Thermal comfort study of occupants in University of Patras

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ABSTRACT

The growing demand for better environmental conditions, especially in offices, has increased the need for appropriate standard in order to success the maximum productivity, to minimize the problems of health and the functional cost of air-condition systems. The purpose of this study is to investigate the thermal environment in offices of occupants in University of Patras. Aims of this study are to compare the PMV-PPD index with the real sensation of the occupants, to research the real thermal environment and the habits in clothing and feeding of Greek people, to research the factors, that have relation with the thermal comfort, and finally to make a proposal for the thermal design of air-conditioned offices for people, who work in such places. The investigation took place during summer months (June, July and September). 75 people (27 women and 48 men), between 21- 57 years old, professors, secretaries and postgraduates, during their work, in their real workplace, for 20 minutes were interviewed with a standard questionnaire. In the same time the characteristic subjects of microclimate (dry and bulb temperature, radiant temperature, relative humidity, air velocity) were measured by one device that is called as BABUC A. This is an approach of the thermal comfort and perception of Greek people in Patras. It is found that the average temperature was 26.25^{o}C, even if the interviewed people believed that the temperature was 24.46^{o}C and that they choose to work in place of 22.27^{o}C. The percentage of occupants, who declared "dissatisfied", was 55.11% and "absolutely dissatisfied" was 4.89%. This study showed too that women prefer to work in warmer rooms with about 1^{o}C in comparison to men and that the thermal comfort depends slightly on the body-construction, the height and the weights.

1. INTRODUCTION

One of the major tasks for the people, who study heating and air-conditioning system or design workplaces, is to create indoor climates where human beings feel thermally comfortable. This condition of mind, which expresses satisfaction with the thermal environment American Society of Heating Refrigerating, and Air-condioting Engineers (ASHRAE), defined as Thermal Comfort (Fanger 1967). This subject has been studied over many years and in different parts of the world. Such studies aim to find acceptable indoor conditions for the design of heating and air-conditioning systems and plants in buildings and develop tools, in order to satisfy the people and to success the best economical function.

There are two main streams of thermal comfort studies, namely, field surveys and controlled climatic chamber studies (Chung and Tong, 1990). While the climate chamber method has the advantage of control over all the variables known to impinge upon the heat balance between subjects and their microclimatic surroundings, it fails to provide the participating subjects with what environmental psychologists call "experiential realism". This raises doubts in the minds of many practicing engineers about the ability to generalize from experimental findings to real-world situations.

Field studies of thermal comfort do not have this problem because they are conducted in

Score	-3	-2	-1	0	1	2	3
Description	cold	cool	slightly cool	neutral	slightly warm	warm	hot

Figure 1: ASHRAE Thermal Sensation Scale.

actual buildings under normal conditions of occupancy, and involve larger and diverse samples of "real" occupants as opposed to "paid college-age subjects" (Cena et al., 1990; Cena, 1994). However, the trade-off in field studies has usually been the precision with which physical environmental measurements were performed.

Microclimate of workstation is a very important task for every occupational activity. Increased evidence shows that indoor environmental conditions influence health and productivity. For example Niemelä et al., (2001) reported decrement in productivity of call centre workers corresponding 1.8% per ^{o}C when the temperature was above 25^{o}C. In addition according to various studies that have been performed in public buildings by the National Institute of Occupational Safety and Health found that the most common complaints about unsatisfactory had got problems with their health and the three most significant symptoms that are experienced in more than 70% of the buildings are dry eyes, dry throat and headaches.

This study is a field study. It was found the summer months of 2004 in buildings of the University of Patras. The subject was visited their workplaces and by the use of a questionnaire was interviewed.

The purpose of this study was to investigate the thermal environment in offices of occupants in University of Patras. Aims of this study are to compare the PMV- PPD index with the real sensation of the occupants, to research the real thermal environment and the habits in clothing and feeding of Greek people, to research the factors, that have relation with the thermal comfort, and finally to make a proposal for the thermal design of air-conditioned offices for people, who work in such places.

2. BACKGROUND

2.1 Human body

The human body interacts with its external thermal environment through balancing the internal heat generated from digesting food and the activity.

According to these theories (Charles, 2003), known as thermoregulation and heat balance theories the human body employs physiological processes (e.g. sweating, shivering, regulating blood flow to the skin) in order to maintain a balance between the heat produced by metabolism and the heat lost from the body.

