Thermal comfort requirements from hot-humid to hot-dry regions

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ABSTRACT

This paper shall investigate thermal comfort requirements for university students in the hot-humid region of Bahrain and the hot-dry region of Saudi Arabia. An extensive field survey shall be conducted among university students in an attempt to define optimum comfort requirements. The field surveys shall deal with the following aspects:

Recording climatic variables, which influence thermal sensation, these are; ambient temperature, radiant temperature, relative humidity and air velocity.

A questionnaire format shall be distributed to a selected sample of university students while they are attending a lecture, working in the design studio, working in a laboratory or studying in the library. The format contains three main sections, these are as follows:

Section 1: For recording the climatic variables of the enclosed space, which should be filled by the researcher.

Section 2: Contains information about the subject; these are the clothing ensembles to determine the clo-value, the activity level to determine the metabolic heat production, the age and sex of the subject.

Section 3: For the evaluation of the thermal environment by the subject. This section is divided into two parts; the first part includes the scale of thermal sensation where the subject is requested to record his/her feeling selecting one of the seven alternatives, these are *very hot, hot, warm, comfortable, cool, cold,* or *very cold.* In the second part the subject shall be requested to record his/her preference by selecting one of the following alternatives, these are; increase ambient temperature, leave the ambient temperature as it is, or decrease the ambient temperature.

INDEX TERMS

Thermal comfort; Field survey; Hot-dry and hot-humid regions; Adaptive thermal comfort

INTRODUCTION

Human thermal comfort is one of the most important objectives of air-conditioning technology. Thermal comfort is defined as *the condition of mind which expresses satisfaction to the thermal environment*, ASHRAE (1977). Most thermal comfort standards acknowledge that there are considerable individual differences between people's thermal sensation and their discomfort caused by local effects, i.e. by air movement (CEN ISO 7730, ASHRAE 55).

A number of field studies of thermal comfort have suggested that design temperatures derived from PMV equation would require more heating and cooling

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energy to achieve thermal comfort than was indicated from the survey results. Both in Bahrain and Saudi Arabia energy consumption for air-conditioning is very high. It is estimated that in both countries buildings are consuming more than 50% of the total energy production and more than 60% of this energy is consumed for air-conditioning. Researchers of thermal comfort indicated that most field studies have suggested that people are not passive receivers of their thermal environment. People usually adapt to their environment to suit themselves. Adaptive theory indicates that the range of acceptable conditions for comfort is greater than predicted by (CEN ISO 7730). According to some researchers the discrepancies between (CEN ISO 7730) and field studies are due to errors in Fanger's equation rather than the adaptive behaviour. Givoni (1998) stated that Fanger's equation neglected the effect of air velocity with respect to sweat evaporation. It only takes into consideration the effect of air velocity with respect to convective heat exchange.

Field surveys dealing with thermal comfort may be conducted in a laboratory or in real buildings. The two approaches are both very important. The scientific attraction of laboratory experiments is that it is possible to eliminate one or two variables and study the effect of thermal sensation of subjects, while keeping all other environmental variables constant. Differences between the response of subjects, may therefore, be ascribed to the effects of the experimentally manipulated variables. However, it is necessary to take precautions with respect to the experimental design. Since the main objective is to ensure thermal comfort, it is essential to conduct studies of comfort in the real live as well as in the laboratory. Thermal comfort surveys in real buildings are mainly conducted to answer specific question that may have no general reference outside the building or organization. Physiological studies should always enable the identification of two groups of variables associated with a thermal balance:

- Environmental variables, which depend on the enclosure, such as air-temperature, radiant temperature, air velocity and relative humidity.
- Subjective variables, which depend on the occupant, such as metabolic rate, sweat rate, skin temperature, clo-value, exposed surface area and posture.

Most field surveys on human thermal comfort have dealt directly with the relationship between warmth and ambient temperature and have asked the respondent to describe his/her feelings of warmth on a rating scale, which consists of a number of named categories. Many rating for thermal comfort studies were developed over the years (Yaglou, 1927; Bedford, 1936; Fanger, 1970). The ASHRAE seven-point scale is used for this study, comprising the following categories; very hot, hot, comfortably warm, comfortable, comfortably cool, cold and very cold.

