EVALUATION OF THERMAL ENVIRONMENTS IN OFFICE BUILDINGS AND SCHOOLS A PORTUGUESE CASE STUDY

AIVC 12093

D.A. Quintela, A.R. Gaspar, V. M. Mendes, M.C. Silva

Departamento de Engenharia Mecânica – FCT, Universidade de Coimbra - Pólo II
3030 Coimbra – PORTUGAL

ABSTRACT

From a global point of view, the climate of the most occidental European country is generally classified as moderate. This recognition has strongly contributed to the actual state of affairs within the building sector, where the thermal comfort requirements of the occupants have deserved so far less attention. The present work was aimed to provide a first evaluation of actual indoor climatic conditions in offices and schools in Portugal.

The analysis of the results clearly shows that complaints are often related with some kind of memorised posture about the workplace itself, thus inhibiting a direct relationship between the sensations felt by people and the real environment conditions. From another point of view, it may be recognized that the reported subjective judgements of those conditions don't seem to be in good agreement with standard comfort models. In a certain sense, the present study seems to corroborate the growing criticism to the universal character of the most widely used comfort standards. According to the portuguese experience, the authors believe that other approaches should be considered, namely those that are linked to the so-called adaptive models of comfort, which are now rising interesting challenges for further research in this field.

In several circumstances, it has been observed that, within the same office room, individual judgements can be rather different or even completely in conflict. This finding suggests that solutions to some difficulties on achieving thermal comfort can be improved if individual control at the workplace is reasonably provided. This issue is actually the main objective of a research study at the University of Coimbra.

KEYWORDS

Thermal comfort; Office buildings; School buildings; Full-scale experiments.

INTRODUCTION

The major part of research work on thermal comfort is mainly related with experiments performed under carefully controlled laboratory conditions. The main conclusions from such studies form the basis of ASHRAE's standard 55 (ASHRAE, 1992) and ISO's standard 7730 (ISO, 1994). Like in other research fields, the theoretical description of reality or the physical modelling often led to results calling for full-scale validation. However, if any comparison or criticism between field studies and climate chamber research is aimed, then it must be recognised that, as far as possible, the well controlled laboratory boundary conditions should have their counterpart in full scale work. Therefore, observation of this simple requirement, yet complex but not impossible to achieve in practice, would probably contribute to a more sounded basis for comparison. At least, some of the differences found so far can be further understood.

The foregoing considerations have found echo in the growing number of high-grade field studies promoted by the thermal comfort community (Schiller et al., 1988; Schiller, 1990; de Dear and Fountain, 1994; Chan et al., 1998). In a certain sense, "that condition of mind which expresses satisfaction with the thermal environment", seems now to be according more emphasis to the individual differences (Parsons, 1995, Humphreys, 1996), in opposition to the more strict prescriptions of current comfort standards. The more recent adaptive models (Humphreys, 1995; de Dear and Schiller, 1998) represent a different approach that seems to be looking for a more realistic and less restrictive alternative to the current comfort guidelines.

In the case of Portugal, the conscientiousness for demanding quality standards for working conditions is still nowadays very incipient. In a great number of office buildings and schools, indoor climates are known to be very unpleasant.

The non-existence of reliable information enabling the quantification of such uncomfortable conditions has motivated the authors to perform a very first evaluation of the thermal environments at seven office buildings and one secondary school of Coimbra, including both the heating and cooling seasons.

This study has been strongly influenced by two well known field measurements in air-conditioned office buildings, developed in the S. Francisco Bay Area (Schiller et al., 1988) and in Townsville, Australia (de Dear, 1994). The objectives, as well as the technical means available for this study, imposed serious restrictions that can be clearly inferred from what follows.

METHODS

As stated before, the present work was intended as a very first evaluation of thermal conditions in office buildings and schools. Another major objective was the characterization of people's preparation or familiarity with problems or complaints related to thermal environments in the workplace. Therefore, priority was given to *blind* evaluations of thermal comfort, with no comparison between laboratory and field measurements in mind.