The equation of thermal balance of human body is:

$$M \pm P \pm C \pm R - E = 0 \qquad (1)$$

2.2 Fanger’s PMV Model

Thermal sensation of human beings can be evaluated in several ways (Kajtàtar, 2000). The most complex assessing method is the determination of PMV (**P**redicted **M**ean **V**ote-Predicted thermal sensation) and PPD (**P**redicted **P**ercentage of **D**issatisfied with the thermal surrounding) [3]. Fanger’s PMV model was developed in the 1970’s laboratory and climate chamber studies. The PMV model combines four physical variables (air temperature, air velocity, mean radiant temperature, and relative humidity) and two personal variables (clothing insulation and activity level) into an index that can be used to predict thermal comfort. The index (Fig. 1) provides a score that corresponds to the ASHRAE thermal sensation scale, and represents the average thermal sensation felt by a large group of people in a space (ASHRAE, 2001; Fanger, 1970).

3. EXPERIMENTAL METHOD

The study took place during summer months in five buildings of Patras University, which were constructed between 1977 and 1981. Seventy-five people, 48 males and 27 females, who work as professors, postgraduates and secretaries in university, were used as subject for this study. The subject was between 21 and fifty-seven 57 years old. The buildings consisted of offices with dimensions about 4X10m or 4X4m. In

these offices are working 1-3 persons.

The method included three steps:

- Objective evaluation of thermal comfort through the measurement of air temperature, relative humidity, radiant mean temperature and relative air velocity,
- Objective evaluation of thermal comfort through the measurement of PMV and PPD,
- Subjective evaluation of thermal comfort on the basis of a questionnaire.

3.2 Measurement

In the course of the measurements the temperature and relative moisture content of the air were determined. All office rooms were measured by one instrument, named as Babuc A for three days in sequence. This instrument can estimate the Dry Temperature T_{dry}, Wet Temperature T_{wet}, Relative Humidity RH, Mean Radiant Temperature T_{Ra} and Relative Air Velocity V_{air}. The instrument was placed nearby to person in a height of about 0.6-0.8 m, in order to be in the middle of the human body. The instrument was fully compliant with ISO 7726 recommendations for accuracy and response times and the duration of the process was about 10-15 min.

3.3 Questionnaire

The subjective survey system was divided into two parts, BACKGROUND and ONLINE. This questionnaire was based on ASHRAE questionnaire, which had used in previous field studies (Cena and De Dear, 1998). The questionnaire was written in Greek language.

The BACKGROUND part covered areas such as demographics, contextual, psychological and health factors. The subject was asked for height, weight, for its occupation, age, psychological condition and for health problems that ever had and related with microclimate as dry eyes, dry throat and headaches. This part was filled only at the first time. Aim of this part was to be categorized the subject, to determine differences in thermal behavior in relation with the gender, body, age, descent and to marked problems that are related with thermal environment. In addition subjects were asked for their psychological condition, in order to be estimated, if it is a factor that influences the accuracy of results.

The ONLINE survey form was given to the subject at the same time as Babuc A was collecting the necessary data from each workplace. This part included questions concerning the subject's assessment of their immediate thermal environment at that point in time. In addition it was collected data about the food, that every person had eaten that day, the water, that he had drunk, the breaks, that he had got etc.

The ONLINE questionnaire included too the traditional scales of Thermal Sensation (T.S.) and thermal preference current clothing garment, The thermal sensation scale was a 7-point scale of warmth ranging from cold (-3) to hot (+3) with neutral (0) in the middle. Thermal sensation was a continuous scale allowing non-integer sensation ratings to be given. The item immediately following thermal sensation dealt with acceptability, with subjects being directly asked if the current temperature was acceptable to them (yes/no). If the answer was no then the subject was asked, “What preferred to be done”. Possible responses were “want warmer”, “want cooler”, “want more humidity”, “want less humidity”, “want more air velocity”.

3.4 Activity Level- BI

Metabolism of subject was not measured. The external work was considered as 0 (Memarzadeh, 2000). According to earlier studies (Donnini et al., 1996; de Dear and Fountain, 1994) there are no important differences between the activity level (A.L.) of sexes and body built categories. So even if they were asked for his work (duration, description etc) and for food, that they had eaten the day of interview, the A.L. was considered as constant at about 1.3 met or about 73 $W/m^2$for all.

Body mass index (BMI) is measure of body fat based on height (m) and weight (Kg) that applies to both adult men and women (Kuczmarski and Flegal, 2000).

$$BMI=W/H^2 \quad (2)$$

According to BMI the subject was categorized in three groups. The limits for each group don’t depend on age or gender. So in this study it was considered that Underweight is someone when BMI<21, normal 21<BMI<27 and overweight when BMI>27.

4. ANALYSIS AND RESULTS

All data of questionnaires and measurements, the data were saved in a Data Base (DB), which was developed by the survey team. This DB included tool for calculating PMV-PPD indices and the statistical analysis.