FIELD SURVEY

The first and fundamental question for the present study is to explore the similarities and differences between thermal comfort requirements in hot-dry and hot-humid climates. The findings from both filed surveys shall be compared with PMV equation and similar studies in hot climates. According to Fanger (1970), the key predictive variables of thermal comfort are: activity level, thermal resistance of clothing, ambient temperature, mean radiant temperature, relative humidity and relative air velocity. The thermal insulation of clothes was estimated using tables of ISO 9920 (1995). The people were free on their choices about clothes, and the observed range of the clothing insulation was from 0.4 in summer to 1.0 in winter.

A thermal comfort field survey has been conducted in two towns from two climatic zones in the Gulf Region; these are Riyadh Saudi Arabia and Bahrain. The first town, Riyadh, represents a hot-dry climate while the second town Bahrain, represents hot-humid climates. For both case studies, university students were chosen as subjects. The description of this survey and the methodology of data analysis are described in details in this paper. The main results and findings are discussed and compared with those of similar surveys conducted elsewhere. The field surveys were carried out during two climatically extreme periods; a hot summer and a cold winter.

Since all the students were seated at rest during the survey, according to McIntyre (1980), their metabolic rate is estimated as 60 W/m^2. All the surveys were conducted in air-conditioned spaces such as design studios and lecture rooms. The main environmental variables affecting thermal sensation, i.e. air temperature, radiant temperature, air movement and relative humidity, were recorded at various points of the indoor space and average values were taken. While the recording of the environmental variable is taking place, the questionnaire format is distributed to the students to give them amble time to record their feelings. The format, which is presented to the students, is divided into five sections. The first section is for recording information about the sex and age group. The second section is for recording the clothing ensembles to determine the clo-value. The third section is for recording the activity level to determine the metabolic heat production. The fourth section, which is dedicated for recording the subjects thermal sensation; is based on the seven-point scale; very cold, cold, comfortably cool, comfortable, comfortably warm, hot and very hot. The fifth section is meant as a check exercise for the subjects voting in the fourth section. In this section the student is asked whether he/she would prefer an increase in the ambient temperature, keep the ambient temperature unchanged or prefer a decrease the ambient temperature. This would reflect whether the student understood the questions in section four.

RESULT ANALYSIS

A summary of the results of the field surveys for Riyadh and Bahrain are shown in Tables 1–4. For the field surveys conducted in Riyadh University during the hot season, the indoor air temperature of the indoor space varied from 24 to 26°C, the relative humidity varied from 40 to 50%, the air speed was about 0.5 m/s, and the clo-value varied from 0.5 to 0.8. Generally speaking, 92.8% of the subjects involved in the field surveys carried out during the hot summer voted within the comfort range (3–5), 3.9% voted within the hot range (6–7), while the remaining 3.3% voted within the cold range (1–2). However, when the subjects were asked to record their preferences, 28.6% of the subjects involved in the surveys conducted during the hot season requested a decrease in temperature, 63.3% were satisfied with the temperature as it was, while only 8.1% of the subjects requested an increase in temperature.

On the other-hand, for the field surveys conducted in Riyadh University during the cold season, the indoor air temperature varied from 23 to 29 degrees Celsius, the relative humidity varied from 43 to 50%, air speed was around 0.5 m/s, the clo-value of the subjects varied from 0.5 to 1.3. The results of these surveys indicated that 95.9% of the subjects voted within the comfort range (3–5), 1.7% voted within the cold range (1–2), and the remaining 2.4% voted within the hot range (6–7). On the other hand, 10.7% of the subjects involved in the field surveys conducted during the cold season requested an increase in temperature, 68.6% were satisfied with the temperature as it was, while the remaining 20.7% requested a reduction in temperature.

