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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^2_P multiple regression coefficient for a regression model with p explanatory variables [−]
R^2_T 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 and global radiation was carried out. The first part of the questionnaire asked personal questions (age, gender, clothing, activity level …), while in the second part the interviewees gave their opinion about their thermal perception through the ASHRAE 7-point scale (cold (−3), cool (−2), slightly cool (−1), neutral (0), slightly warm (+1), warm (+2) and hot (+3)) and their thermal preference through the McIntyre scale (cooler (−1), no change (0) and warmer (+1)). Then for every questionnaire the corresponding PET value was calculated.

This study wants to give instruments and information that can be useful to architects, engineers, designers and urban planners for the organization or “requalification” of outdoor spaces in the Mediterranean area. Indeed, as testified by the results of the project REPUBLIC-MED (REtrofitting PUBLic spaces in Intelligent MEDiterranean Cities) [31], outdoor spaces play a key role in achieving sustainability in city environments and mitigating the so-called Urban Heat Island (UHI) effect. Apart from creating a healthy and comfortable environment for pedestrians, a correct planning of outdoor spaces can contribute to the reduction of energy demand for cooling purposes of buildings, especially in Mediterranean cities during the summer period.

For these reasons neutral and preferred PET values were determined together with the PET comfort range and a new empirical index able to predict, according to the ASHRAE 7-point scale, the thermal perception of the Mediterranean population in outdoor environments was calculated. However this index, called MOCI (Mediterranean Outdoor Comfort Index), can predict an average vote; hence it can be useful to know the number of people who are thermally dissatisfied with certain climatic conditions. This is why the PPD (Predicted Percentage of Dissatisfied) relation suggested by the ISO 7730 [11] was adapted to the Mediterranean population.

To summarize what was carried out previously and understand the relations that can be found between similar studies and this paper, section “2. Previous studies” reports the methodology of other field surveys (covering different climates and geographical contexts). Then further sections reports the features of this study: section “3. Study area” describes the climate in Rome and the measurement sites, while section “4. Material and methods” examines the method adopted. This is why subsection “4.1 Field data collection” contains some information concerning both the microclimatic conditions analyzed and the sample taken into consideration; subsection “4.2 Micrometeorological measurements” analyzes the instrumentation used and the procedure for the assessment of microclimatic variables' values; subsection “4.3 The questionnaire” describes the set of questions submitted to the interviewees and the method to evaluate the clothing insulation and metabolic rate; subsection “4.4 Thermal comfort indexes” deals with PET, PMV and PPD. Moving on to section “5. Results and discussion”, it is divided into five subsections based on the outcomes: “5.1. Neutral PETs and temperatures”, “5.2. Preferred PETs”, “5.3. “Optimal” comfort ranges”, “5.4. Towards the new empirical Mediterranean Outdoor Comfort Index (MOCI)” and “5.5. Correction of the Predicted Percentage of Dissatisfied (PPD) relation”. This section also presents a comparison with previous studies. Finally section “6. Conclusions” reports the findings of the research.

2. Previous studies

Even if outdoor thermal comfort is a recent field of study, during the last ten years the number of researches concerning this subject has been growing. These studies were carried out in different nations, each characterized by specific climatic and cultural conditions and most of them were performed through field surveys (Table 1) [8].

The 90% of these studies is characterized by a transversal approach: this means that every person took part to the survey only once. The rest of the studies presents a longitudinal approach where a limited number of people were exposed to different microclimatic conditions in different moments during the field survey. This type of research involves a range of interviewees between 8 and 36 people, whereas the transversal studies present a wider range, between 8 and 2700.

The places of the interviews were outdoor public spaces, as: parks, squares and pedestrian areas; just few studies included suburban areas and in six cases the study was carried out in university campuses. The number of sites of the research was between one and thirteen and it was proportional to the number of the interviewees.

A higher variation can be noticed in the duration of the field surveys: between one day and an entire year. Many studies examined more than one season, generally summer and winter, while other cases covered longer periods (i.e., an entire year). From this point of view, it is important to focus the attention on the fact that about half of the studies found a seasonal difference in the ranges of thermal comfort and/or neutral temperatures. This means that the season affects thermal perception and this has an influence on the answers of the interviewees which is higher among climates characterized by different seasons, such as the Mediterranean. The studies also differ in the part of the day during which the field surveys were performed: in many cases they were carried out in the afternoon, while a lower number included morning and evening.

A further difference was the structure of the questionnaire: even though all studies except five asked questions about the thermal perception (i.e., “How do you feel right now?”), different subjective judgment scales were used. The most common scale is the so-called ASHRAE 7-point scale (cold (−3), cool (−2), slightly cool (−1), neutral (0), slightly warm (+1), warm (+2), hot (+3)) which was used in fifteen studies. Twelve studies used a 5-point scale and four studies a 9-point scale. A different approach was then adopted by Stathopoulos et al. [32] who asked to give an opinion on some statements (“the air temperature is high”, “the air is humid”, “the wind force is strong”, “the solar radiation is warm”) through a 5-point scale ranging from disagree (−2) to agree (+2) with the possibility to choose a condition of uncertainty (0). The situation is different for what concerns the surveys of Xi et al. [33] and Kántor et al. [25,34]: they used differential (continuous) scales which allowed the interviewees to choose among fixed values, i.e., −1.5 (between cool and slightly cool).

Finally, a different choice, for what concerns thermal perception, was made by Sangkertadi [35] and by those who took part to the project REPUBLIC-MED [36–40]. The first used a 7-point scale with values ranging between −2 (cold) and +4 (very−very hot and feeling pain) where 0 corresponded to a thermal neutrality whereas, in the second case, thermal sensations were rated on a 7-point scale ranging from +1 (too cold) to +7 (too hot).

Most of the studies also included questions as “How would you prefer to be now?” and the most investigated variables were the air temperature and the wind velocity (both studied in seventeen cases). In a lower number of surveys other variables were evaluated in terms of preference: humidity (fifteen cases) and solar radiation (fourteen cases). As happened for thermal perception, these analyses were performed through different scales and the most commonly used was the McIntyre scale [41] (cooler (−1), no change (0), warmer (+1)).

On the other hand, all studies (except fourteen) evaluated at least one index for the examination of thermal comfort, neutrality and preference. From this point of view, the most common index was the Physiological Equivalent Temperature (PET), followed by the (rational) Standard Effective Temperature (SET*) and the

Table 1
Countries, cities of the studies where field surveys were performed and season, time of the day and number of the interviewees [8].

