Thermo-hygrometric comfort in the lecture hall of a library: methodology and experimental evidence.

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Abstract

The present study verifies the thermo hygrometric comfort conditions in subjects of a university library users, evaluating the differences and peculiarities in the data collected at the measurement campaign.

Particularities of the investigation is the period studied concerning the time frame of the Middle season, which is not expected to power the air conditioning systems.

Based on assumptions on the thermal resistance of clothing in the spring and the metabolic type of subjects, the environmental parameters were monitored in some work position in the reading hall in the library of the Faculty of Medicine and Surgery of the University of Palermo.

The article presents analyses of the measured data correlating the passive structure behavior and the variation of the internal temperature increases caused by the occupants and by the external temperature gradient.

These results are compared with the limits and the guidelines provided by legislation for the main variables measured and derived, and which constitute the essential support to test the tolerability of the occupiers against the thermal environment with which they interact.

Keywords: PMV PPD Indexes, Thermo-hygrometric comfort, acceptability classes.

1. Introduction

Thermo-hygrometric comfort is important in work and study places, where discomfort can influence both the users' health and their work efficiency (e.g., discomfort could cause a loss of concentration).

With the aim of verifying the coherence of the measured data to the normative and legislative standards, this research was conducted to determine the thermo-hygrometric comfort inside the library of the Faculty of Medicine and Surgery of the University of Palermo during the period of inactivity of the Heating Ventilation Air Conditioning system (spring season) [1]. According to Italian laws, the air temperature of a library does not have to maintain restrictive values.

Because of the absence of an air-conditioning system, the correlations between the external temperature fluctuations and the increasing index of crowding in the library have been identified [2],[3].

1.1 Characteristics of the environment

The studied environment has a rectangular layout (length: 10.70 m, width: 18.00 m). The reading room is on the ground floor, and there are small balconies in an upper level, where the books are stored in a system of shelves. The room height is 8.70 m.

Generally, a reading hall is not greatly different from a common office in which sedentary activities are carried out.

The consultation of the library books is carried out while the users are seated, but the users can stand to check out or shelve a book.

The library under study is particularly suitable for surveying because, for obvious reasons of safety, it is not possible to open windows or doors to interact with the outside environment; for this reason, the task of maintaining a comfortable indoor microclimate depends exclusively on the air-conditioning system. [4],[5]. Figure 1 shows the library plan and a photo of the room.

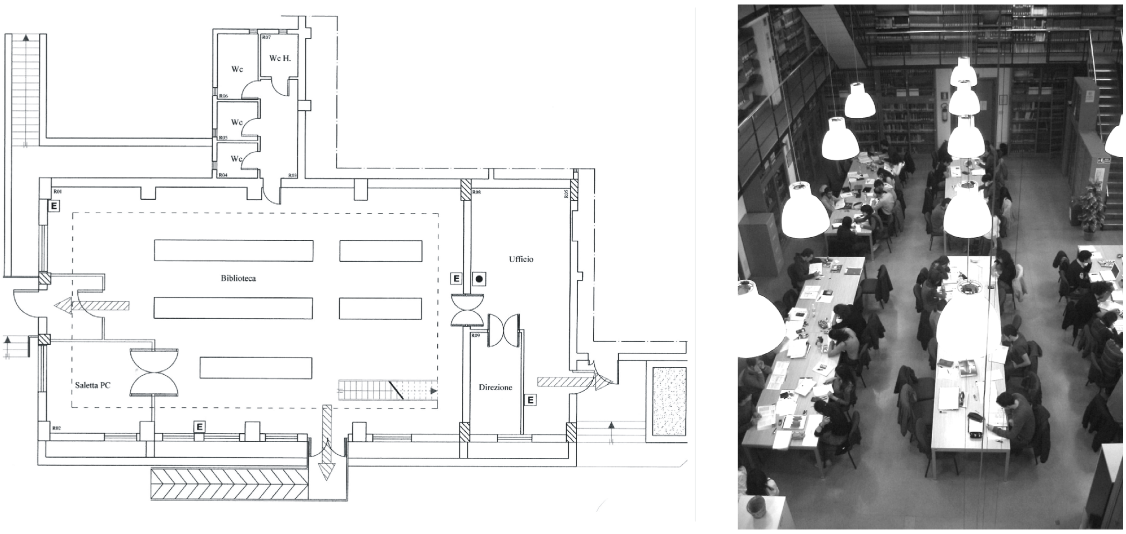

Figure 1 - Library plan and photo of the room.

