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Evaluation of thermal comfort in university classrooms through objective approach and subjective preference analysis

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ABSTRACT

Assessing thermal comfort becomes more relevant when the aim is to maximise learning and productivity performances, as typically occurs in offices and schools. However, if, in the offices, the Fanger model well represents the thermal occupant response, then on the contrary, in schools, adaptive mechanisms significantly influence the occupants' thermal preference. In this study, an experimental approach was performed in the Polytechnic University of Bari, during the first days of March, in free running conditions. First, the results of questionnaires were compared according to the application of the Fanger model and the adaptive model; second, using a subjective scale, a complete analysis was performed on thermal preference in terms of acceptability, neutrality and preference, with particular focus on the influence of gender. The user possibility to control the indoor plant system produced a significant impact on the thermal sensation and the acceptability of the thermal environment. Gender was also demonstrated to greatly influence the thermal judgement of the thermal environment when an outdoor cold climate occurs.

1. Introduction

Assessing the Indoor Environmental Quality (IEQ) is the first step to design a low energy building and to ensure the comfort of the occupants, according to high quality standards. This process becomes more relevant when offices or schools are taken into account; here, the workers' needs also must be "efficient" in terms of learning and productivity.

Recent studies have analysed the close relationship between performance and thermal comfort of the occupants in workplaces. Remarkable results (Lorsch and Abdou, 1994a, 1994b; Akimoto et al., 2010; Berglund et al., 1990; Clements-Croome, 2001; Jokl, 1982; Sensharma et al., 1998) must be considered. Better indoor comfort conditions correlated more than just the best result in terms of work productivity because thermal comfort is related to several factors. Furthermore, the lack of comfort causes an "environmental stress", thereby producing a negative trend (Ossama et al., 2006). Office employees working in suitable hygrothermal conditions were proven to be more productive and less prone to absenteeism and grievances, also increasing the level of attention, thereby reducing the risk of accidents during working time (BOSTI, 1982).

Fisk and Rosenfeld (1997) analysed the impact on production and social costs that comfort conditions have in offices in the United States. The indoor comfort improvement causes a direct increase of 0.5–5% in U.S. productivity, i.e., potentially, an annual economic enhancement between 12 and 125 billion U.S. $ (Lan et al., 2012).

Similarly, students attending classes in a comfortable environment can improve their performances in terms of attention, concentration and learning. In the late 1960s, Pepler and Warner (1968) were the first researchers to investigate the effects of the thermal environment on the intellectual performances of students. The experiments were conducted on 36 women and 36 men in climatic chambers. The results indicated an inverse U-shape relationship with time to complete a task and temperature, with the best performance corresponding to 26.7 °C. At this temperature, the students involved completed the assigned work in the shortest time.

This paper provides an additional contribution to the investigations on thermal comfort performed in schools, validating different thermal models according to international standards. The correlation between hygrothermal comfort perception and control of climate parameters was investigated, considering the climate of Bari (Italy).

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1.1. Comfort models

Physiologically, hygrothermal comfort is achieved when the thermoregulatory mechanisms of the body are minimised in response to the signals transmitted by the thermal receptors. In moderate thermal environments, the subjective individual condition must be considered significant regarding mental as well as physical comfort.

Current European Standards dealing with the "Ergonomics of the thermal environment" provide two different approaches for evaluating comfort in moderate environments, based on different assumptions: the rational model of Fanger (EN ISO 7730, 2005) and the adaptive approach (EN 15251, 2007).

Fanger's model is based on an energy balance of the human body, considered as a thermodynamic system that exchanges heat with the external environment. This model was first developed in the 1970s and is based on tests performed in a climatic chamber for 1296 Danish students (Fanger, 1970). The model is based on three fundamental assumptions:

1. passive people: users without any possibility of controlling the environment in which they are;
2. the same results are achieved for equal values of the six input variables;
3. steady-state model: only small time variations of the environmental parameters are allowed.

This model provides results that are very close to the real ones when the values do not vary, i.e., when considering an HVAC system with passive behaviour of the occupants and fixed wear. The best application for this model was for offices, often with a centralised HVAC, where the occupants had work schedules, fixed locations, and sometimes even a standard work wear.