City	Climate symbol	Latitude	Longitude	Altitude [m]	Season	Time of the day	Votes
Mendoza, Argentina [21]	BWh	32.4° S	68.5° W	750	July, December	Morning, afternoon, evening	622
Sydney, Australia [2]	Cfa	33.9° S	151.2° E	19	All year	Not specified	1018
Curitiba, Brazil [50]	Cfb	25.5° S	49.2° W	926	January–August	Morning to afternoon	1654
Sao Paulo, Brazil [51]	Cfa	23.3° S	46.4° W	760	Summer, winter	Not specified	1750
Montreal, Canada [32]	Dfb	45.5° N	73.5° W	30	Spring, autumn	Midday (noontime)	466
Guangzhou, China [33]	Cfa	23.1° N	113.3° E	5	July	Daytime	114[a]
Hong Kong, China [54]	Cwa	22.3° N	114.2° E	142	Summer, winter	Morning, afternoon, evening	2702
Hong Kong, China [45]	Cwa	22.3° N	114.2° E	142	Summer, winter	Morning, afternoon, evening	286[b]
Nanjing, China [53]	Cfa	32.0° N	118.8° E	30	August	Whole day	205
Tianjin, China [47]	Dwa	38.3° N	116.4° E	3	March to January	10 a. m.–4 p. m.	1565
Wuhan, China [52]	Cfa	30.6° N	114.2° E	37	August to November	8 a. m.–12 a. m. 3 p. m.–9 p. m.	490
Obrovac, Croatia [36,37]	Cfa	44.1° N	15.4° E	50	September	n. a.	261[c]
Pag, Croatia [36,37]	Csa	44.2° N	14.6° E	0	September	n. a.	261[c]
Zadar, Croatia [36,37]	Csa	44.1° N	15.1° E	0	September	n. a.	261[c]
Cairo, Egypt [55]	BWh	31.0° N	31.3° E	50	Summer, winter	Afternoon	300
Nice, France [38,56]	Csb	43.4° N	7.2° E	10	April	Afternoon	180
Kassel, Germany [23,24]	Cfb	51.3° N	9.5° E	178	All year	Morning to evening	824
Athens, Greece [23,24]	Csa	38.0° N	23.7° E	70	All year	Morning to evening	1503
Piraeus, Greece [57,58]	Csa	37.6° N	23.4° E	14	September	8 a. m.–8 p. m.	81
Thessaloniki, Greece [23,24]	Cfa	40.6° N	22.9° E	44	All year	Morning to evening	1813
Szeged, Hungary [25,34]	Cfb	46.3° N	20.1° E	77	Autumn, spring	Afternoon	967
Manado, Indonesia [35]	Af	1.3° N	124.6° E	3	May to September	Morning to afternoon	300
Yotvata, Israel [59]	BWh	29.6° N	34.9° E	86	July	24 h	~100[d]
Milan, Italy [23,24]	Cfb	45.5° N	9.2° E	122	All year	Morning to evening	1173
Modena, Italy [40]	Cfa	44.4° N	10.6° E	34	July	12 a. m.–4 p. m.	12
Novi di Modena, Italy [39]	Cfa	44.5° N	10.5° E	21	July	12 a. m.–2 p. m.	8
Matsudo, Japan [60]	Cfa	35.8° N	139.9° E	9	March, May	Morning to afternoon	1142
Yokohama, Japan [48]	Cfa	35.4° N	139.6° E	11	All seasons	Morning to afternoon	1,134[e]
Putrajaya, Malaysia [61]	Af	2.9° N	101.7° E	45	March–April	Morning, afternoon	200
Lisbon, Portugal [62]	Csa	38.7° N	9.2° W	84	March–April	Afternoon	91
Lisbon, Portugal [4]	Csa	38.7° N	9.2° W	84	All year	Afternoon	943
Singapore, Singapore [63]	Af	1.4° N	103.7° E	5	August–May	Morning, afternoon, evening	2036
Albalat de la Ribera, Spain [64]	Csa	39.1° N	0.2° W	14	May, June	Morning	97
Sueca, Spain [65]	Csa	39.1° N	0.2° W	3	May, June	Morning	100
Gothenburg, Sweden [44]	Cfb	57.7° N	12.0° E	36	July to October	Afternoon	285
Gothenburg, Sweden [66]	Cfb	57.7° N	12.0° E	36	October, January, April, June	Morning, afternoon	1379
Fribourg, Switzerland [23,24]	Cfb	46.8° N	7.0° E	646	All year	Morning to evening	1920
Damascus, Syria [26]	BSk	33.6° N	36.3° E	689	Summer, winter	Morning, afternoon	920
Chiayi, Taiwan [27]	Cwa	23.3° N	120.4° E	252	Winter to summer	Not specified	1,644[f]
Taichung, Taiwan [67]	Cwa	24.1° N	120.7° E	26	All year	Afternoon	505
Taichung, Taiwan [27]	Cwa	24.1° N	120.7° E	26	Winter to summer	Not specified	1,644[f]
Yunlin, Taiwan [27]	Cwa	23.7° N	120.5° E	18	Winter to summer	Not specified	1,644[f]
Birmingham, UK [49]	Cfb	52.5° N	1.9° W	127	August–February	Afternoon	451
Cambridge, UK [23,24]	Cfb	52.2° N	0.1° E	17	All year	Morning to evening	948
Glasgow, UK [28,68]	Cfb	55.9° N	4.3° W	31	March to July	Morning to afternoon	573
Sheffield, UK [23,24]	Cfb	53.4° N	1.5° W	97	All year	Morning to evening	1008
Rome, Italy (present study)	Csa	41.5° N	12.3° E	21	All year	Morning to evening	941[g]

[a] A group of 21 students.
[b] A group of 8 students.
[c] Total for the three cities.
[d] A group of 36 students.
[e] A group of 6 students.
[f] total for the three cities.
[g] During the field survey 1009 questionnaires were filled. However 68 of them were discarded because they were not complete and 941 valid questionnaires were obtained after the screening process.

Predicted Mean Vote (PMV). The use of the firsts two indexes has been increasing in the past few years, whereas a decrease of the studies that have adopted the PMV was found. The cause could be that several studies discovered a poor correlation between the PMV and the subjective thermal perception [42–45]. Then in two case only [46,47] the Universal Thermal Climate Index (UTCI) was calculated, but it is probable that its use will increase gradually because it is a relatively new index.

In about half of the studies, thermal comfort indexes were adjusted through subjective thermal perceptions and a tendency to adapt thermal indexes and their comfort zones on a national or regional level was noticed. In many cases the correlation (R^2) was increased by using medium values of the subjective thermal sensations in bins of about 1 °C.

In order to obtain indexes able to evaluate outdoor thermal comfort at a local level, there is a growth of the studies that relate, through multiple regressions, the subjective responses of the interviewees about thermal perception to the climatic variables measured [21,35,48–52]. About this point it must be specified that in all cases, except one [53], the measurements were performed near the interviewee.

Finally, some studies determined the neutral air or index temperatures, whereas the preferred air or index temperatures were seldom estimated.

3. Study area

The field survey was performed in two different sites in Rome (41°55′ N, 12°29′ E, 20 m above the sea level, 1285.30 km^2), the most populated city of Italy with 2,844,821 inhabitants [69]. It is characterized by a typical Mediterranean climate (Fig. 1) and it presents maximum average temperatures always higher than 10 °C and higher than 31 °C in July and August. This type of climate is mild and comforting in spring and fall with a monthly average temperature lower than 10 °C only during winter (December, January, February). The most rainy periods are winter and early spring and the average annual precipitations reach the value of about 800 mm. Then wind velocity has an average annual value of 4.4 m/s at the height of 10 m above the ground level and it is also interesting to notice how the average values of the relative humidity range, during a whole year, between 70% and 80%.

