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FIELD EVALUATION OF A COMFORT METER

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ABSTRACT

Field measurements were made by a commercially available comfort meter. Subjective assessment of the thermal comfort in the same spaces was made simultaneously by a questionnaire. Comparison of the results showed reasonable agreement between the two methods.

INTRODUCTION

Air conditioning is a common factor among buildings in Saudi Arabia. It was reported that more than 40% of the total electric energy generated in the country is consumed by air-conditioning equipment (MOP 1984; AEC 1985). One of the major objectives in air-conditioning a building is to establish indoor thermal conditions that will satisfy 80% or more of the building occupants (ASHRAE 1981). ANSI/ASHRAE Standard 55-1981 specifies the comfort zone for both winter and summer for persons clothed in typical summer or winter clothing at sedentary activity. This standard was a result of several research activities undertaken by ASHRAE either independently or jointly with several research laboratories in the U.S.A. and in Europe. The International Standards Organization (ISO) adopted the Fanger comfort equation as the basis for general neutrality under sedentary activity and 1.0 clo clothing level. The predicted mean vote (PMV) and the predicted percentage dissatisfied for comfort under the above conditions are given as (ISO 1984):

$$-5 < \text{PMV} < +0.5 \quad (1)$$

$$\text{PPD} < 10\% \quad (2)$$

In Saudi Arabia and in the Middle East in general, very little research has been done on human comfort (Abdelrahman 1982, 1983). The air-conditioning engineers in these countries are using ASHRAE recommendations in design and selection of air-conditioning systems. To avoid future complaints, engineers oversize the machines and the space is either undercooled in summer or overheated in winter. The results of a survey of indoor conditions of office buildings in Dhahran, Saudi Arabia, showed that for 50% of the time the indoor temperature was below 23°C in summer and for 80% of the time it was above 24°C in winter (Figure 1). Figure 2 shows the indoor relative humidity in the same offices. Inappropriate indoor conditions are one of the major factors that contributed to big energy consumption. The adjustment of these conditions would require the deployment of several measuring instruments to measure all the parameters affecting the thermal comfort and then calculation of a thermal index to assess the comfort level.

The availability of a comfort meter will greatly reduce the task of assessing comfort level. However, since the comfort meter was developed on the basis of the comfort equation, with coefficients obtained under controlled laboratory tests, field validation of this instrument is necessary (Fanger 1973). The validation should be carried out in places of different climatic conditions to accommodate the effect of variation in outdoor conditions and clothing habits (Humphreys 1979). This paper reports the results of preliminary field work to validate a commercial comfort meter in Dhahran, Saudi Arabia (Lat. 26° 23′ - Long. 50° 00′).

OBJECTIVE

The objective of this work was to verify the capability of a comfort meter in assessing the comfort level in air-conditioned classrooms of a university located in a hot and humid climate. To achieve this objective, the subjective sensory responses of some selected students were compared with meter readings.

THE COMFORT METER

The subjective and physiological reaction of a person in a thermal environment depends on body heat generation and

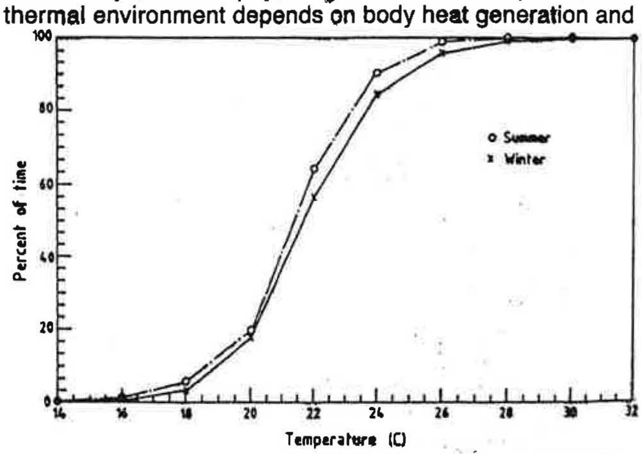

Figure 1 Cumulative distribution of space temperature in office buildings

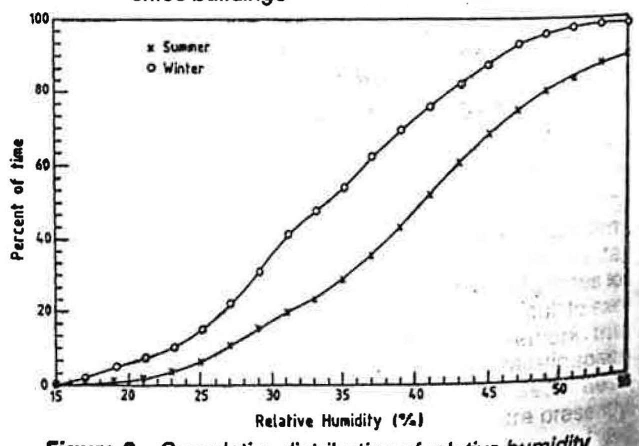

Figure 2 Cumulative distribution of relative humidity in office buildings

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TABLE 1
Results of Comfort Assessment by Questionnaire and Comfort Meter