Climatic environment

The city of Coimbra, besides its very old University, created in 1290, has nowadays more than 100.000 inhabitants with major activities on the commercial and service sectors. The urban agglomeration is concentrated on a land area of about 20 km^2, on both hilly sides of the Mondego river valley. Coimbra, at latitude 40° N, is located in the central region of Portugal at nearly 40 km from the Atlantic ocean, which bears a maritime influence on the Mediterranean climate of Coimbra. Control of the river flow has provided a beautiful water basin that has increased the occurrence of foggy mornings, which are attenuating the daily temperature swings, namely in summer. The 30-year normal (1961-90) mean monthly air temperatures and humidity are presented in Figure 1.

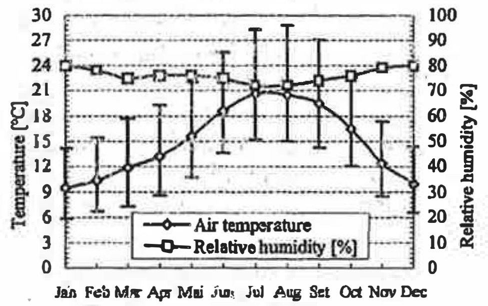

Figure 1 Monthy mean temperature and relative humidity (1961-1990).

Meteorological observations

During the summer study period (July-August 1996), the average daily maximum temperature was 29.5°C, the average daily minimum was 15.0°C and the average daily was 20.3°C. For winter (February 1997), the corresponding temperatures were 17.3°C, 8.3°C and 11.9°C, respectively. With respect to Figure 1, this shows that the summer study was representative of typical conditions of Coimbra. The winter measurements were performed under favourable conditions, with average temperatures approximately 2°C above normal values.

Data collection procedure

The choice of the buildings was essentially determined by practical reasons. As expected, it has been verified that the institutional permission for conducting such studies was easier to obtain from public services than from private organizations. In the case of the city of Coimbra this has became an advantage for two reasons: people working in the public sector represents more than two thirds and the majority of the public buildings are common and relatively ancient naturally ventilated buildings that have been adapted to offices. Table 1 summarizes some characteristics of the office and school buildings monitored in this study, together with the number of questionnaires.

Demographic characteristics of the subjects participating in this work are briefly described in Table 2. The sample sizes during the heating and cooling seasons were limited to 123 and 67, respectively.

Prior to the measurement sessions, each building was visited by two of the authors in order to identify those places where thermal conditions were probably less favorable. Since the majority of the buildings are naturally ventilated, the building exposure to solar radiation has been verified to play here a very important role. During the visit, detailed information was given to the building owners about the main objectives of the thermal evaluation and the individual questionnaires.

In the case of the school, the authors were given the unique opportunity of making measurements in a few classrooms under real conditions, with lessons running normally. This made the results more meaningful as these particular workplaces are very sensible to the internal heat loads due to people, which are changing every 45 to 50 minutes.

The Indoor Climate Analyser (ICA) type 1213 from Brüel & Kjær was used to measure the physical parameters, according to ISO 7726 and 7730. Five transducers measuring air temperature, humidity, air velocity and operative temperature were

Table 1 Summary of the office buildings and school surveyed.

Building Code	Type of Tenant	Number of Questionaires		Air-Conditioning	Floor Plan Layout
		Summer	Winter		
A	gov	5	-	no	small offices
B	private	5	-	yes	mixed
C	gov	5	-	no	small offices
D	gov	8	-	no	small offices
E	gov	10	-	no	small offices
F	public	17	8	yes	mixed
G	gov	17	12	yes	mixed
School	gov	-	103	no	classroom

Table 2 Summary of demographic characteristics of the subjects.