According to Köppen-Geiger classification, this type of climate belongs to the Csa category [70] (Table 2).

The sites taken into account for the research are the outdoor areas of the campus of the "Sapienza" University of Rome and of the Faculty of Engineering (Fig. 2). They were chosen in order to cover a wide variety of environmental conditions in terms of local climate, topographic characteristics and urban morphology and, within a survey site, areas with different microclimatic conditions (i.e., shaded, un-shaded, windy, wind-stagnant areas and so on) were identified and accounted for in the survey.

As a proof to what was previously said, outside the campus there is a big parking space whose ground surface is made of asphalt (Fig. 2B), a green space with trees (Fig. 2C), a yard with a fountain (Fig. 2D) and typical urban canyons (Fig. 2E–F). The situation is different for the Faculty of Engineering [71]: here the survey was carried out only inside the historical cloister which characterizes the building (Fig. 2A). It sees the presence of a portico made of ceramic tiles and a cobblestoned yard; the sky view factor ranged between 0.20 and 0.60, values that can refer to the Local Climate Zone LCZ 2_3 [72]. Such classification is based on the examination of the surrounding urban texture and could be applied to the other site as well.

Usually people in the sites perform the activity of walking or just passing through, meeting with friends, studying, eating or relaxing.

Table 2
Description of Köppen-Geiger climates classification and definition criteria (referring to the C category, representative of mild climates).

1st	2nd	3rd	Description	Criteria
C			Temperate	$T_{HOT}>10$ and $0<T_{COLD}<18$
	s		Dry summer	$P_{SDRY}<40$ and $P_{SDRY} < P_{WWET}/3$
	w		Dry winter	$P_{WDRY} < P_{SWET}/10$
	f		Without dry season	Not (Cs) or (Cw)
		a	Hot summer	$T_{HOT} \geq 22$
		b	Warm summer	Not (a) and $T_{MON10} \geq 4$
		c	Cold summer	Not (a or b) and $1 \leq T_{MON10} < 4$

4. Material and methods

4.1. Field data collection

To study people's thermal preference and perception and to evaluate the influence of the microclimatic conditions, the field survey was performed simultaneously with micrometeorological measurements of: air temperature, globe temperature, relative humidity, wind velocity and global radiation. Different conditions (Table 3), that could be considered representative of the typical Mediterranean climate, were examined. This is why it took a year to perform this research: it started on February 2014 and ended on January 2015 thus covering all seasons.

To have data as generic as possible and be able to investigate different situations, the field survey was not carried out simultaneously in more than one site. Even choosing a certain period of

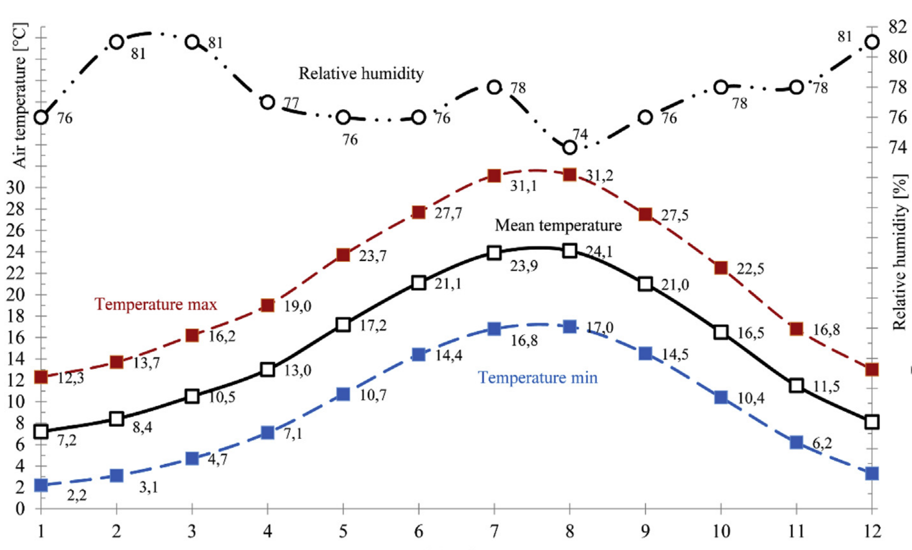

Fig. 1. Temperature and relative humidity in Rome [69].

Fig. 2. A–F. Measurement sites in the city of Rome.

time during the day depended on the intention of trying to examine different situations with different outdoor conditions. Therefore, one day was divided into 4 intervals [24]: morning (08:00–11:59), midday (12:00–14:59), afternoon (15:00–17:59) and evening (18:00–20:59). Sometimes the research was performed during just one of the intervals, whereas other cases covered longer periods until reaching a 13-h-investigation.

The sample collected in the field survey was represented by 1009 questionnaires; however 68 were discarded during the screening process because they were not complete and a number of 941 valid questionnaires was obtained. It can be considered acceptable observing what was reported by Johansson et al. [8] who stated that for numerous populations the sample could be considered satisfying when it presented a range between 400 and 500 people. In this study the sample had a good balance for what concerns the gender percentage (59% men and 41% women) and the distribution of the interviews over the course of time (27% in summer, 18% in fall, 32% in winter and 23% in spring); on the other hand the age of the interviewees was affected by the fact that the sites examined are academic environments where young people go regularly (66% between 19 and 24 years, 31% between 25 and 29 years and 3% higher ranges).

4.2. Micrometeorological measurements

The micrometeorological measurements of the globe temperature, air temperature, wind velocity, relative humidity and global radiation were always performed at a distance of less than 3 m from the interviewee [2,33]. These measurements were carried out at a height of 0.6 m for the subjects who were seated and at a height of 1.1 m for those standing (complying with the ISO 7726) [73]. These values are representative of the position of human body's centre of gravity and the collocation of the probes at these heights permitted, for what concerns the wind velocity, to avoid the use of the wind profile power law (it could be incorrect in cases where the stability of the atmosphere is not neutral or if the air is very turbulent).

Table 3
Summary of the physical data of outdoor climate.

	Min	Max
Air temperature T_A [°C]	3.2	35.9
Wind velocity WS [m s^{-1}]	0.0	2.5
Relative humidity RH [%]	34.0	92.1
Mean radiant temperature T_{MR} [°C]	7.6	48.1
Global radiation I_S [W m^{-2}]	0.0	990.0

This type of study, together with the necessity to measure the variables in different zones at different heights, required instruments which could be carried easily (Table 4). Hence, a mobile microclimate control unit and a datalogger connected to a pyranometer to measure the global radiation were used.

