The influence of clothing distribution and local discomfort on the assessment of global thermal comfort

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ABSTRACT

A field study was carried out in a hypermarket located in Southern Italy in order to evaluate the environmental comfort in large-scale retail trade buildings. Global and local thermal comfort conditions were studied by collecting exposure data and subjective responses of employees using both questionnaires and simultaneous physical measurements. In a few cases discrepancies appeared between subjective ratings and the corresponding PMV-index, suggesting that the latter could be unable to reliably estimate thermal comfort when clothing insulation is unevenly distributed on human body. Analysis of collected data confirmed this, with particular reference to female workers wearing skirts. In addition, such effects may be further emphasized by local thermal discomfort, which may finally influence global thermal perception. Analysis of the results showed that cold floor and radiant temperature asymmetry caused by warm ceiling played a major role in emphasizing the negative effects due to uneven clothing distribution, confirming that this particular combination of events may bias PMV model accuracy.

1. Introduction

Fanger's PMV-index [1], described in ISO 7730 [2], is the most used parameter to evaluate thermal comfort. Its reliability was widely demonstrated in air-conditioned environments [3,4] including, in particular, hypermarkets [5]. However, only a few researches discuss how this index works when environmental conditions deviate from reference model. Several studies were carried out in order to evaluate clothing insulation (I_{cl}), taking into account the aspects, which could modify the I_{cl} value (e.g. air movement, vapour resistance, further insulation provided by chair seat). However, in a lot of cases (e.g. for steady and light work activities and for more frequently worn clothing combination) the improvement in I_{cl} accuracy is not as high to justify the more cumbersome calculations [6].

Moreover, ISO 7730 standard takes into account local thermal discomfort but its assessment is carried out independent of global thermal comfort, and only a few researches deal with their reciprocal influence on thermal perception [7].

Taking advantage of the results collected during a survey of thermal comfort conditions carried out in a hypermarket, the paper investigates in greater detail the above aspects, with the specific aim of understanding some unusual discrepancies between subjective ratings and those resulting from predictive models.

2. Methods

2.1. Local climate

The research was carried out in a hypermarket located in Bari, a city in Southern Italy facing the Adriatic Sea. It has climate conditions common in Mediterranean area, with warm humid summers and mild winters. The Adriatic Sea gives mild temperature ranges: in January, the coldest month, the mean temperature is 8.7 °C while in August, the warmest one, it is 24.3 °C (Table 1). The conventional period in which heating is used starts on November 15 and ends on March 31.

2.2. Building description

The shopping centre is a prefabricated one-floor structure built between 2000 and 2005. It is situated at road level and consists of a shopping arcade and a hypermarket. The hypermarket covers a total floor area of about 17,000 m², 10,900 m² of which is occupied by the air-conditioned sales floor, 4200 m² by naturally ventilated warehouses and 1900 m² by air-conditioned food processing divisions. The mean ceiling height is 6.5 m in the sales area and warehouses, and 3.5 m in the food processing divisions because of suspended ceilings. The entrances for customers and staff are different as the first get to the sales area through the shopping arcade, and the latter from the office area which is directly connected to the outside environment.

Symbols

AMV	actual mean vote
DR	draught rate
DTS	desired thermal sensation
I_{cl}	clothing insulation
PD_{floor}	percentage of dissatisfied due to floor temperature
PD_{wc}	percentage of dissatisfied due to radiant asymmetry (warm ceiling)
PMV	predicted mean vote
PPD	predicted percentage of dissatisfied
TSat	thermal satisfaction

The arrangement of different goods on sale is outlined in Fig. 1. Refrigerated decks, fish, fruit and vegetables divisions, and the frozen food section may be found near the checkouts. The sales floor is air-conditioned by three air handling units (AHU), and the food processing divisions by a fourth AHU dedicated to "cold" stores. The system provides heating in the conventional period, cooling in summer, and fresh air supply in the remaining periods.

