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Thermal comfort in Italian classrooms under free running conditions during mid seasons: Assessment through objective and subjective approaches

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ABSTRACT

This work shows the results of a field study about indoor thermal comfort, based on investigations in Italian classrooms. The surveys were carried out in Turin, in the North–West of Italy. The monitoring campaigns were performed during the mid season, in free running conditions. This study follows a previous one based on a monitoring campaign performed during the heating season. The responses from these two different configurations were integrated, analyzed and compared.

The field study was conducted by physical observations, survey questionnaires and behavioral observations. Both field measurements and subjective surveys were performed at the same time during the regular lesson period. Thermal environment parameters were measured: indoor air temperature, mean radiant temperature, air relative humidity, air velocity and outdoor air temperature. Through these data, Fanger's comfort indices were calculated (predicted mean vote and predicted percentage of dissatisfied people), the actual people clothing and metabolic rate being known; furthermore an adaptive model was applied to obtain acceptable ranges for the indoor operative temperature, in function of the outdoor climatic conditions. The subjective survey investigated the thermal sensation, the thermal acceptability and the thermal preference, using subjective scales. The subjective judgments about the thermal environment were compared with the results of the field measurements. Moreover, the thermal sensation votes were compared with the votes of acceptability and preference. The responses from this study and from the previous one, performed during the heating season, were compared. The results show a trend characterized by a gradual change in the thermal preference from the heating season to the mid and warm season. In fact, the results show a preference for environments judged slightly warm or warm during the heating period and a preference for neutral environments in the mid season.

1. Introduction

The indoor environmental quality (IEQ) affects not only health and comfort, but also the occupants' productivity, so it strongly influences working and learning efficiency, with repercussion on production and social costs. In particular, schools are a category of buildings in which a high level of environmental quality may considerably improve occupants' attention, concentration, learning, hearing and performances [1].

An interesting review of the first scientific studies about the effects of the thermal quality on the students' performances in classrooms is given in the work of Pepler and Warner [2]. Numerous studies, in the last years, have been focused on finding relationships between the indoor environment and occupants' performance and productivity in schools and working environments [3].

Some studies are focused on the analysis of the different influence of the single aspects of the IEQ, such as acoustical, thermal, indoor air and visual quality on the overall quality assessment [4].

Thermal comfort is an important factor for the IEQ and it is also one of the main sources of energy consumption in buildings.

This study is focused on thermal comfort and aims at achieving a better knowledge about the subjective perception in naturally ventilated environments, in which the occupants have only some opportunities of behavioral adjustment. A particular, but significant, case is here analysed: Italian naturally ventilated classrooms.

At present, two different approaches for the definition of thermal comfort coexist, each one with its potentialities and limits: one can be defined "rational", the other "adaptive".

Fanger's model [5] based on steady state heat transfer theory, has a rational approach and provides the basis of the main thermal comfort standards [6,7], for mechanically controlled environments. The PMV (predicted mean vote), based on this theory and deriving from climatic chamber studies, is the most widely used thermal comfort index.

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Adaptive comfort models derive from field studies, having the purpose of analysing the real acceptability of thermal environment, which strongly depends on the context, on the behavior of occupants and on their expectations. The analysis of "real-world" settings, through field research, is necessary, in order to test the validity of PMV in every-day environments [8,9]. Furthermore it reveals that thermal preferences depend on the way people interact with their environment, modifying their own behavior and adapting their expectations, to match the thermal environment [10].

Various field studies have investigated the preference votes regarding the indoor thermal environment, with respect to conditions of thermal neutrality. Preferred temperatures do not necessarily coincide with thermal neutrality. McIntyre [13] found that people of warm climates may prefer what they call a "slightly cool" environment and, on the contrary, people of cold climates may prefer what they call a "slightly warm" environment. Recent field studies confirm the same tendency outlined by McIntyre's research and add new findings [11,12,14].

Moreover recent field studies find that people in naturally ventilated indoor environments are comfortable within a range of microclimatic values that is larger than in fully conditioned indoor environments [11,15,16].

In particular, several studies demonstrate that in a warm climate, in naturally ventilated environments, people can achieve comfort at higher indoor temperatures, compared to the recommendations based on the PMV calculation. They also find a good relationship between indoor comfort and outdoor conditions [11,17,18].

The latest revision of the ASHRAE Standard 55/2004 [6] includes an adaptive thermal comfort diagram for "occupant-controlled naturally conditioned spaces" (office or similar type), characterized by near sedentary activities (1–1.3 met), clothing flexibility and a high level of control over the indoor climate from the occupants, mainly through windows opening; this diagram derives form the Research Project ASHRAE RP-884 [11].