Four probes were installed on the control unit:

- A PT 100 platinum resistance thermometer to measure the air temperature;
- A psychrometric probe with forced ventilation and distilled water tank to measure the relative humidity;
- A hot wire anemometer to measure the air velocity;
- A spherical globethermometer to measure the globe temperature with a 150 mm diameter black opaque copper globe.

Considering that the questionnaire could be filled in about 90 s, during each interview 3 measurements were performed for every variable (relative humidity, air temperature, global radiation and mean radiant temperature) and the thermal perception of the interviewee was related to their average value.

To determine the mean radiant temperature the Eq. (1) [73] was used (this approach was adopted in half of the studies reviewed in Table 1):

$$T_{MR} = \left[(T_{GLOBE} + 273.15)^4 + \frac{1.1 \cdot 10^8 \cdot WS^{0.6}}{\varepsilon \cdot D^{0.4}} \cdot (T_{GLOBE} - T_A) \right]^{0.25} - 273.15 \quad (1)$$

Table 4
Metrologic properties of the measuring instruments used.

Type of probe	Variable measured	Field of measurement	Resolution	Accuracy
PT 100 platinum resistance thermometer	Air temperature [°C]	−25 ÷ +85	0.1	±0.5 °C above −7 °C
Hot wire anemometer	Wind velocity [m s^{-1}]	0 ÷ 20	0.1	±1 m/s
Forced ventilation psychrometer	Relative humidity [%]	0 ÷ 100	0.2	±3% (0–90%), ±4% (90–100%)
Globe-thermometer	Globe temperature [°C]	−40 ÷ 80	0.1	≤0.1 °C°C at 0 °C DIN 43760 1/3
Pyranometer	Global radiation [W m^{-2}]	0 ÷ 2000	0.1	±5%

The situation was different when dealing with the wind: thermal comfort was not only affected by its velocity, but also by its variability [74]. As a consequence, observing the studies of Oliveira and Andrade [62] and Andrade et al. [4], the Eq. (2) was used:

$$WS = WS_{MAX} + sWS \tag{2}$$

where the maximum value (WS_{MAX}) measured during each interview was combined with the wind variability adding the term sWS which represented the standard deviation of the 3 observations.

Finally, every instrument used was tested and calibrated before the beginning of the field survey.

4.3. The questionnaire

The questionnaire was submitted to people selected randomly in the sites where the field survey was performed and the interviewee was always introduced to the topics examined.

It was characterized by a plain and simple language and could be filled in about 90 s. It was divided into two parts: the first concerned personal questions about the interviewee (gender, age, weight, height, time of residency, time of exposure, clothing, activity), whereas the second investigated their thermal perception and preference with reference to the measured variables.

For the evaluation of thermal perception the so-called ASHRAE 7-point scale was used (cold (−3), cool (−2), slightly cool (−1), neutral (0), slightly warm (+1), warm (+2) and hot (+3)) while for thermal preference the McIntyre scale (cooler (−1), no change (0) and warmer (+1)).

The way the questions were organized complied with the ISO 10551 [75] and was similar to the one used by Oertel et al. [28]. In particular, in order to have a sample that could represent the Mediterranean population and according to Krüger et al. [68], the time of residency was used as a criteria of exclusion when the value was lower than 6 months and pregnant women were excluded.

For what concerns the metabolic rate of the activity performed by the interviewee, what reported in the ASHRAE Standard 55–2004 [76] was taken into consideration: it must be estimated as an average value during a period ranging between 0.5 and 1 h before measuring the thermal parameters and before beginning the interview. For this reason, it was decided to observe the method of Bouden and Ghrab [3] and consider the activities performed by the interviewee both in the exact moment when he/she was filling the questionnaire and 0.5 h before. The weights of 0.7 and 0.3 were respectively assigned to these activities and the corresponding metabolic rates M were determined per unit skin area of an average adult (Dubois area = 1.8 m^2) [76]. For example, if the interviewee was sitting (metabolic rate M = 60 W/m^2), while 0.5 h before he/she was standing (metabolic rate M = 70 W/m^2), the metabolic rate M assigned would have been of $0.7 \cdot 60 + 0.3 \cdot 70 = 63$ W/m^2.

For every interviewee the clothing insulation I_{CL} was also estimated. Complying with the method 1 suggested by the ASHRAE Standard 55–2004 [76], in the first part of every questionnaire a list of clothing ensembles was reported where the interviewee could choose what was similar to what she/he was wearing. They also had the possibility to add or remove a single garment. However it must be specified that the clothing insulation $I_{CL\ INACTIVE}$, determined through this method, concerned people who were not moving.

Body movement decreases the clothing insulation by pumping air through the openings of the clothes and/or causing air movements inside it. This is why for those who were moving, the clothing insulation $I_{CL\ INACTIVE}$ determined through the questionnaire was adjusted according to the Eq. (3):

$$\begin{aligned} I_{CL} &= I_{CL\ ACTIVE} \\ &= I_{CL\ INACTIVE} \cdot (0.6 + 0.4/M) \quad 1.2\ met < M < 2.0\ met \end{aligned} \tag{3}$$

where M is the metabolic rate expressed in met (1 met = 58 W/m^2). Finally, if M assumes values lower than or equal to 1.2 met, it is not necessary to adjust the value of the clothing insulation and $I_{CL} = I_{CL\ INACTIVE}$.

4.4. Thermal comfort indexes

Thanks to the simultaneous measurement of the micrometeorological variables, the values of air temperature, mean radiant temperature, wind velocity, relative humidity and global radiation were associated to each questionnaire. Consequently the votes given by the interviewees concerning their thermal perception and preference were related to the corresponding values of the Physiological Equivalent Temperature (PET).

Such index, expressed in degree Celsius, is defined by Höppe [19] as the equivalent temperature to the air temperature in which, for a typical internal situation, the thermal balance of the human does not change, considering the same core and skin temperatures as in the original situation. In this typical indoor setting, there is no radiation ($T_{MR} = T_A$), the air is calm (its velocity is fixed at 0.1 m/s) and the vapor pressure is 12 hPa (approximately equivalent to a relative humidity of 50% at 20 °C). This index derives from the Munich Energy Balance Model for Individual (MEMI), which is a heat balance of the human body. Its calculation assumes constant values for clothing (0.9 clo) and activity (metabolic rate of 80 W plus basic metabolism) and it is one of the indexes whose use is suggested by German standards in urban and regional planning [77]. In this study the PET was calculated from the measured micrometeorological data using the Rayman software [78].

Another widely used thermal index which appears in this research is the Predicted Mean Vote (PMV) [10]. It was developed by Fanger on the basis of test data for 1565 subjects in an indoor setting. However, through a parameterization of the complex radiation fluxes [13], this model has become applicable to outdoor environments under the name “Klima-Michel model” (KMM). It predicts the mean value of the thermal votes of a large group of people exposed to the same environment and six input parameters are required for its calculation: four climatic parameters and two operative parameters related to the pedestrians. The climatic parameters are air temperature, mean radiant temperature, wind velocity and relative humidity, while the operative parameters are metabolic rate and clothing insulation. Similarly to what was done in this research, in order to evaluate thermal perception, this index is rated on a 7-point scale ranging from −3 (cold) to +3 (hot). Then its computation in this study does not derive from the measured data since the PMV values ranging between −3 and +3 were taken into consideration to calculate and graph the trend of the Predicted Percentage of Dissatisfied (PPD) according to the ISO 7730 [11] (subsection 5.5).