		Age [Year]	Height [m]	Weight [Kg]	Gender	
					# Female	# Male
School	Mean	16.4	1.6	59.4		
	Maximum	19.0	1.7	67.7	60	43
	Minimum	14.0	1.5	56.8	(58.2%)	(41.8)
	Stdev	1.4	0.1	4.5		
Offices	Mean	42.3	1.6	62.5		
	Maximum	62.0	1.8	95.0	49	18
	Minimum	22.0	1.5	48.0	(73.1%)	(29.9%)
	Stdev	9.2	0.1	9.6		

mounted on a tripod at 0.6 m above the floor. All transducers comply with ISO 7726 specifications. Further details can be found elsewhere (Brüel & Kjær, 1990). The ICA data logger performed data acquisition. A tripod with the four transducers was placed nearby the workstation, within a distance of one meter. All physical measurements were averaged on a five-minute basis. During this time, the field researcher left the workplace area while the participants were asked to complete the individual questionnaire without leaving their desks.

The questionnaire was designed in order to estimate the subjective judgement of the occupants about the indoor thermal environments. The questions in the Thermal Assessment Survey were adapted from previous field studies (Schiller et al., 1998; de Dear and Fountain, 1994), including the ASHRAE seven-point Thermal Sensation scale and the three-point McIntyre scale, together with an estimate of room temperature. Subjective assessment of air movement was also required in terms of acceptability and preference. Separate female and male clothing checklists were provided on the basis of a four-point relative weight scale. The physical activity and meals during the previous 30 minutes were also inquired. The time needed for completion of the questionnaire was typically within 5 to 7 minutes.

From these checklists, the activity level and effective clothing insulation were estimated later, according to ISO 7730.

During both seasons, the mean clothing patterns are in good agreement with standard values, with 0.46 clo (summer) and 1.0 clo (winter). In summer, women wore lighter clothing than men; mean clo values for women were 0.42 an for men were 0.50. In winter, there was practically no difference between genders, both with 0.92 clo. In the case of the school, clothing patterns for winter are again quite similar. The highest observed mean clo values (1.13 – females; 1.12 – males) are in accordance with the coolest environments found in this study.

Additional insulation effects due to subject's chair were considered throughout this study. The chair insulation increment was fixed to 0.15 clo. On average, this increased the insulation values to 0.61 clo in summer and to 1.10 and 1.28 clo during winter, for offices and school, respectively.

The metabolic rates were estimated as corresponding to 1.2 met in both seasons, independently of sex or age.

RESULTS

Statistical summaries of the indoor climatic conditions and the PMV/PPD indices are presented in Table 3. The overall mean air temperature difference between both seasons, about 7°C, is representative of the so-called free running buildings. A simple plot (not shown here) of the measured mean values on the ASHRAE format psychrometric chart has shown that, during summer, none of the seven buildings surveyed clearly falls within the central zone of the standard's 90% thermal acceptability prescription. The thermal conditions in three buildings (C, D and E) are very close to the warm margin (>26°C ET*), three (A, F and G) show humidity levels exceeding the upper limit (60% RH) and only one (B) lies close to the cool guideline (<23°C ET*). In winter, only one of the three buildings (G) is well inside the comfort zone. Indoor climatic conditions prevailing in other buildings (F and school) fall beyond the cool margin, a departure that is particularly important in the case of the school.

Frequency distributions of the Thermal Sensation votes obtained during both seasons are shown in Figure 2. According to Fanger's suggestion that comfortable conditions may be identified with the three central categories of the ASHRAE Thermal Sensation scale (Fanger, 1970), Figure 2 suggests that approximately 45% of office workers feel uncomfortable in summer, while during winter almost 30% of the students feel the same at the opposite side of the scale. In contrast, offices in winter are judged more comfortable. In general terms, it can be said that the majority of thermal sensation votes try to counteract the prevailing thermal characteristic of the season (heating – cold side; cooling – warm side). This global behavior may be reflecting outdoor conditions.

Table 3 Summary of the indoor climatic conditions.