4.1 Clothing

It is well known that clothing is a very important factor for thermal comfort. It functions as thermal insulation and influences the comfort of body movement. The clothing depended on age, climate and traditions of each region. The clothing was estimated using the ON LINE part of questionnaire. This part included a form with a large group of clothes, which were categorized in very specific categories. Using ASHRAE Standard 55-92 the clo index was calculated.

The results showed that men were worn with clothing with insulation of 0.47± 0.02 clo and women with an insulation of 0.43±0.02 clo. The subject support that their clothing was pleasant and comfort. Finally the insulation of the chair that was about 0.15 clo (Cena and De Dear, 1998) was added to the previous values.

4.2 Measurements of thermal environment

The survey took place in summer months of 2004 (June, July, September). In this period the climate of Patras is characterized from high temperature (about 28 ^{o}C) and high humidity (about 60%). Table 1 shows the statistical results of the measurements of survey.

4.3 Acceptability-Satisfaction

The estimation of thermal sensation and thermal acceptability was succeeded by the following two methods. The temperature range was separated for in 0.5 ^{o}C parts. The first method was based on the above-mentioned thermal 7-scale sensation (in this survey the answers were between –2 and 2). The second method was based on answers to the questions "Which is the temperature of air now in this room (without thermometer)" and "Which temperature do you prefer to work".

Table 1: Statistical data from measurements.

Description	T_{dry}	T_{rad}	RH	V_{air}
Average	26.28	26.70	0.43	0.43
St. Dev.	1.523	1.30	0.069	0.069
Max	29.21	29.94	0.634	0.634
Min	20.4	22.13	0.259	0.259

Table 2: Estimated and Preferred Temperature in correlation to sex and body built (^{o}C).

	Tdry	Est. Tem.		Pref. Tem.	
	Av.	Av.	S.D.	Av.	S.D
Male	26.21	24.77	3.00	22.28	2.96
Female	26.40	23.91	3.75	22.17	3.1
Underw.	26.53	23.15	3.96	21.74	2.69
Normal	26.31	25.14	3.00	22.97	2.94
Overw.	26.01	23.39	2.96	20.69	2.75
Total	26.25	24.46	3.31	22.24	3.00

Table 3: Thermal Sensation for Males and Females in variant temperatures.

	24.5	25	25.5	26	26.5	27
Males	.46	.50	.43	.80	.44	.75
Females	.14	.38	.11	.45	.36	.50

The analysis included two steps. The first is the average score of 7scale. In the second was calculated the percentage of absolutely satisfaction ("Neutral" answers/total answers). The answers were categorized based on sex, body built and temperature of room.

Sex-Body built

The survey showed that there is correlation between sexes and body built- categories. The most women worked in environment with air-temperature about 26.40^{o}C on average, while men worked in places with air temperature about 26.21^{o}C on average. The most measurements were in a range of 25-26 for men and 26-27 for women. Table 3 shows that the best score of Thermal Sensation succeed in temperature of 25.5^{o}C for men and in 25.5 for women. Males feel warmer in all temperatures and the most "Neutral" answers are noted in 25^{o}C. On the other hand females gave the most "Neutral" answers in 26^{o}C.

In addition while the predicted air temperature men was about 24.77±3.00, they declared that would prefer to work in lower temperature of about 22.28±2.96^{o}C. At this moment women predicted the air- temperature 23.91±3.1^{o}C, and they preferred 22.17±3.1.

That implied that males wished a decrease of temperature for 2.49^{o}C and females about 1.74^{o}C. Even if humans cannot estimate with accuracy the temperature, the previous imply that men wish a larger decrease of temperature.