This index, indeed, is a function of the PMV and is able to predict the number of subjects may feel uncomfortably warm or cool establishing a quantitative prediction of the number of thermally dissatisfied people.

5. Results and discussion

5.1. Neutral PETs and temperatures

The levels of adaptation to certain local conditions were established as a function of the previous exposure and can affect deeply how a thermal environment is perceived. The temperature at which people judge an environment as comfortable is close to what they have experienced and this is why the neutral temperature is examined during hot and cool seasons. It is defined as the temperature at which people feel thermal neutral (neither cool nor warm) [79] and coincides with the central thermal sensation (TSV = 0) in the ASHRAE 7-point scale.

In order to determine its values, the mean thermal sensation votes (MTSVs) of the interviewees for every temperature interval with a bins width of 1 °C PET were determined [80] and the regression lines (Fig. 3) between MTSV and PET in hot and cool seasons are as follows:

$$\text{Hot season}: \ MTSV = -4.575 + 0.170 \cdot PET \quad R^2 = 0.847 \tag{4}$$

$$\text{Cool season}: \ MTSV = -2.941 + 0.118 \cdot PET \quad R^2 = 0.949 \tag{5}$$

By substituting MTSV = 0 in Eq. (4) and Eq. (5), the following values of the neutral PET were determined: 26.9 and 24.9 °C respectively for hot and cold seasons.

These results show the influence of a moderate seasonal adaptation effect and the highest neutral PET during the hot season is a consequence of the climatic characteristics of the city of Rome. It was characterized by a Mediterranean climate and it belongs to the Csa category according to Köppen-Geiger climates classification [70]: summer is hot, the average temperature of the hottest month is higher than 22 °C and, during the entire year, low temperatures are rarely registered. This could be why people tend to tolerate more high temperatures.

It is then necessary to perform a comparison with other studies (Table 5).

Similar results were reported by Lin [67] through a study carried out in Taichung City, Taiwan. In this case the neutral PET values, during hot and cold seasons, were respectively 25.6 and 23.7 °C, about 1.2-÷1.3 °C lower than those registered in Rome. These similar values can find a reason in the fact that Taichung City belongs to the Cwa category of Köppen-Geiger climates classification [70] and it is characterized by an average temperature during the hottest month higher than 22 °C. It should also be kept in mind that this city is located in the Northern part of the island of Taiwan and is characterized by a climate which does not present the tropical conditions of the Southern cities.

Slightly higher neutral PET values were registered in the city of Cairo, Egypt [55]. Indeed, in this case the neutral PET was of 26.5 °C during winter and 27.4 °C in summer. However it should not be forgotten that these values were determined as average values of the neutral PET in 9 measuring points in a park, whereas the field survey carried out in Rome examined urban contexts with various characteristics. Therefore evapotranspiration phenomena and the decrease in the mean radiant temperature and air temperature in the park mitigated the high average temperatures of the Egyptian city, which in summer are 5 °C higher than those registered in Rome. This is why the difference between the values registered in both cities was lower than the one that could be measured considering the same urban sites.

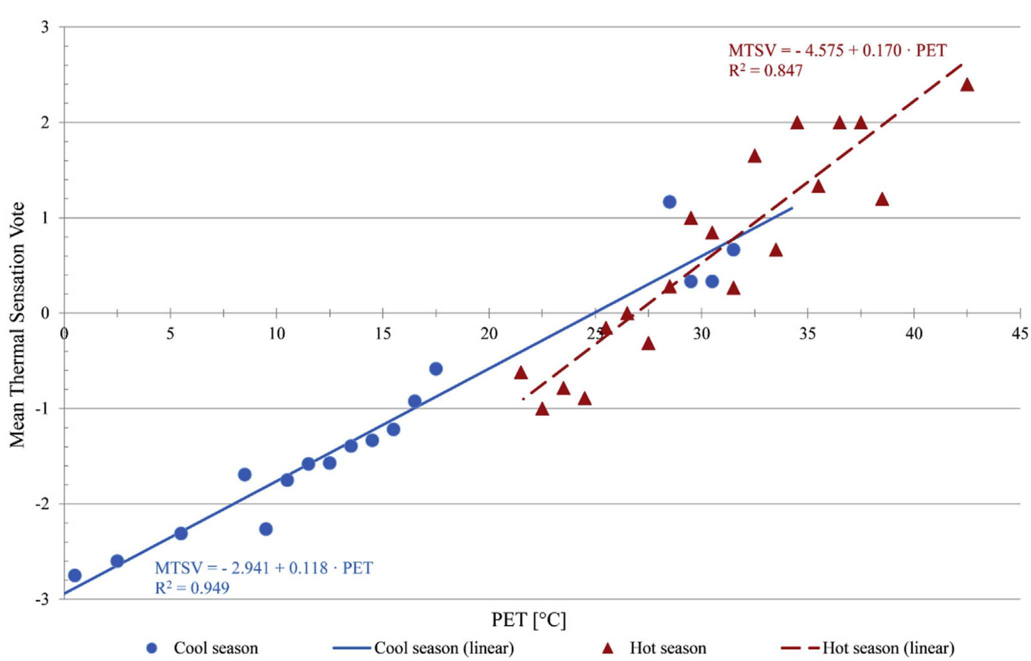

Fig. 3. Correlation between the mean thermal sensation votes (MTSVs) and PET in cool and hot seasons.

Table 5
Results provided by other studies in terms of neutral PET, neutral air temperature and neutral operative temperature.

City	Neutral PET [°C]		Neutral air temperature [°C]		Neutral operative temperature [°C]
	Summer	Winter	Summer	Winter	Whole year
Taichung City, Taiwan [67]	25.6	23.7	–	–	–
Cairo, Egypt [55]	27.4	26.5	–	–	–
Hong Kong, China [45]	25	21	–	–	–
Damascus, Syria [26]	15.8	23.4	–	–	–
Sydney, Australia [2]	22.9	28.8	–	–	–
Athens, Greece [24]	–	–	28.5	21.5	–
Thessaloniki, Greece [24]	–	–	28.9	15.0	–
Fribourg, Switzerland [24]	–	–	15.8	11.9	–
Milan, Italy [24]	–	–	21.5	21.1	–
Cambridge, UK [24]	–	–	18.0	n.a.	–
Sheffield, UK [24]	–	–	15.8	10.8	–
Kassel, Germany [24]	–	–	22.1	15.2	–
Singapore, Singapore [63]	–	–	–	–	28.7
Rome, Italy (present study)	26.9	24.9	27.2	22.1	–

Probably the site also had an influence on the results provided by the study of Cheng et al. [45] in Hong Kong. In this case the longitudinal survey was performed in an open yard with similar characteristics to those that could be found in an urban park and this led to a neutral PET value of 25 °C in summer and 21 °C in winter. In particular, the influence of the site chose on outdoor thermal comfort was evident from the fact that the average air temperature registered in Hong Kong is generally higher than the one in Rome: this difference is about 4–5 °C in summer and 8 °C in winter.