Similarly, the standard EN15251/2007 [19] includes an adaptive thermal comfort diagram for the same type of environment, which was developed in a recent EU-funded research project coordinated by the Oxford Brookes University (Fig. 1) [18].

For the aim of this study, considering the geographical zone in which it was performed, this diagram was chosen as the most correspondent to the examined environments and it was applied in the field study.

The diagram of Fig. 1 expresses the acceptable tolerance ranges for the indoor operative temperature, corresponding to three different expected percentages of satisfied people (category I = 90%; category II = 80%; category III = 65%), as a function of an outdoor temperature index, called "outdoor running mean temperature".

The outdoor running mean temperature is defined as the exponentially-weighted running mean of the outdoor temperature. It is calculated from the outdoor daily mean temperatures of the days preceding the examined one (day n), with this formula [18,19]:

$$t_{\mathrm{ORM}(n)} = (1-\alpha)\left(t_{\mathrm{ODM}(n-1)} + \alpha t_{\mathrm{ODM}(n-2)} + \alpha^2 t_{\mathrm{ODM}(n-3)} + \cdots\right), \tag{1}$$

where $t_{\mathrm{ORM}(n)}$ is the running mean temperature in the day n, $t_{\mathrm{ODM}(n)}$ is the outdoor daily mean temperature in the day n and α is a constant between 0 and 1, defining the speed at which the running mean temperature responds to the outdoor temperature (a value of 0.8 implies that the characteristic time subjects take to fully adjust to a change in the outdoor temperature is around 5 days and corresponds to the highest correlation with comfort sensation).

In this study, the comparison between the subjective votes and the predicted votes, deriving from the objective monitoring of thermal parameters, allows the test in field of different existing criteria, based both on a rational approach and on an adaptive approach.

The adaptive actions of the students to modify the microclimate parameters may include adding or removing layer of clothing, opening or closing windows, moving sun shading devices, etc. [20,21]. Nevertheless, classrooms are an example of indoor environment in which the adaptive opportunities are quite limited during the lessons period, but they are free during the hourly lesson breaks. In fact, students have to spend lots of time in listening and understanding lessons, remaining sitting at their desk. Moreover, the freedom of students in modifying and adjusting their activity level according to the thermal environment is, to a certain extent, limited during the lesson time, as well as the possibility to change the functioning parameters of the HVAC systems or to open/close the windows. But the same actions are free during the lessons breaks.

This study is part of a wider research started by the TEBE Research Group (see http://www.polito.it/tebe) of the Politecnico di Torino, which was focused on environmental comfort in Italian

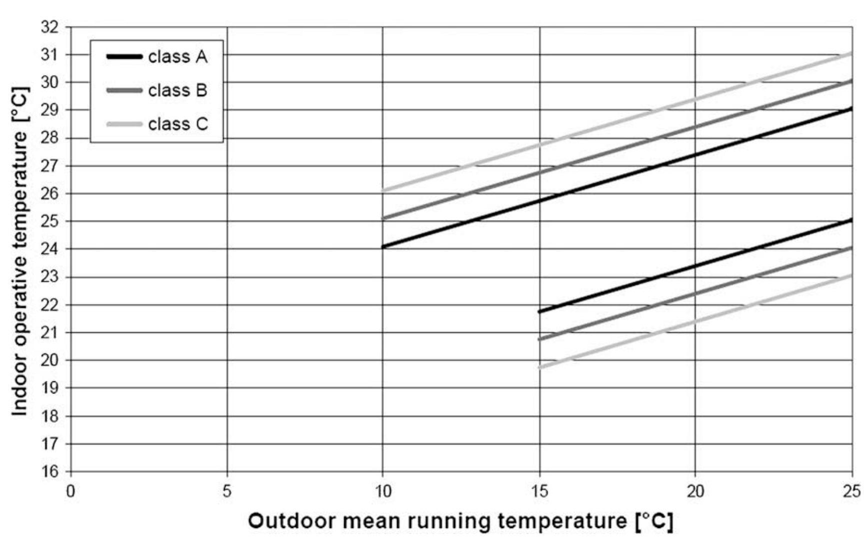

Fig. 1. Adaptive thermal comfort diagram for the design of naturally ventilated environments, adopted into Standard EN15251/2007 (the three sets of lines define the temperature ranges for category I, II and III).