Figure 2 shows that almost in every

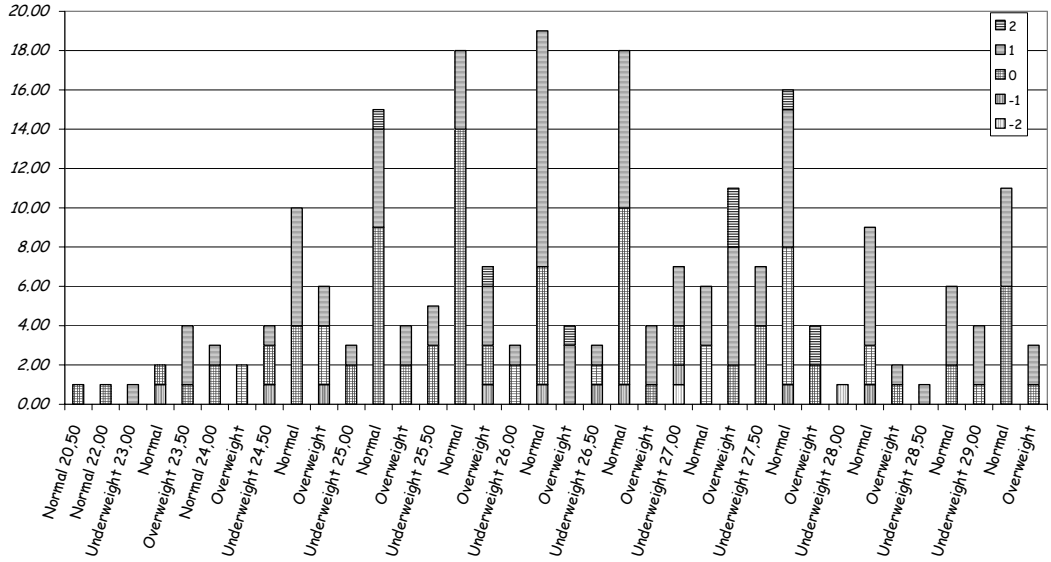

Figure 2: Answers of Thermal sensation in correlation body built.

temperature the overweight people feel warmer than the rest. In addition even if they used to work in the coolest room, they wish the largest decrease of temperature, as it is shown in Tables 2 and 4. Comparing, so the body built groups we can support that this factor influences the thermal sensation.

4.4 PMV-PPD indices

According to the measurements of thermal environment and clo estimation were calculated the PMV- PPD indexes. The results are shown n in the table9 for categories of subject.

It is shown that exist little declinations between PMV and T.S. in all categories. In additional in table 10 it is shown that the average dissatisfied people from their environment are 55.11% and the absolutely dissatisfied (people that answers warm or cold) are 4.89% on average.

Table 4: PPD index and Thermal Sensation for variant groups of subject.

	PMV		T.S.	
	Av.	St. D	Av.	St. D
Male	0.14	0.66	0.56	0.62
Female	0.10	0.63	0.48	0.69
Underweight	-0.01	0.56	0.17	0.91
Normal	0.03	0.58	0.49	0.65
Overweight	0.30	0.73	0.57	0.65
Total	0.1	0.63	0.48	0.69

5. DISCUSSION

Although the number of male and female subjects was not the same in the present study, regression lines and neutral temperatures between the two groups of subjects can still be compared and the results show that this difference in the neutral temperature is about 1^{o}C. Table 3 shows that Males seem to fell warmer than females in all temperatures.

It seems, also, that men prefer environment with temperature little below than 25°C and women little below 26°C. This conforms to the findings by McIntyre and Chung and Tong on analyzing KSU data that the slopes of thermal sensation for females were bigger than that for males. Furthermore, since the metabolic rate of females is less than that of males, females may fell cooler than males. The effect is, however,

Table 5: PPD index, Dissatisfaction Level, Absolutely Dissatisfaction Level.

Category	PPD	D.L.	A.D.L.
Male	16.24%	56.94%	4.17%
Female	9.68%	51.85%	6.17%
Underweight	10.56%	58.33%	8.33%
Normal	13.25%	53.19%	4.26%
Overweight	18.92%	58.33%	5.00%
Total	14.3%	55.11%	4.89%

somewhat offset at higher temperature regions where the skin wettedness due to evaporative heat loss for females is lower than that of males which may be due to the lower metabolic rate of females.

This study showed that the body built influence the thermal comfort. In all temperatures the most fat (overweights) declared that they feel warmer than the rest groups. These results don't conform to the findings other surveys (Chung and Tong, 1990). Even if it was examined, there weren't found important differences between the variant ages of subject.

Comparing the PMV index with the Thermal Sensation it is concluded that the two indices have got declination. These declinations may exist because of velocity of air, which influences PMV index. The subject used to keep the windows opened, in order to ventilate the offices. Air velocity makes people feel more comfortable. In addition if the PPD index is compared with the percentage of dissatisfied and the absolutely satisfied the results are close. It seems that the answers of subject compared to PPD are closer for absolutely dissatisfied and there are important declinations with dissatisfied people.

6. CONCLUSION

This study showed that the thermal comfort and sensation are different between males and females, and overweight people, normal and underweight people. The subjects used to work in temperature 26.25^{o}C, but there was a pleasure for decrease. It was estimated that men prefer to work temperature about 25^{o}C and women about 26^{o}C. Women were worn slightly lighter than men

The acceptability of thermal environment was about 45% but the absolutely dissatisfaction was about 5%. There were declinations between the results of survey and PMV- PPD indices, especially with PPD index.

Finally this study showed that it is difficult to design offices, which could satisfy all people, especially with big differences in BMI. It is important sometimes to use local thermal or air-conditioning units, in order to increase the health and comfort level of occupants.

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