2. Materials and Methods

The study of microclimatic comfort was carried out according to the ASHRAE Standard 55/2004 [6] and UNI EN ISO 7730:2006 [7].

In a preliminary phase, measurements of the main thermo-hygrometric parameters were made using a multi-acquisition station with the aim of determining the more interesting points of the room to establish more representative points to carry out the continuative measures.

From such preventive surveying, it was gathered that the fluctuations of the air temperature, relative humidity and speed values of the air did not vary widely, instead showing a remarkable level of uniformity.

This uniformity, which confirmed when the HVAC system was switched off, led the researchers to place the probes for continuous measurement at a barycentric point sufficiently distant from the main door and from the windows.

The values found at such a point, considering also the height from the ground, can be considered to be representative of the thermo-hygrometric conditions of the hall.

The purpose of this survey is not to study eventual and tolerable fluctuations of the values that are measurable at different heights. The measurements were carried out by a multi-acquisition station (datalogger) with 11 channels and a memory of 20 000 samples. The system had been programmed in 5 minutes cycles. A short description of the probes used during the measurements follows. A probe to measure the air temperature (accuracy ± 0.17 °C); an anemometric probe with a warm wire to measure the average air speed and the intensity of turbulence (accuracy ± 5 cm for Va between 0 ÷ 0.5 m/s, ± 10 cm for Va between 0.5 ÷ 1.5 m/s and 4% for Va > 1.5 m/s); a globe-thermometer probe in opaque black copper (reflection < 2%) with a 15 cm diameter to measure of the mean radiant temperature (accuracy ± 0.17 °C); and a psychometric probe with forced ventilation (temperature accuracy ± 0.13 °C, relative humidity ± 2%). The measurements took place on 29 and 30 March 2010 from 10:00 a.m. to 6:00 p.m., which are the hours of maximum use of the library. After the placement of the probes, the data acquisitions started after 15 minutes to allow the probes to reach equilibrium with the microclimatic conditions of the environment. The external values of the air temperature were acquired simultaneously.

3. Acceptability Criteria for an Environment

The PMV (Predicted Mean Vote) and PPD (Predicted Percentage of Dissatisfied) are excellent indices of sensations [8]. These indexes represent an average score expressed by a large number of subjects in the same microclimate. The first index is derived from the thermal balance equation. This index is composed of four environmental variables, two physiological and two subjective, and the index shows the average opinion on thermal sensations. The second index, which is analytically derived from the former, shows the number of unsatisfied subjects on microclimate conditions. The PMV allows stating, across the following equation (1), the thermal sensation of a subject inside an indoor environment [9].

$$\begin{aligned} \mathrm{PMV} = & \left[0.303 \cdot \exp(-0.036 \cdot M) + 0.028\right] \cdot \{(M-W) - 3.05 \cdot 10^{-3} \cdot [5\,733 - 6.99 \cdot (M-W) - p_a] + \\ & -0.42 \cdot [(M-W) - 58.15] - 1.7 \cdot 10^{-5} \cdot M \cdot (5\,867 - p_a) - 0.0014 \cdot M \cdot (34 - T_a) - 3.96 \cdot 10^{-8} \cdot f_{cl} \cdot \\ & \cdot \left[(t_{cl} + 273)^4 - (\bar{t}_r + 273)^4\right] - f_{cl} \cdot h_c \cdot (t_{cl} - t_a) \end{aligned} \tag{1}$$