Table 1 Summary of the recorded values for Riyadh during the hot season

No. of Sub.	Temp.	R.H.	Warmth vote							Preference		
			1	2	3	4	5	6	7	1	2	3
120	24.0	50%	0	4	28	41	43	4	0	43	69	8
88	24.5	40%	0	2	18	34	34	0	0	31	45	12
64	25.0	45%	0	1	9	25	26	2	1	26	37	1
37	25.5	40%	0	1	9	11	14	0	2	17	16	4
124	26.0	45%	2	4	38	10	62	8	0	7	107	10
433	–	–	2	12	102	121	179	14	3	124	274	35
100%			0.5%	2.8%	23.6%	27.9%	41.3%	3.2%	0.7%	28.6%	63.3%	8.1%

Table 2 Summary of the recorded values for Riyadh during the cold season

No. of Sub.	Temp.	R.H.	Warmth vote							Preference		
			1	2	3	4	5	6	7	1	2	3
50	23.0	50%	1	0	11	28	9	0	1	9	31	10
94	24.0	50%	0	0	14	73	7	0	0	5	81	8
16	24.5	43%	0	0	5	11	1	0	0	0	11	5
59	26.0	50%	1	2	4	36	13	3	0	18	39	2
21	27.0	43%	1	0	1	8	10	1	0	11	8	2
50	29.0	43%	0	0	5	29	14	2	0	17	29	4
290	–	–	3	2	40	184	54	6	1	60	199	31
100%			1%	0.7%	13.8%	63.5%	18.6%	2.1%	0.3%	20.7%	68.6%	10.7%

Table 3 Summary of the recorded values for Bahrain during the hot season

No. of Sub.	Temp.	R.H.	Warmth vote.							Preference		
			1	2	3	4	5	6	7	1	2	3
146	24.0	50%	0	4	28	41	53	20	0	59	79	8
106	24.5	40%	0	2	18	34	41	11	0	38	54	4
54	25.0	45%	0	1	9	20	21	2	1	21	32	1
67	25.5	40%	0	1	9	20	25	10	2	27	26	14
140	26.0	45%	4	6	48	16	58	8	0	24	112	14
513	26.5	50%	4	14	112	131	198	51	3	169	303	41
100%			0.8%	2.7%	21.8%	25.5%	38.6%	10.0%	0.6%	32.9%	59.1%	8%

Table 4 Summary of the recorded values for Bahrain during the cold season

No. of Sub.	Te mp.	R.H.	Warmth vote							Preference		
			1	2	3	4	5	6	7	1	2	3
64	23.0	50%	1	2	11	39	9	1	1	9	38	17
194	24.0	50%	0	5	24	103	37	20	5	25	131	38
46	24.5	43%	0	0	5	31	10	0	0	5	31	10
99	26.0	50%	1	10	16	56	13	3	0	28	59	12
53	27.0	43%	1	5	10	20	14	2	1	29	12	12
75	29.0	43%	0	5	10	34	19	5	2	22	49	4
531	–	–	3	27	76	283	102	31	9	118	320	93
100%			0.6%	5.1%	14.3%	53.3%	19.2%	5.8%	1.7%	22.2%	60.3%	17.5%

As for the University of Bahrain, the field surveys were conducted during June which represents the hot season and January which represents the cold season. A total of 513 students; 84 male students and 429 female students participated in the study. During the hot season the indoor temperature varied from 24 to 26.5°C, relative humidity varied from 40 to 50%, air speed was around 0.5 m/s. The results of these

surveys indicated that 85.9% of the subjects voted within the comfort range (3–5), 3.5% voted within the cold range (1–2) and the remaining 10.6% voted within the hot range (6–7). On the other hand, 8% of the subjects involved requested an increase in temperature, 59.1 % were satisfied with the temperature as it was, while the remaining 32.9% requested a reduction in temperature. As for the field surveys conducted in Bahrain University during the cold season, the results of these surveys indicated that 86.8% of the subjects voted within the comfort range (3–5), 5.7% voted within the cold range (1-2) and the remaining 10.6% voted within the hot range (6–7). On the other hand, 17.5% of the subjects involved in the field surveys conducted during the cold season requested an increase in temperature, 60.3% were satisfied with the temperature as it is, while 22.2% requested a decrease in temperature.

CONCLUSIONS

The analysis of the results recorded from all the field surveys indicated that university students who are acclimatized to the hot dry environment are more tolerant to higher level of temperature. During the hot season 92.8% of the students of King Saud University in Riyadh voted comfortable while only 85.9% of the students of Bahrain University voted comfortable when they are exposed to the same climatic conditions.

For both locations it seems that most students would prefer a lower temperature during the cold season. This is due to the fact that students are wearing heavy clothes and they cannot adapt their clo-value by taking off the heavy clothes when they enter the air conditioned space.

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