On the other hand different results were obtained by Yahia and Johansson [26] and Spagnolo and de Dear [2] who demonstrated how, respectively for Damasco and Sydney, the neutral PET values presented an opposite trend: in winter the values of 23.4 and 28.8 °C were registered, whereas in summer 15.8 and 22.9 °C. Even if can seem surprising that summer neutral PETs are lower than those in winter, this phenomenon can be explained through the concept of alliesthesia. It is a psychological mechanism which leads people to consider positively everything that warms them when the environment is cool and vice versa.

However, it is necessary to consider that not in every study these evaluations were made through the PET. For example, Nikolopoulou and Lykoudis [24] reported the results of a transversal study carried out in 7 different European cities where the neutral air temperature was examined. Therefore, in order to make a wider comparison, it was also evaluated in this study following the method described previously in this subsection and considering air temperature bins with a width of 1 °C. Such approach determined, for the city of Rome, a neutral air temperature of 22.1 °C in winter and 27.2 °C in summer. While examining these results and comparing them with those of Athens, Thessaloniki, Fribourg, Milan, Cambridge, Sheffield and Kassel, it can be said that even for the city of Rome, neutral temperatures appear to follow the profile of the respective climatic temperatures on a seasonal basis. Moreover, based on what Nikolopoulou and Lykoudis [24] reported, even in this study the difference between neutral air temperatures and average seasonal temperatures decreased in summer and increased in winter; hence the trend of this difference was inversely proportional to the average air temperature of the city. This can be explained from a physical point of view as well, since in warm conditions people have the required mechanisms to adapt more easily than in cold conditions [43].

Finally, a different approach was adopted by Yang et al. [63] in Singapore: they examined the operative temperature determining a neutral value of 28.7 °C. However this variable is not here analyzed, hence it is not possible to make a comparison.

5.2. Preferred PETs

Even if the preferred PET was examined only in a few studies, its analysis can be interesting. It can be defined as the thermal condition in which people prefer neither cooler nor warmer temperatures [81]: in other words it is the temperature that people actively prefer and its analysis allows to study the effects of the season expectations on thermal comfort.

Hence to determine its values, both in hot and cold seasons, this study takes into consideration the thermal preferences of the interviewees given as answers in the questionnaires through the McIntyre scale (cooler (−1), no change (0) and warmer (+1)). Then all the preferences were evaluated considering bins with a width of 1 °C PET and were correlated to the PET through a logistic curve model with the probit function [82]. The PET value, where the curves of “prefer warmer” and “prefer cooler” referring to every season intertwined, represented the preferred PET [80]. Fig. 4 shows that preferred PETs differ in both seasons: values characterizing hot and cool seasons were respectively 24.8 °C and 22.5 °C, 2.1 °C and 2.4 °C lower than neutral PET.

This demonstrates that in the city of Rome there is a certain thermal adaptation through the seasons.

As done previously, the results obtained were compared with those of other studies (Table 6).

A similar situation was reported by Lin [67] in Taichung City, Taiwan. The preferred PETs are 23 °C in the cool season and 24.5 °C in the hot season and even in this case there was a decrease respect to neutral PET values.

Even if the focus was on the operative temperature, it was registered a decrease in the preferred value in Singapore [63] as well: in this case the decrease was of 2.2 °C and the preferred operative temperature was of 26.5 °C.

To conclude, Spagnolo and de Dear [2] found in Sydney a preferred PET of 30.9 °C for the cool season and 23.4 °C for the hot season. As for the neutral PETs, in the study of Spagnolo and de Dear [2] the value concerning the cool season was higher and, if in the other reviewed studies the preferred PETs (or from a more general point of view the preferred values of the variables) reported a decrease respect to the neutral values, in the case of Sydney [2] there is the opposite situation due to the influence of the alliesthesia mechanism.

5.3. “Optimal” comfort ranges

The influence of the acclimatization and personal expectations was evident even examining the PET ranges corresponding to

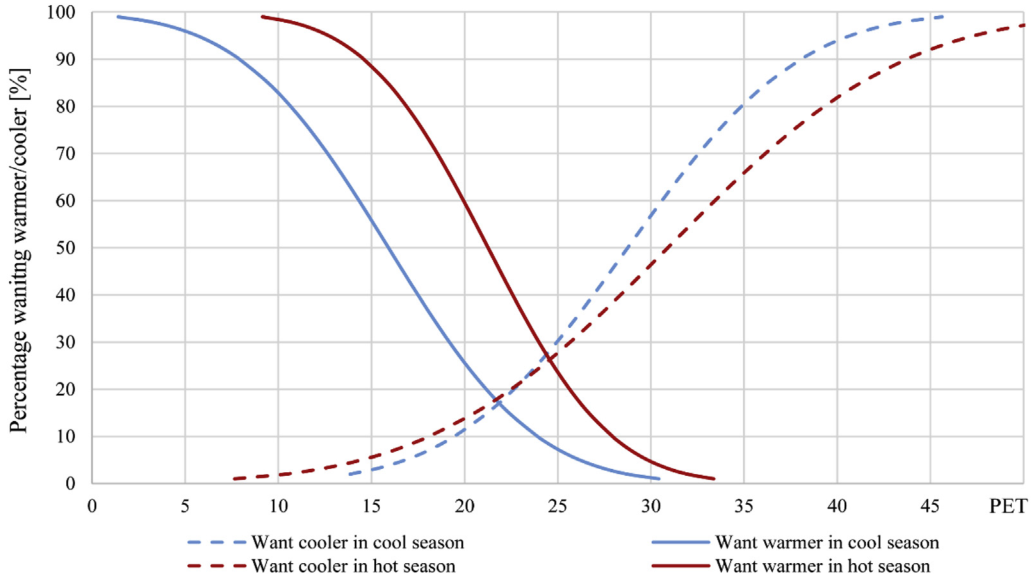

Fig. 4. Preferred PETs in cool and hot seasons.

thermally satisfying environments.

The answers given by the interviewees on thermal perception were related to the corresponding PET values and bins whose width was 1 °C PET were considered. For each bin the mean thermal sensation votes (MTSVs) were calculated and, contrary to what has been previously done (subsection 5.1 and 5.2), the answers were not divided according to the seasons.

From this analysis, through a linear regression, the Eq. (6) was determined:

$$MTSV = -3.115 + 0.124 \cdot PET \quad R^2 = 0.941 \tag{6}$$

Its trend was represented in Fig. 5 and it allowed to determine the comfort range in Rome in terms of PET. It ranges between 21.1 °C and 29.2 °C (Table 7) and it was calculated by assuming that the comfort range was the interval −0.5÷0.5 of the ASHRAE 7-point scale (which was used in this study) [25,68].

