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Application of a new 13-value thermal comfort scale to moderate environments

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HIGHLIGHTS

- Thermal comfort evaluation within non-residential environment using adaptive approach.
- Development and application of a new 13-value comfort scale.
- Comparison between different methodologies using for the thermal comfort sensation.

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ABSTRACT

A new 13-value thermal comfort scale is adopted in the present study, in order to evaluate the thermal comfort sensation within non-residential buildings with the adaptive approach.

18 classrooms located both in Pavia and Perugia, the Fraschini Theatre, and one auditorium located in Pavia were investigated from October 2014 to October 2015 collecting about 1600 questionnaires. All the information reported in the questionnaires was correlated by defining several indexes and a comparative analysis was carried out between the two comfort scales (13-value and 7-value scale).

Results showed that using the new 13-value scale the percentage of people who declared a thermal sensation equal to 0 greatly decreased: from 66% to 41% for the classrooms and from 47% to 36% for the theatre-auditorium. The percentage of occupants who considered the environments not thermally comfortable, although they declared a thermal sensation equal to 0, also decreased, from a mean value of 10.4% to 2.7% for the classrooms and from 6.0% to 2.6% for the theatre-auditorium.

Considering the 7-value scale, although a thermal sensation equal to 0 was declared, a higher percentage of people who would feel a little bit cooler or a little bit warmer was found. Instead using the 13-value scale, this percentage significantly decreased, because people declared a thermal sensation equal to ±0.5 (more than 50% of cases) instead of 0.

In agreement with these results, the new scale seems to be more accurate than the traditional one, allowing a better correlation among all the data reported in the questionnaires.

1. Introduction

Thermal comfort in crowded environments is a very important issue, due to the high heat loads and to the impossibility for occupants to modify the environmental conditions, especially when centralized HVAC systems are present.

Many studies were carried out for the evaluation of thermal comfort in different kind of environments; when the thermal comfort condition is an achievable goal, the environments are defined "moderate"; on the contrary, if the main target is the occupants' health, they are called "severe". In the Literature many studies were carried out considering moderate environments such as classrooms, residential, and office buildings [1–9]. All of them applied the classic approach introduced by Fanger, i.e. based on the indexes Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD), also defined and used in UNI EN ISO 7730 [10], which provides a method to calculate and to interpret global and local thermal comfort. However, the data acquisition requires specific instruments, not always available, and is very time demanding. Other scientific works tried to evaluate the thermal comfort sensation by using also mathematical models. In particular [11] was focused on thermal comfort evaluation in Galatsi Arena in Athens, Kim et al. [12] presented an analysis on whether the

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Nomenclature

I_{cl}	thermal insulation of clothing (clo)
MTS	Mean Thermal Sensation (–)
n	number of sample data
RH	relative humidity (%)
s	variances of the sample data
t	t-values of the *t*-test
T_a	air temperature (°C)
TSV0	percentage of people who declared a thermal sensation equal to 0 (%)
TC	percentage of people who considered the environment thermally comfortable (%)
T_{mr}	mean radiant temperature (°C)
TNC	percentage of people that considered the environment not thermally comfortable (%)
TNA	percentage of people that considered the environment not thermally acceptable (%)
TNCV0	percentage of people that considered the environment not thermally comfortable although they declared a thermal sensation equal to 0 (%)
v	air velocity (m/s)
X	mean value of the thermal sensation declared in the questionnaires

Subscripts

q	questionnaire
7	7-value scale
13	13-value scale

application of a under floor air distribution system for a large cultural facility space could result in higher satisfaction level for indoor thermal comfort. Buratti et al. [13] developed an improved model, based on the Rholes approach, allowing the evaluation of PMV by measuring temperature and relative humidity for different range of values of the thermal insulation of clothing.