	Ambient Conditions			Questionnaire				Comfort Meter		
					PMV%					
Case #	t °C	RH %	v m/s	PPD	−1,0	0	0,+1	Comfort Temp. °C	Difference Temp. °C	PPD %
1	23.0	61	0.22	20	20	80	0	23.2	5.5	20
2	25.0	54	0.20	0	0	100	0	24.2	2.7	18
3	23.6	59	0.27	20	20	80	0	24.0	3.2	19
4	24.3	59	0.24	20	20	80	0	23.5	2.4	16
5	23.7	54	0.2	20	20	80	0	23.4	2.3	16
6	22.7	52	0.17	40	40	60	0	24.5	1.8	12

t = ambient temperature; RH = relative humidity; v = air velocity; PPD = predicted percent of dissatisfied; PMV = predicted mean vote

emission, which are functions of the air temperature, air velocity, mean radiant temperature, and vapor pressure, as well as the metabolic rate and clothing insulation effect. Several instruments were developed to measure one or more of these parameters, and the measurements were then used to calculate the degree of thermal comfort (Humphreys 1979). The ideal solution would be to determine the expected degree of discomfort with a single instrument that gives a single value of comfort. This became possible when the Predicted Mean Vote (PMV) was used to develop the required instrument (Madsen 1976). The meter must be preset with the clothing insulation value, the metabolic rate, and the vapor pressure, and then it gives the combined effect of the six parameters mentioned above. Its use is limited to moderate indoor environments. In one of his early papers, Madsen stated that "in practice, it is the occupants and not the measuring equipment that set the limits for how accurately the predicted degree of thermal comfort can be decided" (Madsen 1976). Therefore, the best way to assess this equipment is to compare its field measurement with simultaneous subjective assessment of comfort.

MEASUREMENTS

The classrooms, which are approximately 5 m by 7 m, were all on the periphery of the buildings, with glass windows on the outer walls. The classrooms were air conditioned, and there was no control on our part of the indoor conditions reported in Table 1. Each condition in Table 1 is for a different room. Fifteen students of average size were selected to answer the questionnaire half an hour after entering the room, and they were the same students for all tests. The tests were carried out on six different days from August 25 to September 15, 1987. August is the hottest and most humid month of the year in the region. The time of the tests was either 11:00 a.m. or 3:00 p.m. to make a three-hour interval after the last meal. The indoor ambient temperature, relative humidity, and air velocity, as well as the comfort level, were measured at the center of the room. No verification was made for temperature uniformity throughout the room. The subjects were 1 m away from the walls; the biggest distance between a subject and the comfort meter was 2.5 m.

The predicted mean vote (PMV) is given by the following relation (Fanger 1970):

$$\text{PMV} = f(t_a, v, t_r, p, M, I_{cl}) \tag{3}$$

where

- t_a = ambient temperature (air temperature), °C
- v = air velocity, m/s
- t_r = mean radiant temperature, °C
- p = partial vapor pressure, mb
- M = metabolic rate, W/m^2 (1 met = 58.2 W/m^2)
- I_{cl} = clothing insulation, clo (1 clo = 0.155 m^2·°C/W)

The metabolic rate, M, and the clothing insulation, I_{cl}, were estimated from data reported in the literature, while the temperature, air velocity, and relative humidity were measured on site.

The Metabolic Rate

A total of 15 subjects participated in each test. The subjects were average adults (70 kg weight and 1.7 m height) selected among the students of the university. The metabolic rate for sedentary activity (58 W/m^2) was assumed.

Clothing

The subjects were all male wearing summer Arabian dress, which was composed of the following:

—"Thoab," which is a long plain cotton dress going from the top of the neck to the ankle. Although the dress is as loose as the European shirt, it has a tight collar that is normally buttoned.

—Underwear, which is composed of two pieces, a light cotton trouser and, usually, a half-sleeved undershirt.

—Sandals.

In the absence of information on clo values for the above clothing, their clo values were estimated by comparison with equivalent European summer clothing and they were assumed to be the same for all subjects. These were (Seppanen et al. 1972; Gagge et al. 1976):

Arabian Dress	Equivalent European	Clo Value
Thoab	long-sleeved woven shirt and maxi skirt	0.44
Undershirt	short-sleeved undershirt	0.09
Light trousers	cool trousers (plain weave)	0.22
Sandals	sandals	0.02

The total clo value of the summer Arabian dress for men may be estimated by the following relation (Sprague and Munson 1974):

$$I_{cl} = 0.727\, Is + 0.113 \tag{4}$$

where Is is the sum of clo values for individual pieces. Hence:

$$I_{cl} = 0.727\,(0.44 + 0.09 + 0.22 + 0.02) + 0.113 = 0.7 \text{ clo} \tag{5}$$

Environmental Parameters

The environmental parameters are the ambient dry-bulb temperature (or air temperature), the relative humidity, and the air velocity. The ambient temperature and the relative humidity were measured by a digital voltmeter. The air velocity was measured by a hot wire anemometer. All the measurements were taken at the center of the occupied space. The ambient temperature and the relative humidity were used to determine the vapor pressure in the space by using the psychrometric chart. The variation in the relative humidity was +5% and in the temperature +2°C during the one-hour duration of the experiment. Therefore, the value of vapor pressure used to set the comfort meter could be selected at the start of the test.