The comparison with the results of the other studies (Table 7), due to the assumptions made, is only possible with those obtained by Krüger et al. [68] in Glasgow, Scotland, and by Lai et al. [47] in Tianjin, China. In the first case a PET comfort range of 9÷18 °C was determined whereas in the second one it corresponds to the interval 11÷24 °C. As done in the present study, they evaluated thermal perception through the ASHRAE 7-point scale, considering a comfort range between −0.5 and + 0.5 and obtaining results that could be considered valid for an entire year.

Through this comparison it can be noticed that there was not a correspondence between the comfort range in Glasgow and the one in Rome: this could be due to the differences characterizing the climates of both cities. As a matter of fact Glasgow presents an average annual air temperature of 8.9 °C, whereas Rome 15.2 °C. On the other hand, a partial correspondence was found with the PET comfort range determined in Tianjin. Indeed the climate of this city sees a monthly average temperature ranging from −3 °C to 26 °C (in Rome it varies between 7.2 °C and 24.1 °C) and this leads its residents to have a wider and lower thermal sensation range.

Considering the studies carried out in Glasgow and Rome, it is also interesting that only in the second there was a partial correspondence with the PET comfort range suggested for the mid-west of Europe, which is 18÷23 °C [29].

This result shows how people coming from different areas present different thermal requirements.

From this point of view, the results of the present research agree with those provided in the Mediterranean area by Mahmoud [55] for Cairo, Egypt, and Yahia and Johansson [26] for Damascus, Syria. However, it should be considered that in the first case winter and summer were considered separately and, as previously said in subsection 5.1, the values obtained could be affected by the type of site (in this case an urban park). In the second case two different PET comfort ranges were calculated: one with a limit of thermal acceptability of 90%, while the other of 80%. Differently, in the city of Rome, the highest value of thermal acceptability is 85% in correspondence of a MTSV = 0 (subsection 5.5).

This factor affected even the comparison with the results provided by other reviewed studies. For example Matzarakis and Lin [29] determined the PET comfort range in Sun Moon Lake, Taiwan, with a thermal acceptability of 88%, while Lin [67], in Taichung City, Taiwan, set the value of 90%. These assumptions made hard a comparison with the results provided by this study where the percentages set in Taiwan were never reached.

The same difficulty could be found in the comparison with the

Table 6
Results of other studies examined in terms of preferred PET.

City	Preferred PET [°C]		Preferred operative temperature [°C]
	Summer	Winter	Whole year
Taichung City, Taiwan [67]	24.5	23.0	–
Sydney, Australia [2]	23.4	30.9	–
Singapore, Singapore [63]	–	–	26.5
Rome, Italy (present study)	24.8	22.5	–

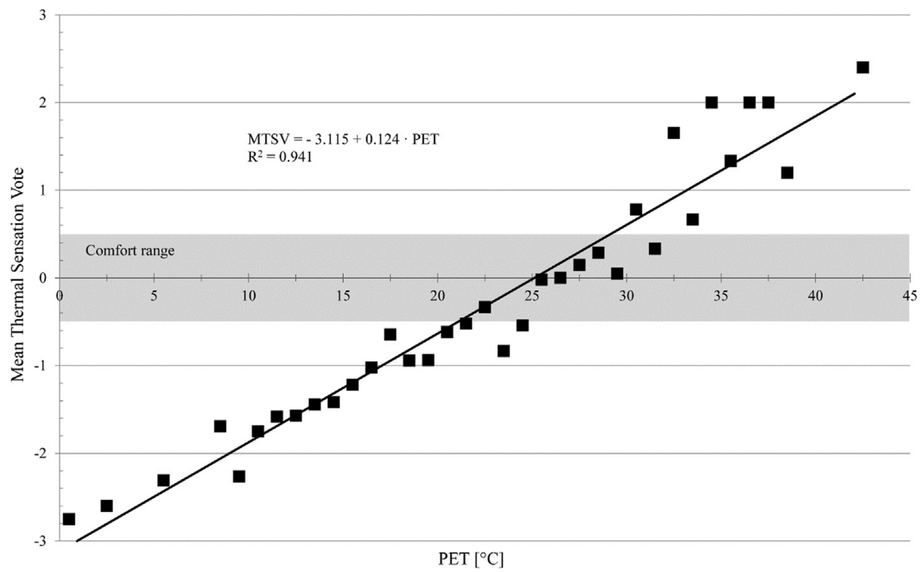

Fig. 5. Correlation between the mean thermal sensation votes (MTSVs) and PET during a whole year and identification of the PET comfort range.

results of Cheng et al. [45] because they determined the comfort range by taking into consideration the interval between the values −1 and +1 of the thermal sensations.

The situation is different for the study of Kantor et al. [25]: even if they considered, as for the city of Rome, a comfort range between −0.5 and + 0.5 of the thermal sensations, they analyzed the seasons of fall and spring.

Another type of analysis, respect to the one carried out in Rome, was then performed by Andrade et al. [4] and Ng and Cheng [54]: in order to define the comfort ranges they respectively determined those PET values where the number of votes “want no change of temperature” and TSV = 0 was higher.

Finally, a different method was used by Yang et al. [63]: the comfort range was calculated in terms of operative temperature and with an 80% of thermal acceptability. These two assumptions made difficult a comparison with the values provided by this research.

5.4. Towards the new empirical Mediterranean Outdoor Comfort Index (MOCI)

While examining the thermal behavior of open spaces and outdoor thermal comfort, it is necessary to consider the influence of adaptation and personal expectations; subjects coming from different regions have different thermal demands. It should be also considered that many rational indexes, usually used to evaluate outdoor thermal comfort, were meant for indoor environments and later were adapted to be used for outdoor conditions as well. This is why one of the goals of this study was the realization of an empirical index called MOCI (Mediterranean Outdoor Comfort Index) and able to measure the thermal perception of the Mediterranean population.

During the first step, it was determined through a multiple regression analysis while considering as dependent variable the vote of the interviewees about the thermal environment and as independent variables the environmental variables (mean radiant temperature, air temperature, relative humidity, global radiation, wind velocity), operative variables (metabolic rate, clothing thermal insulation) and some personal factors (age, time of exposure).

These independent variables were reduced through the VIF (Variance Inflation Factor) analysis and the evaluation of multicollinearity: collinear variables do not provide further information and it is difficult to identify the effect that each of them has on the dependent variables. This is why, observing what stated by Marquardt [83] and what done by Eliasson et al. [66], independent variables with a VIF > 10 should be excluded.

However some choices must be justified. From a preliminary analysis of the VIF, the variables that at first had a VIF >10 were: age, mean radiant temperature and air temperature. It was hypothesized though that a high VIF of the mean radiant temperature

Table 7
Results of other studies examined in terms of PET and operative temperature comfort ranges.