Other works [14–20] were focused on the evaluation of thermal comfort by using the adaptive approach; some of them highlighted the criticality of the experimental method and in particular the different results provided by Fanger's static model and by the adaptive approach. This new approach considers the occupants of an environment as active subjects who can have the opportunity to interact with the environment and to adapt themselves to the climatic conditions; it therefore allows to consider a gradual process of individual adaptation (conscious or involuntary) depending on the context, on the thermal history, and on expectation of specific thermal indoor conditions by the occupants. The adaptive approach should not be considered as an alternative or opposed method for the thermal comfort evaluation, but as its development.

Other works [21–24] tried to evaluate the thermal comfort sensation by calculating the indoor air temperature by means of proven simulation algorithms, such as Artificial Neural Networks; all these papers implemented Fitting Neural Networks, which are the common networks applied in the engineering field.

When studying the thermal comfort sensation in various environments, such as theatres [18,25], classrooms [19], and open plan offices [20], authors highlighted that the questionnaire data varied in a wider range of values than experimental ones, due to the possibility of giving only whole numbers.

In many papers [14–20], the application of the adaptive approach showed a very different thermal sensation within the environments when compared to experimental data calculated basing on the static approach, especially in large environments. Another important problem was also highlighted [14–20], i.e. the poor correlation between the data collected with the questionnaires and the experimental ones. In many cases the thermal sensation declared on the 7-value scale did not agree with other information reported in the questionnaires, such as the state of annoyance. In particular when a thermal sensation equal to 0 is declared on the 7-value scale, a high percentage of people who declared a state of annoyance was nevertheless found, declaring that they would like to have a slight warmer or colder. This particular trend is mainly due to the limited choice of the thermal comfort scale (7-value scale), which allows to declare only whole numbers. On the basis of these results, a redefinition of the thermal comfort scale was therefore proposed by using a 0.5 increase. In particular, in [18] the authors proposed a new thermal comfort scale which was to be tested in different environments.

The novelty of the present paper is the application and the test of the new thermal comfort scale (13-value) in different environments; it represents an innovative application because it has never been applied before. In [18] the 13-value scale was only proposed because the subjects' judgments vary in a wide range of values than the data measured and calculated with the Fanger static model; this is due to the possibility for people of giving only whole numbers. Therefore, for better comparing questionnaires and measured data, a scale varying vote by 0.5 instead of 1 should be more reliable. For this reason a 13-value scale was proposed. In the experimental campaigns reported in this paper, it was applied to real case studies together with the 7-value scale and, in order to check its efficiency, the results obtained with the two scales were compared.

In particular the correlation between the main data reported in the questionnaires was carried out and compared by using both scales, in order to highlight the efficiency of the new thermal comfort scale. New experimental campaigns were purposely designed and carried out in the same theatre Fraschini investigated in [18], in the same classrooms located in Pavia and Perugia already monitored in [19], and in other new classrooms located both in Pavia and Perugia. The new 13-value scale for the thermal comfort sensation (Fig. 1) was for the first time proposed to the occupants. In order to evaluate its effectiveness (13-value) with respect to the traditional Fanger one (7-value), both the scales were inserted in the questionnaires. All the occupants had to indicate the perceived thermal sensation on the 13-value scale, and when an intermediate feeling (−2.5, −1.5, −0.5, +0.5, +1.5, +2.5) was declared, they would also indicate the perceived thermal sensation on the 7-value scale, by choosing the value nearest to their feeling. The highest and the lowest values on the 7-value scale are the same as the ones on the 13-value scale and the 0.5 points were inserted between the existing values to allow for a finer choice.

With respect to [18,19], the questionnaire was modified by cutting the part related to the climate control by the occupants, because it was not present in all the investigated environments.

The aim of the present paper is to test the new thermal comfort scale (13-value) and to compare it with the traditional one (7-value), in order to evaluate their reliability and their compliance with data reported in the questionnaires. The goal of the research is also to check the effectiveness of the new scale in order to propose it as the thermal comfort scale alternatively to the traditional one. A statistical *t*-test was performed in order to quantify the significance of the difference between the two scales. Data obtained by considering the two scales was also related to the one obtained