With:

$$\mathrm{T_{cl}} = 35{,}7 - 0.028(M-V) - I_{cl}\left[3{,}96 \cdot 10^{-8} f_{cl}\left\{(t_{cl}+273)^4 - (t_{MR}+273)^4\right\} + f_{cl} h_{cl} (t_{cl} - t_a)\right]$$

$$h_c = 2{,}38\,(t_{cl} - t_a)^{0{,}25} \quad \mathrm{se:} \quad 2{,}38\,(t_{cl} - t_a)^{0{,}25} > 12{,}1\sqrt{V_{ar}}$$

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$$f_{cl} = 1{,}00 + 1{,}29 I_{cl} \quad \mathrm{se:} \quad R_K < 0{,}078\ (\mathrm{m^2 \cdot °C})/\mathrm{W}$$

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Where:

M = Produced metabolism [W/m^2]

W = Produced power [W/m^2]

P_a = Water vapour pressure [Pa]

T_{mr}= Mean Radiant Temperature [°C]

t_a = Air temperature [°C]

T_{cl} = Mean surface temperature of clothes [°C]

V_{ar} = Relative air speed [m/s]

I_{cl} = Clothing resistance [(m^2·K)/W]

f_{cl} = Ratio between clothed skin surface and see-through clothes

h_c = Convection heat transfer coefficient [(m^2·K)/W]

The PPD is derived from the PMV through the following equation (2):

$$PPD = 100 - 95\exp - (0{,}03353 PMV^4 + 0{,}2179 PMV^2) \tag{2}$$

The UNI EN ISO 7730/2006 introduces three quality classes (C, B, A) that, in the same order, are characterised by increasingly restrictive requirements or by accepted ranges for increasingly smaller quality indices. This three-class scheme is applied to both global comfort indexes (PMV and PPD) and local discomfort indexes. Table 1 shows the maximum acceptable number of unsatisfied percentages.

Table 1- Comfort classes by UNI EN ISO 7730/2006

Classes	Global comfort	
	PMV	PPD
A	-0.2 ÷ +0.2	< 6%
B	-0.5 ÷ +0.5	< 10%
C	-0.7 ÷ +0.7	< 15%

Results

Starting from the environmental parameters measured, it is possible to obtain the values of discomfort indices. It is necessary to suppose values referring to the subjects' activity (Met) and the thermal resistance of their clothes (Clo).

The physical activity has been supposed as sedentary with a value of 1.25 Met (72.75 W/m^2).

The Clo index, considering the spring season, was estimated while considering the different kinds of dress between men and women. The values supposed are 1.00 Clo (0.155 m^2 K/W) for men and 0.9 Clo (0.139 m2 K/W) for women.

The estimated values, as PMV and PPD indices, were related to optimal values suggested by laws. The graphs in Figure 2 report the outside temperature, PMV and PPD values on 29 and 30 March. The values are different, even if they are related to consecutive days.

