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Outdoor thermal comfort in the Mediterranean area. A transversal study in Rome, Italy

Ferdinando Salata [a, *, 1], Iacopo Golasi [a, 1], Roberto de Lieto Vollaro [b, 2], Andrea de Lieto Vollaro [a, 1]

[a] DIAEE – Area Fisica Tecnica, Università degli Studi di Roma "Sapienza", Italy
[b] DIMI – Università degli Studi "Roma TRE", Italy

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ABSTRACT

This paper examines the outdoor thermal comfort in the Mediterranean area. A transversal field survey has been conducted in Rome and, during an entire year, over 1000 questionnaires were filled and combined with micrometeorological measurements. In the first part of the questionnaire, the interviewees answered to personal questions, whereas in the second they evaluated their thermal perception and preference through the ASHRAE 7-point scale and the McIntyre scale respectively. Regression lines were obtained by elaborating the thermal perception votes and determining a PET (Physiological Equivalent Temperature) value for each questionnaire. These regression lines gave the possibility to calculate the neutral PET values: 26.9 °C for the hot season and 24.9 °C for the cold one. Differently, the votes concerning the thermal preference were related to the corresponding PET values through a logistic curve model with the probit function: for the hot season a preferred PET value of 24.8 °C was calculated, whereas for the cold season 22.5 °C. This shows the influence of thermal adaptation. Then since the thermal comfort interval should correspond to the range −0.5÷0.5 of the ASHRAE 7-point scale, a PET comfort range of 21.1÷29.2 °C was obtained. Finally two indexes were determined: the first, called MOCI (Mediterranean Outdoor Comfort Index), is based on the ASHRAE 7-point scale and predicts the mean value of the votes Mediterranean people might give to judge the thermal qualities of an environment; the second is the adaptation of the PPD (Predicted Percentage of Dissatisfied) relation to the Mediterranean population.

1. Introduction

In the last few years the interest in the design of outdoor urban spaces thermally comfortable increased because it is known that they can improve the quality of life in the cities [1].

However, during the study of outdoor thermal comfort two factors must be taken into consideration: it is different from indoor thermal comfort and people present different thermal requirements according to the region they live in.

For what concerns the first factor, the thermal quality of an outdoor space varies significantly with respect to an indoor one. Indeed, in indoor environments thermohygrometric conditions can be controlled thanks to air-conditioning systems, whereas outdoor environments, due to natural phenomena, are affected by higher variations of some variables, as air temperature, wind velocity, humidity, temperature of the radiant surfaces and solar radiation. Hence, people have comfort thermal sensations in a wider range of conditions when they are outdoors as they feel they can not control the factors that determine the thermal qualities of a space [2–4].

However thermal comfort is not affected by environmental parameters only; as a matter of fact there are events of different nature which have a deep influence on the refusal or acceptance of microclimatic conditions. Changing clothes according to the season and changes of the metabolic rate, the variation of the posture and position together with memory and personal expectations become significant parameters [5,6]. This is why it is necessary to consider those adaptation processes that people use to reach a thermal

* Corresponding author.
E-mail addresses: ferdinando.salata@uniroma1.it (F. Salata), iacopo.golasi@uniroma1.it (I. Golasi), roberto.delietovollaro@uniroma3.it (R. de Lieto Vollaro), andrea.delietovollaro@uniroma1.it (A. de Lieto Vollaro).
[1] Via Eudossiana, 18, 00184 Rome, Italy.
[2] Via Vito Volterra, 62, Rome 00146, Italy.