The Comfort Meter

The comfort meter was kept at the center of the occupied space. The activity was set at 1 met, the clothing was set at 0.7 clo, and the vapor pressure was obtained and set by the above measurements. The meter was left on for 30 minutes to stabilize before taking the readings.

The Questionnaire

The questionnaire used in this study is given in Appendix A*. The only difference from that used in Denmark is in the clothing section where the Arabian dress was included.

After distributing the questionnaire among the selected subjects, the intention behind the experiment and all the sections of the questionnaire were explained. Voting was made after 45 minutes in the space.

RESULTS AND DISCUSSION

The average results of the environmental measurements, the readings of the comfort meter, and the results of the questionnaire are listed in Table 1. Some comments on the results of the questionnaire are reported in Table 2. The data reported in Table 1 show little variation from one case to the other because all the spaces were air conditioned and kept more or less under similar conditions of temperature and relative humidity. Nevertheless, in view of the ASHRAE definition of comfort, the data show reasonable agreement between the assessment of the comfort level by the comfort meter and the subjective sensory response of the occupants. The positive values of the differential temperature indicate that higher ambient temperatures could be used in air-conditioning these spaces without impairing the comfort. This is supported by the results of the questionnaire, which showed a feeling of coolness rather than warmth among some of the subjects. The feeling of warmth and coolness expressed by the subjects for different parts of the body means that either air velocity or both velocity and temperature were not uniform throughout the space.

The comments given in Table 2 show that when the choice was between comfort and discomfort, the subjects voted for comfort. But some differences appeared when wider choice was given on the thermal scale. The subjects should be able to distinguish between warm and slightly warm or cool and slightly cool. Our future plans include measurements with a wider variation of moderate field conditions.

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*Personal communication with Dr. B. Olesen, Technical University of Denmark.

TABLE 2
Comments on the Questionnaire Responses

Case No.	Comments
1	80% of the subjects felt comfortable; 80% felt neutral on the thermal scale; 40% felt air movement around the face; 40% felt stuffy air.
2	100% felt comfortable; 100% felt neutral on the thermal scale; 20% felt dry air; 60% felt air movement around the face; 20% felt cold feet and warm and 20% felt the opposite; no one felt stuffy air.
3	100% felt comfortable; 80% felt neutral on the thermal scale; 40% felt dry air; 60% felt air movement around the face; 50% felt warm hands; 40% felt cold feet; 20% felt warm head.
4	100% felt comfortable; 80% felt neutral on the thermal scale; 60% felt warm feet; 40% felt warm head; 20% felt stuffy air.
5	80% felt comfortable; 80% felt neutral on the thermal scale; 30% felt dry air; 20% felt air movement around the face; 40% felt warm feet; 20% felt warm head; 20% felt stuffy air.
6	100% felt comfortable; 60% felt neutral on the thermal scale; 60% felt air movement around the face; 30% felt warm feet; 30% felt warm head.

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APPENDIX A

SAMPLE QUESTIONNAIRE FOR SUBJECTIVE ASSESSMENT OF COMFORT

Questionnaire

Date .... Hour ....
Approximate weight: ....kg Approximate Height: ....m
Nationality .... Age ....

Please answer the questions below concerning your opinion of the thermal environment in your normal place of work *right now*. Impressions at other times are of no relevance in this connection. We ask you to answer the questions independently without preliminary discussion with your colleagues.

1) How does the indoor climate seem at this moment?	Comfortable Uncomfortable
2) Does the thermal environment seem	Hot Warm Slightly warm Neutral Slightly cool Cool Cold
3) Does the air seem	Very dry Dry Normal Humid Very humid

4) Can you feel any air movements? (If no, go to point 5)	No Yes
Do the air movements seem uncomfortable?	No Yes
Where can you feel the air movements?	Face Back of the neck Hands Feet Elsewhere
5) Do your hands seem	Cold Neutral Warm
6) Do your feet seem	Cold Neutral Warm
7) Does your head seem	Cold Neutral Warm
8) Does the air seem	Very fresh Fresh Neutral Stuffy Very stuffy

9) Do you know whether you are	particularly sensitive to temperature and draft normally sensitive to temperature and draft slightly sensitive to temperature and draft
10) Work place	Office Lab Shop
11) Office Location	East West North South
12) Floor Location	1 2 3 4 5 6

Clothing

Circle the appropriate items:

Vest:	No Sleeves	T-Shirt	
Trousers:	Light	Medium	Heavy
Shirt:	Short-sleeved	Long-sleeved	
Tie:	Yes	No	
Sweater:	Light	Medium	Heavy
Waistcoat:	Light	Medium	Heavy
Jacket:	Light	Medium	Heavy
Socks:	Half	Long	
Footwear:	Sandals	Shoes	Boots
Arabian dress:	Thoab		
Headwear:	Qutra + Tagiah		Other
Underwear:	Brief	Long	