2.3. Data acquisition

The surveys investigated the comfort conditions of the hypermarket staff mainly in winter and summer, analysing environment quality with the most unfavourable climatic conditions [8–12]. However field measurements were also carried out during spring and fall to study the influence that the step changes in external climatic conditions have on comfort sensations. Continuous physical measurements were carried out at fixed measurement points during working days. Time intervals varying from 1 to 5 h were considered, during which HVAC system was always turned on. At the same time, employees were randomly invited to answer a questionnaire, while they were occupied in their work, moving to the measurement station closer to their usual workplace. Anyway, they were asked to answer considering their subjective sensations when and where the questionnaire was filled in, even if it was not their customary workplace. The questionnaire was anonymous and it was filled in avoiding any influence from researchers, co-workers or superiors.

Thermal environment measurements were carried out using a microclimatic station with a datalogger. The unit complies with ISO 7726 standard [12] and includes the following probes: a 150 mm diameter globe thermometer (0.01 °C resolution and ±0.01 °C accuracy), a floor temperature probe (0.01 °C resolution and ±0.01 °C accuracy), an omni-directional hot wire anemometer (0.01 m/s resolution and ±0.02 m/s accuracy from 0 to 1 m/s and ±0.1 m/s accuracy from 1 to 5 m/s), a net radiometer for radiation asymmetry measurements (0.01 °C resolution and ±0.01 °C accuracy), a dry-bulb temperature and relative humidity sensor as well as an air temperature difference probe (0.1 °C resolution and ±0.15 °C accuracy). The probes were placed at a height of 1.1 m from the floor at a reasonable distance from radiant surfaces. The data acquisition rate was 15 s. In order to correlate objective

parameters with subjective responses, thermal measurements were averaged considering the 10-min interval before the end of questionnaire filling.

Outdoor climate data were taken from the website of the Italian Civil Protection National Service (www.protezionecivile.puglia.it) that provides temperature and relative humidity data measured at a weather-station near the shopping mall.

2.4. Data collection points

Most employees have jobs that require them to move between many different areas, so it is hard to define a fixed workplace. Because of the slow response time of some instruments, monitoring and evaluation points were kept fixed. The location of fixed point was decided taking into account the hypermarket layout, the nature and organization of each job and the need to characterize every workplace, including, in particular, those showing interesting deviations from the average conditions [13] (Fig. 1).

2.5. Questionnaires

The questionnaire layout and questions were based largely on the survey form developed in the HOPE project [14] and on ISO 10551:1995 standard [15], and its comprehension was verified in a previous study [5].

The form begins with a section concerning socio-anagraphic data of respondents and general information about their work. In this section the workers are also asked to choose among a selection of garments (derived from ISO 9920 standard [16]), the combination which better suits what they actually wear.

The ASHRAE seven-point scale from "very cold" to "very hot" is used to evaluate actual (AMV) and desired (DTS) thermal sensation [17]. Thermal satisfaction (TSat) is assessed through a seven-point scale from "very unsatisfied" to "very satisfied" and with a dichotomous question about environmental acceptability [10] (Table 2).

Local thermal discomfort is studied through a multiple-choice question. Respondents are asked if they perceive draughts and may point out whether some parts of the body are colder or hotter than others, with the opportunity to suggest types of discomfort other than those listed. Finally, the questionnaire takes into account also visual and acoustic aspects, as described in detail in ref. [5], but they are not discussed in the present paper.

A total of 610 questionnaires, filled in anonymously by about 120 workers, were collected from February 2010 to July 2011, equally distributed between summer, winter, and fall/spring. The demographic composition and job typology of the sample resulting from questionnaires are listed in Table 3.

3. Results and analysis

3.1. Influence of job type

The first step to analyse the large amount of data collected during the survey was aimed at investigating possible correlations between subjective perceptions and the job of the respondents. The

Table 1
Outdoor climate conditions in Bari (average from 1971 to 2000).

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
$T_{max\ mean}$ (°C)	12.6	12.9	15.0	18.0	22.8	26.8	29.2	29.2	25.9	21.5	16.8	13.9
$T_{min\ mean}$ (°C)	4.9	4.8	6.3	8.6	12.9	16.7	19.3	19.4	16.3	12.6	8.6	6.2
T_{mean} (°C)	8.7	8.8	10.6	13.3	17.8	21.7	24.2	24.3	21.1	17.0	12.7	10.0
UR (%)	76	73	72	69	69	66	65	67	70	75	77	77

Data are from Atlante Climatico d'Italia, Servizio Meteorologico dell'Aeronautica Militare http://www.meteoam.it/.