The adaptive approach comes from field studies that began in the mid-1970s in response to the oil-shocks. This approach considers the individual user interaction with the environment, performing a thermal adaptation on three different levels (deDear et al., 1997):

1. conscious or unconscious behavioural adjustment, directly connected to the human body energy balance, classified as: individual (referring to wear, activity, posture, hot/cold drink consumption, moving to other rooms), technological (referring to the user's ability to change plant system settings, opening/closing windows, or window solar shadings), and cultural (working time and breaks);
2. physiological: a prolonged exposure to particular environmental conditions determines a reduction in stress and an increase in tolerance, which is distinguishable as genetic adaptation and acclimatisation;
3. psychological: regarding previous experiences, expectations, or the perception of microclimate control possibility.

The adaptive model is based on a simple correlation between the optimum internal temperature and the external reference temperature. ASHRAE Standard 55 (2013) considers a reference external temperature based on no fewer than 7 and no more than 30 sequential days prior to the day in question. EN 15251 Standard (2007) considers, accurately, a Running Mean temperature, i.e., a weighted mean value of the daily mean temperatures of the seven previous days. The individual thermal sensation was observed to be more strongly influenced by the outdoor temperature recorded in the days closer to the real one than by monthly mean temperature values (Brager and deDear, 1998).

Experimental tests have demonstrated that the adaptive model provides more realistic results in naturally ventilated environments, especially where the occupants can control the microclimatic parameters. In addition, the range of comfort values in naturally ventilated environments is larger than those in HVAC environments (Brager and deDear, 1998). Several researchers found that the experimental results are closer to the real judgement of the occupants than the results achieved in climatic chambers. McIntyre (1978), comparing the results obtained by Fanger in climatic chambers with those achieved by observations, considered that some variables of the real world cannot be reproduced in a climatic chamber. Oseland (1995) and Becker and Paciuk (2009) confirmed the McIntyre results involving study of hygrothermal comfort, both in offices and in residential buildings.

However, the Fanger model can be considered the most reliable and the only scientific model for the hygrothermal comfort assessment. The Fanger model takes into account the most important variables affecting the thermal sensation, unlike the adaptive model, which considers only an external reference temperature. To improve the model, Fanger and Toftum (2002) introduced a correction to the model by the new PMVe model. Fanger has corrected the expectation of the occupants in warm climates in buildings without air-conditioning via introduction of a factor of expectation in the comfort equation.

Several campaign surveys have been conducted in three different continents, and the PMVe model validation is still ongoing; further results are required before it could be considered a standard.

A completely different approach was provided by Yao et al. (2009) for the comfort evaluation. He defined a theoretical adaptive model of thermal comfort, aPMV (adaptive Predicted Mean Vote), based on the theory of black-box, whereas the cultural, climatic, social, psychological and behavioural adaptation factors play an important role in thermal sensation. Employing the aPMV model, based on the mechanisms of cybernetics in buildings without HVAC, note that the PMV predicted by Fanger overestimates the current average rating.

Recent studies on thermal comfort, taking into account the thermal preferences and people's acceptability (Corgnati et al., 2009; Dili et al., 2010; Buratti and Ricciardi, 2009), have determined that the thermal judgement of the users is more complex than a simple thermal vote.

McIntyre (1980) indicated that the preferred temperature is not the neutral one, but it depends on the place where the users are. People of cold climates may prefer what they call a "slightly warm" environment and vice versa.

Brager and deDear (1998) have defined this aspect as the "semantic effect", describing the deviation between the preferred and the neutral temperature in full air-conditioned environments by a linear relationship, depending on the outdoor daily average temperature. In naturally ventilated environments, it is not possible to establish a general relation because it varies greatly depending on the geographical area due to the adaptation mechanisms of the people.

1.2. Recent studies carried out in schools

In offices, the clothing is often fixed, and the average age of the occupants is highly variable; there are centralised HVAC plants, and the users cannot control the microclimatic parameters (i.e., opening of windows and controlling solar shadings). On the contrary, in classrooms, a greater control of conditioning plants is possible by adapting the indoor microclimate during the hourly lesson breaks, but it is limited during school time.

Several surveys were conducted in schools at different levels. The microclimatic parameters were set in relation to the judgement