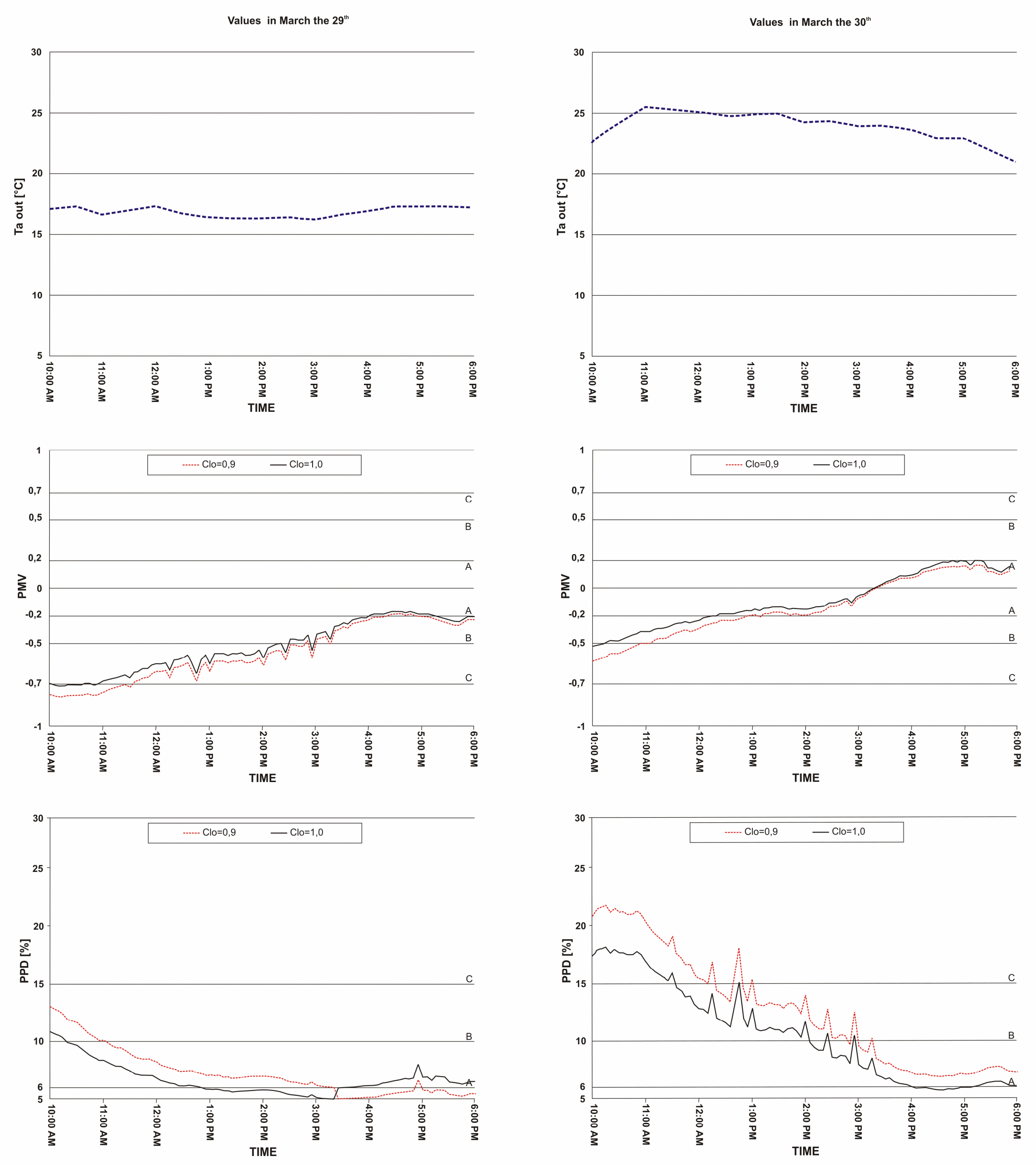


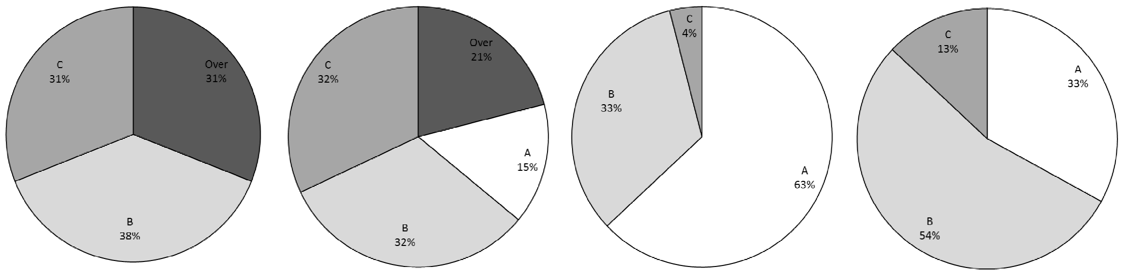
Figure 2 – External air temperature, PMV and PPD values (left column 29 March; right column 30 March)