Building		Air Temperature [°C]	Operative Temperature [°C]	Dewpoint [°C]	Relative Humidity [%]	Air Velocity [m/s]	PMV	PPD
			Summer					
A	Mean	27.2	26.8	18.1	58	0.1	0.4	9.5
	Maximum	28.5	28.2	21.8	68	0.1	0.8	19.2
	Minimum	25.7	25.9	14.6	46	0.0	0.0	5.0
	Stdev	0.1	0.1	0.7	3	0.0	0.0	0.6
B	Mean	22.7	23.0	10.3	45	0.1	-0.7	15.5
	Maximum	23.2	23.2	11.4	52	0.2	-0.5	22.2
	Minimum	21.6	22.4	7.3	39	0.1	-0.9	6.7
	Stdev	0.1	0.1	0.8	3	0.0	0.1	2.0
C	Mean	26.2	26.1	15.4	51	0.2	0.2	7.7
	Maximum	27.9	27.4	17.1	55	0.4	0.4	8.7
	Minimum	23.8	24.4	10.8	44	0.0	-0.4	6.1
	Stdev	0.0	0.1	0.5	2	0.0	0.0	0.5
D	Mean	26.0	26.1	13.5	46	0.1	0.2	6.7
	Maximum	27.5	27.1	18.4	58	0.3	0.5	10.8
	Minimum	24.0	25.1	10.7	38	0.0	-0.1	5.0
	Stdev	0.1	0.1	0.2	1	0.0	0.0	0.4
E	Mean	26.3	26.0	14.8	49	0.2	0.1	7.7
	Maximum	29.7	29.2	16.9	58	0.7	0.9	22.7
	Minimum	23.3	23.7	13.2	43	0.0	-0.5	5.0
	Stdev	0.1	0.1	0.2	1	0.0	0.1	0.6
F	Mean	26.6	26.4	17.7	58	0.1	0.4	8.3
	Maximum	27.2	26.7	18.4	61	0.2	0.6	11.4
	Minimum	25.1	25.9	15.3	54	0.0	0.2	5.6
	Stdev	0.1	0.0	0.4	1	0.0	0.0	0.4
G	Mean	25.4	25.4	16.8	59	0.1	0.2	6.2
	Maximum	26.1	26.0	18.6	67	0.2	0.5	9.2
	Minimum	24.6	24.6	15.2	52	0.0	-0.1	5.0
	Stdev	0.1	0.1	0.6	2	0.0	0.0	0.2
			Winter					
F	Mean	19.1	18.6	8.1	49	0.0	-0.4	9.2
	Maximum	19.8	18.9	9.9	57	0.1	-0.4	10.5
	Minimum	18.5	18.2	5.3	41	0.0	-0.5	7.6
	Stdev	0.1	0.1	0.5	2	0.0	0.0	0.7
G	Mean	21.6	20.9	10.7	50	0.0	-0.3	6.8
	Maximum	22.5	21.6	12.9	59	0.1	-0.1	9.5
	Minimum	21.0	20.4	10.0	46	0.0	-0.5	5.2
	Stdev	0.0	0.0	0.5	2	0.0	0.0	0.6
School	Mean	14.6	14.2	9.5	72	0.1	-1.1	30.8
	Maximum	15.8	15.2	11.9	80	0.2	-0.9	47.7
	Minimum	13.2	13.2	7.4	62	0.0	-1.4	21.2
	Stdev	0.3	0.2	0.5	2	0.0	0.1	3.3

Figure 3 presents an equivalent approach in terms of the McIntyre votes. Analysis of the results shows that the foregoing trends are maintained. Almost 90% of the students prefer to be warmer in winter and 56% of office workers in summer would like to be cooler. Again, offices in winter show a much better performance as compared to the school. Indeed, buildings F and G are the most recent and the only ones that have been specifically designed for office work.

