classroom buildings are equal to 914 ppm. Meanwhile, it shows that classroom of educational building no. 7 exhibits the highest value equal to 1040ppm, while that for classrooms of educational building no.2 exhibits the lowest value equal to 751ppm, see Table 5.

no.7 is due to that, size (area and height) of classroom of educational building no.7 is not sufficient corresponding to the number of students attending the classroom, see Table 1.

Thus, air-conditioned educational buildings in Kuwait during summer season are within the criteria limits of 1000ppm, see Table 5. However, the slight increase of CO2, concentration in classroom of educational building. However, this may require considering increase ventilation rate either by mechanical means or natural by opening windows, doors etc. In addition number of student has to be proportional to the size of classrooms in

order to maintain CO2, concentration within limits of 1000ppm.

Table 5. CO2 concentrations for each set of measurements

Classroom	CO_2 Concentration			
	Min.	Max.	STD	Mean
1	920	1121	88.74	991
2	722	802	34.16	751
3	752	800	22.94	776
4	945	1038	38.6	991
5	879	1021	62.3	956
6	763	948	76.7	896
7	913	1097	79.36	1040

5. Conclusion and Implications

A total of 136 students in seven classrooms from seven air-conditioned educational buildings in college of technological studies campus were conducted in dry desert climate like that of Kuwait during summer 2017. The surveys were involving environmental parameters and human thermal comfort responses. The main objective of this study is to examine and investigate the range of neutral operative temperature and indoor air quality (IAQ). The important main results of this study are as follows:

- The neutral operative temperature for students of air conditioned educational buildings was found to be 22.9°C. This was obtained by linear regression analysis of mean actual vote on operative temperature.
- The recommended nationwide indoor set point (thermostat temperature) for air-conditioning for educational building in state of Kuwait is equal to 22.9°C.
- The Actual Mean Vote (AMV) fell within -1.8 to 2 ranges with students mean thermal sensation of 0.11, while that for predicted mean vote (PMV) is within 0.08 to 1.01 ranges with predicted mean vote equal to 0.51.
- The operative temperatures were neutralities for AMV and PMV determined to be 22.9°C and 18.9°C, respectively. PMV predictions underestimated observed neutrality by less than AMV of about 4°C, attributing psychological adaptation effect.
- Students who vote inside the central three categories limits of (-0.5, 0, +0.5) which accounts for 90% or predicted percentage of dissatisfaction (PPD) of 10% is between 20°C - 25.9°C.
- Results of indoor CO_2 concentration levels for the surveyed air-conditioned educational buildings are between 722ppm, as the lowest value and 1121ppm as a highest value. In addition, the mean CO_2 concentration level values of all surveyed buildings show that classroom of educational buildings no. 7 exhibits the highest value equal to 1040ppm, while that for classroom of educational buildings no. 2 exhibits the lowest value equal to 751ppm. However, air-conditioned educational buildings in Kuwait during summer season are in spite of that, within the criteria limits of 1000ppm.

However, Mechanical engineers, architects, or builders may consider increasing ventilation rate in Kuwaiti educational buildings.

Further investigation, studying how occupants persist overcooled environment of air-conditioned educational buildings in dry desert climate without interruption of his thermal comfort may be called for.

Acknowledgments

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