Discussion

Analysing the diagrams, the correlation between the external temperature and the tendency of the PMV elevation toward positive values appears immediate, even if it is inside the acceptability classes. The fluctuation of the diagrams shows little difference between the male (Clo=1.0) and female subjects (Clo=0.9). On the first day of observation, the maximum legal limit of 15% on the predicted percentage of unsatisfied (PPD) subjects was exceeded, and the PMV values were negative (values that are slightly cold) for the short period of time of the first opening hours of the library. The phenomenon is easily understandable, considering that the air conditioning system was switched off. Moreover, the data of the subjects' feelings are superimposable to the relatively low levels of external temperature during the first hours of the day and to the insufficient internal temperature gains (artificial lights and number of people). Afterward, the global discomfort index tends to reduce its value: it is included in the C class (PMV -0.7÷ 0.5; PPD < 15%) for 31% of the time with a Clo of 0.9 and for 32% of the time with a Clo of 1.0. Next, the index enters the B class (PMV -0.5 ÷ -0.2; PPD < 10%) for 38% of the time. Finally, considering only a Clo=1.0 the global discomfort index results are included in the A Class (PMV<-0.2; PPD<6%) for 15% of the time. During the second day of surveying, the results seem to be different. The PMV and PPD values are always included in the acceptability range, and they enter the A Class for a significant period of time (from 12:00 p.m. to the end of the surveying period). In this case, the index fluctuation varies from negative to positive values, reaching a PMV=0.2. As shown, the PPD values are included in the C class from 10:00 a.m. to 11:00 a.m., in the B class from 11:00 a.m. to 3:00 p.m. and in the A class from 3:30 p.m. to 6:00 p.m. When the Clo is 0.1 (male subject), the calculated value at the end of the monitoring time tends to increase, exceeding the A Comfort Class range. The results of the synoptic analysis of the phenomena between the male and female genders in the two days to be considered are reported in following graphics (Figure 3).

Conclusions

March 29th **March 30th**



Clo = 0.9 Clo = 1.0 Clo = 0.9 Clo = 1.0

PPD (%) mean = 12.66 PPD (%) mean = 10.54 PPD (%) mean = 7.29 PPD (%) mean = 6.70

Figure 3 – Time distribution of the acceptability classes for March 29 (left) and March 30 (right).

The PMV and PPD indices do not significantly deviate from the neutral thermal state for either the male or female subjects. The results clearly show a slight fluctuation given by the lower Clo index. The sensation indices are confirmed to be a versatile instrument to “objectify” the thermo-hygrometric feelings of the people who operate in heterogeneous conditions. Articles 180 and 181 of Italian law, which are concerned with security and health in workplaces (in this case a lecture hall), show the necessity of evaluating the risk factors of microclimate; however, specific parameters are not given. Therefore, technical and scientific knowledge plays a leading role in correct evaluation of the workplace. In this task, the role of occupational and health doctors cannot be prescinded among all of the aspects regarding sanitary surveillance, to analyse the health data of the subjects and to conduct research of the possible problems in the workplace. This analysis requires a preventive knowledge background of the physical parameters with the subjects who interact in the workplaces.

This information can be deduced by the required “Documents of risk evaluation”. The results obtained from sanitary surveillance are instruments for implementing the correction and integration of prevention measures. By analysing the results obtained in this study, it is possible to express a positive opinion about the global thermo-hygrometric tolerability of the considered environment. These results confirm the observance of the limits imposed by the Annex IV of the Legislative Decree n.81 of 2008, which regulates the microclimate and thermal conditions of workers. The law guarantees the IAQ limits to maintain healthy air and thermal conditions to enable workers to carry out their tasks. It seems clear that the working conditions of a library differ greatly from industrial or craft indoor environments. Nevertheless, the occupants’ comfort can be disturbed by the urban setting, the design of the building, the construction materials, the furniture, the presence of an air-conditioning system and, finally, by poor space and task distribution. The individuation and management of the risk factors requires the cooperation of different skilled personnel, such as architects, occupational health experts, industrial hygienists, engineers and designers of HVAC systems to remove the causes of health problems and reach the target comfort level.

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