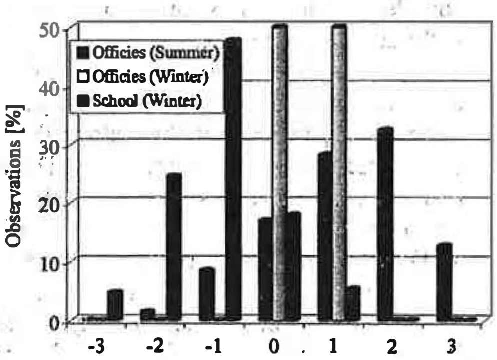

Figure 2 Frequency distributions of thermal sensations votes.

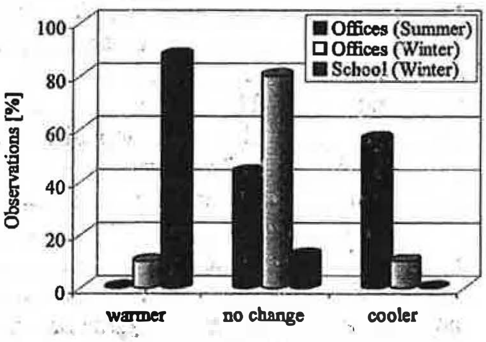

Figure 3 Frequency distributions of McIntyre votes.

Table 4 shows cross-tabulations to the questions leading to the results presented in Figures 2 and 3, in order to identify eventual contradictions. According to Table 4, 68% of the students voted within the three central categories of thermal sensation, 52% feeling slightly cool wanted to be warmer and 60% reporting a neutral sensation still preferred a change in their thermal state. In the case of

Table 4 Thermal sensation versus McIntyre Votes.

	Warmer	No Change	Cooler
School (winter)			
-3	6.1	0.0	0.0
-2	26.3	0.0	0.0
-1	51.5	2.0	0.0
0	6.1	8.1	0.0
1	0.0	0.0	0.0
2	0.0	0.0	0.0
3	0.0	0.0	0.0
Offices (Summer)			
	Warmer	No Change	Cooler
-3	0.0	0.0	0.0
-2	0.0	1.9	0.0
-1	0.0	9.3	1.9
0	0.0	14.8	1.9
1	0.0	11.1	18.5
2	0.0	5.6	24.1
3	0.0	0.0	11.1

the office buildings monitored in winter, all votes were within the warm side of the central categories, with 20% wanting to be either warmer or cooler. During the summer period, the results presented in Table 4 suggest that the central categories gathered 58% of the votes while 23% still wanted to be cooler. Only 2% of the voters felt cool without desiring any change to their thermal condition. Bearing in mind the restrictions imposed by the sample sizes, the results seem to be reasonably consistent. On the other hand, the results support the idea pointed out by Schiller (1988) that a neutral state is not necessarily the most preferred for all people and that there will be always some individuals that prefer to feel warm or cool.

The results shown in Figure 4 represent a tentative comparison between the observed mean thermal sensation votes (OMV) and the corresponding predicted PMV values. Calculations were made including the chair increment. For both seasons, the mean activity level was 1.2 met. Owing to the small sample size and uncertainties on estimated clothing and activity levels, the following considerations must be regarded with some precaution. Nevertheless, some tendencies can be dressed from Figure 4. During the summer, OMV suggests that achievement of thermal neutrality would require cooler environments. In contrast, comfortable conditions during the winter season may be satisfied with comparatively lower temperatures. These contrasting trends are believed to agree with the common practice of Portuguese people, particularly within the great majority that works in naturally ventilated buildings. In general, it may be argued that occupants are more able to adapt to colder environments, by changing clothing accordingly and using local heating devices as well. In schools, for instance, students often keep their outdoor garments during the early morning classes. Under warm conditions, adaptive postures are less efficient and neutral temperatures are aimed to be lower than static comfort models would predict.

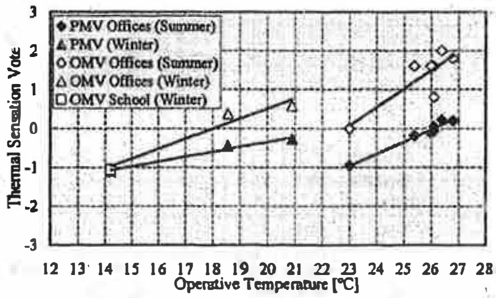

Figure 4 Thermal sensation votes versus PMV.