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Nomenclature

C_P	it measures the difference between the estimated regression model and the true model [−]
ET	Effective Temperature [°C]
I_{CL}	clothing insulation [clo]; it is equal to $I_{CL\ INACTIVE}$ if M < 1.2 met and to $I_{CL\ ACTIVE}$ if 1.2 met < M < 2.0 met
$I_{CL\ INACTIVE}$	clothing insulation for people who are not moving [clo]
$I_{CL\ ACTIVE}$	clothing insulation for people who are moving [clo]
I_S	global radiation [W/m^2]
LCZ	Local Climate Zone [−]
M	metabolic rate [W/m^2]
MOCI	Mediterranean Outdoor Comfort Index [−]
MSE	Mean Square Error [it has the same units of measurement as the square of the quantity being estimated]
MTSV	Mean Thermal Sensation Vote [−]
n	number of observations [−]
OUT_SET*	Outdoor Standard Effective Temperature [°C]
p	number of explanatory variables put in the regression model [−]
PET	Physiological Equivalent Temperature [°C]
PMV	Predicted Mean Vote [−]
PPD	Predicted Percentage of Dissatisfied [%]
P_{SDRY}	precipitation of the driest month during the summer [mm]
P_{SWET}	precipitation of the wettest month during the summer [mm]
P_{WDRY}	precipitation of the driest month during winter [mm]
P_{WWET}	precipitation of the wettest month during winter [mm]
R^2	coefficient of determination [-]
R_P^2	multiple regression coefficient for a regression model with p explanatory variables [−]
R_T^2	multiple regression coefficient for the complete regression model [−]
RH	relative humidity [%]
r	Pearson coefficient [−]
SET*	(rational) Standard Effective Temperature [°C]
sWS	standard deviation of the three wind velocity values measured during each interview [m/s]
T	total number of parameters (intercept included) that must be calculated in the full regression model [−]
TSV	Thermal Sensation Vote [−]
T_A	air temperature [°C]
T_{COLD}	temperature of the coldest month [°C]
T_{GLOBE}	globe temperature [°C]
T_{HOT}	temperature of the hottest month [°C]
T_{MON10}	months where the temperature is above 10 °C [−]
T_{MR}	mean radiant temperature [°C]
UTCI	Universal Thermal Climate Index [°C]
VIF	Variance Inflation Factor [−]
WS	wind velocity [m/s]
WS_{MAX}	highest wind velocity value measured during each interview [m/s].

balance with the environmental conditions.

A further difference between indoor and outdoor environments is represented by different times of exposure: we tend to spend most of our time inside buildings and a lower amount of hours in open spaces, especially during certain seasons. A research [7] demonstrated that in the United States and Canada people spend an average of 2–4% of their time in outdoor spaces during winter, whereas a 10% in summertime. Even if in other types of climates, as the Mediterranean, it can be assumed that these times of exposure are higher, they don't allow the human body to reach a balance with outdoor environment.

Nevertheless, several rational indexes used for outdoor thermal comfort evaluation are based on those conditions that might occur after the acclimatization. This depends on the fact that many of those indexes were originally developed for indoor spaces [8,9]. For example, the Predicted Mean Vote (PMV) [10], whose use is suggested by ISO 7730 [11] and ASHRAE 55 [12], was adapted later to outdoor environments [13] by taking into consideration the influence of the shortwave radiation. A similar condition characterizes the (rational) Standard Effective Temperature (SET*) [14] which was adapted to the OUT_SET* [15] for outdoor environments through the method of Jendritzky and Staiger [16]. The Effective Temperature (ET) [17,18] is also used mainly for indoor spaces: it is for this reason that clothing and metabolic rate are standardized for an indoor sedentary activity. Then the same standardization is used for the Physiological Equivalent Temperature (PET) [19], a rational index meant for the evaluation of outdoor environments. Differently, for what concerns the Universal Thermal Climate Index (UTCI) [20], the reference conditions regard only the activity: a metabolic rate of 135 W/m^2 and a walking speed of 1.1 m/s are assumed.

Consequently a difference between each subjective response and the results provided by different outdoor thermal comfort indexes both in the summer and winter was noticed. Ruiz and Correa [21] carried out a study in Mendoza (Argentina) and tested six different indexes (PMV and PET included) revealing predictive abilities lower than 25%. This is a consequence of the differences between outdoor and indoor thermal comfort, but it should not be forgotten the influence of thermal adaptation and people's residential area. Experience directly affects people's expectations, i.e. what the environment should be like, rather than what it actually is [5,22].

From this point of view several studies revealed, through field surveys, differences concerning perceptions and thermal requirements of people adapted to different climatic conditions. An example can be found in the results of the project RUROS (Rediscovering the Urban Realm and Open Spaces) [23], a wide-scale research organized to evaluate different comfort conditions (i.e., thermal, visual, audible). In particular, Nikolopoulou and Lykoudis [24] determined the neutral air temperature in 7 different European cities reporting a trend of this variable that appears to follow the profile of the respective climatic temperatures on a seasonal basis. Variations according to the climates of the cities where the field surveys took place were also found in terms of neutral PET [25,26] and neutral SET* [26,27]. Finally, some studies showed the variation of the comfort range of different populations [26,28,29].

Therefore, keeping in mind what was previously said, the research focuses on outdoor thermal comfort in the Mediterranean area.

The hypothesis of this paper is that predicting thermal comfort in outdoor spaces requires a subjective approach on a specific population adapted to specific climatic and cultural conditions (rules, norms and values) [30]. For this reason, a transversal field survey in Rome where over 1000 questionnaires were filled during an entire year with the simultaneous measurement of air temperature, mean radiant temperature, relative humidity, wind velocity