CONCLUSIONS

The present case study has given the authors a first insight towards indoor climates in office buildings and schools, during summer and winter conditions in the city of Coimbra. The field measurements confirmed the occurrence of uncomfortable working conditions, namely in the case of the secondary school. However, analysis of the questionnaires supports the idea that thermal acceptability can be obtained outwards the most widely accepted comfort standards.

In particular, it is believed that field studies should be carefully weighted by weather conditions, namely those characterizing the previous few days, let's say three to five. For instance, attention must be given to the occurrence of hot or cold spots as the thermal sensation during or just after such periods is somehow affected. This is obviously more relevant in the case of free running buildings where indoor conditions are strongly dictated by thermal inertia.

It has been demonstrated, for the case of Coimbra, that the subjective background of participants should be carefully accounted. In a certain sense, each person that fills the questionnaire, since he or she is under *real* working conditions, must be considered as *real* as possible. Background questionnaires will thus be added to the next thermal comfort evaluations by the authors. This is believed to be particularly true in the case of Portugal or other latitudes, whenever application of comfort standards is still absent from daily concern. People participating at such evaluations, independently of age, sex or cultural background, should be carefully informed first about a few aspects governing thermal comfort.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the assistance of the *Instituto de Desenvolvimento e Inspecção das Condições de Trabalho* (IDICT) and the direction of *Escola Secundária de D. Duarte*, for their original interest and co-operation.

A special acknowledgement is also due to the graduate students that gently participated in the data collection.

REFERENCES

ASHRAE (1992) *ANSI/ASHRAE Standard 55-1992, Thermal environmental conditions for human occupancy*. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta.

Brüel & Kjær (1990) *Indoor Climate Analyser Type 1213 Instruction Manual.* Brüel & Kjær, Denmark.

Chan, D.W.T., Burnett, J., de Dear, R.J. and Ng, S.C.H. (1998) A large-scale survey of thermal comfort in office premises in Hong Kong. *ASHRAE Transactions*, 104(1).

de Dear, R.J. and Fountain, M.E. (1994) Field experiments on occupant comfort and office thermal environments in a hot-humid climate. *ASHRAE Transactions*, 100(2), 457-475.

de Dear, R.J. and Brager, G.S. (1998) Developing an adaptive model of thermal comfort and preference. *ASHRAE Transactions*, 104(1).

Fanger, P.O. (1970) *Thermal Comfort – Analysis and Applications in Environmental Engineering.* McGraw-Hill, New York.

Humphreys, M.A. and Nicol, J.F. (1995) An adaptive guideline for UK office temperatures, in *Standards for thermal comfort - indoor air temperature standards for the 21st century* (edited by F. Nicol, M. Humphreys, O. Sykes and S. Roaf). Chapman & Hall, London.

Humphreys, M.A. (1996) Thermal comfort temperatures world-wide - the current position. *Renewable Energy*, 8, 139-144.

ISO (1994) *International Standard ISO 7730, Moderate thermal environments - determination of PMV and PPD indices and specification of the conditions for thermal comfort.* International Organization for Standardization, Genève.

Parsons, K.C. (1985) Introduction, in *Standards for thermal comfort - indoor air temperature standards for the 21st century* (edited by F. Nicol, M. Humphreys, O.

Sykes and S. Roaf). Chapman & Hall, London.

Schiller, G.E., Arens, E.A., Bauman, F.S. and Benton, C., Foutain, M., Doherty, T. (1988) A field study of thermal environments and comfort in office buildings. *ASHRAE Transactions*, 94(2), 280-308.

Schiller, G.E. (1990) A comparison of measured and predicted comfort in office buildings. *ASHRAE Transactions*, 96(1), 609-622.