City	PET comfort range [°C]				Operative temperature comfort range [°C]
	Summer	Winter	Transient seasons	Whole year	Whole year
Glasgow, Scotland [68]	–	–	–	9÷18	–
Tianjin, China [47]	–	–	–	11÷24	–
Western/Middle Europe [29]	–	–	–	18÷23	–
Cairo, Egypt [55]	22÷30	21÷29	–	–	–
Damascus, Syria [26]	n.a.÷31	21÷n.a.	–	–	–
Sun Moon Lake, Taiwan [29]	–	–	–	26÷30	–
Taichung City, Taiwan [67]	–	–	–	21.3÷28.5	–
Hong Kong, China [45]	n.a.÷32	12÷n.a.	–	–	–
Szeged, Hungary [25]	–	–	13.7÷20.3	–	–
Lisbon, Portugal [4]	–	–	–	21÷23	–
Hong Kong, China [54]	27÷29	14÷16	–	–	–
Singapore, Singapore [63]	–	–	–	–	26.3÷31.7
Rome, Italy (present study)	–	–	–	21.1÷29.2	–

and air temperature could partly depend on the global radiation (with a VIF of about 10); moreover, if it is true that when the global radiation is high there is also a high mean radiant temperature, the result is not the same in the opposite situation. As a matter of fact, high mean radiant temperature values could be provoked not only by a direct shortwave radiation. This is why, together with the importance of the air temperature for outdoor thermal comfort, age and global radiation were excluded from the independent variables.

Then the VIF was calculated again for the rest of the variables with satisfying results (VIF < 10 for every variable considered).

In the next step, a Best Subsets analysis was performed. Thanks to this method and through different criteria, 127 possible regression models were evaluated considering the set of the independent variables previously determined.

The first criteria was the adjusted R^2: in this case the R^2 was adjusted by taking into consideration the number of explanatory variables inserted in the model and the width of the sample. Such evaluation was useful because this study compares models with a different number of explanatory variables.

A second criteria, usually employed to compare different regression models, was the C_P statistic [84]. This statistic measures the difference between the estimated regression model and the true model. It is defined according to the Eq. (7):

$$C_P = \frac{\left(1 - R_P^2\right)(n - T)}{1 - R_T^2} - [n - 2(p + 1)] \tag{7}$$

where:

→ p is the number of explanatory variables inserted in the regression model;
→ T is the total number of parameters (intercept included) that must be estimated in the complete regression model;
→ n is the number of observations;
→ R_P^2 is the multiple regression coefficient for a regression model with p explanatory variables;
→ R_T^2 is the multiple regression coefficient for the complete regression model.

If a regression model with p explanatory variables differs from the true model due to random errors only, the average value of the C_P statistic is (p+1). Hence, the goal was to identify those models with a C_P value lower than or equal to p+1.

In the present study, among those models observing the condition $C_P \le (p+1)$, the one with the highest adjusted R^2 was the model with the following variables: wind velocity, air temperature, mean radiant temperature, relative humidity and clothing insulation. Indeed it presented an adjusted R^2 value of 0.395, a R^2 value of 0.398 and a Pearson coefficient r of 0.631.

The next step was the development of the multiple regression model (Table 8).

While taking into consideration the coefficients reported in Table 8, the Eq. (8) of the new empirical index suggested, the MOCI (Mediterranean Outdoor Comfort Index), was obtained:

$$MOCI = -4.068 - 0.272 \cdot WS + 0.005 \cdot RH + 0.083 \cdot T_{MR} + 0.058 \cdot T_A + 0.264 \cdot I_{CL} \tag{8}$$

The intercept, −4.068, is the index value that we would have if the variables of the model were 0. This value could correspond to a thermal sensation of intense cold. However such assertion should be examined in reference to the ranges measured for the independent variables; for example an I_{CL} value of 0 (that would mean that the subject is naked) has never been registered.

Then the slope of each variable provided information about the variation of the MOCI due to the unitary variation of each of them (keeping constant the values of the others). For example, an increase of 1 °C in the mean radiant temperature led to an index growth of 0.083, always assuming that the other variables were constant.

In this case it was decided to use a linear regression model because the residuals did not show a structured trend and the value of the test F (123,57) confirmed a significant relation between the dependent variable and the set of explanatory variables. Indeed this value was higher than 2.21, critical value for a distribution F with 5 and 941 degrees of freedom determined by the 95° percentile of Fischer's pdf with a significance level of 0.05.

It can be also interesting to verify if there is a significant linear relation between the independent variables and the new index suggested; this is possible if the values assumed by the t statistic exceed the range ±1.960 (this value is determined by the percentile $(1 - \alpha)$% of Student's pdf with a significance level of 0.05 and 941 degrees of freedom). Therefore, by examining Table 8, it is possible to see how there is a significant linear relation between the MOCI and the mean radiant temperature, air temperature and wind velocity.

The contribution of each independent variable was also estimated. For this type of analysis the partial F test criteria was used: it measures the contribution that each independent variable gives to the sum of squares once the others had been included in the model. When there is more than just one independent variable, the contribution of each of them can be evaluated through the sum of squares of the regression for a model containing all the explanatory variables except the one examined, SQR (all the variables except the k-th). Hence, the contribution of the variable k, assuming that all other variables are included in the model, can be determined according to the Eq. (9):

$$\begin{aligned} &SQR\,(X_k|all\ variables\ except\ the\ k-th) \\ &\quad = SQR\,(all\ variables\ k-th\ included) \\ &\qquad - SQR\,(all\ variables\ except\ the\ k-th) \end{aligned} \tag{9}$$

Then the partial F test was determined through the Eq. (10):

$$F = \frac{SQR(X_k|all\ variables\ except\ the\ k-th)}{MSE} \tag{10}$$

where F is the F statistic and MSE is the Mean Square Error.

Table 8
Results derived from the development of the multiple regression model.

	Coefficient	Standard error	t statistic	Sig.	VIF
Intercept	−4.068	0.439	−9.268	0.000	–
Clothing insulation I_{CL}	0.264	0.158	1.672	0.095	2.064
Mean radiant temperature T_{MR}	0.083	0.009	9.023	0.000	4.271
Air temperature T_A	0.058	0.015	3.843	0.000	6.498
Relative humidity RH	0.005	0.004	1.284	0.199	2.057
Wind velocity WS	−0.272	0.079	−3.445	0.001	1.111

Therefore the values of the partial F test were:

$$F(T_A) = 14.769; \quad (11)$$

$$F(T_{MR}) = 81.415; \quad (12)$$

$$F(WS) = 11.868; \quad (13)$$

$$F(RH) = 1.649; \quad (14)$$

$$F(I_{CL}) = 2.795. \quad (15)$$

While comparing them with the critical value 2.21 (as previously said it was determined by the 95° percentile of Fischer's pdf), it can be noticed how partial F test values of the mean radiant temperature, air temperature, wind velocity and clothing insulation were higher, whereas the partial F test of the relative humidity was lower.

This is why the model showed a significant improvement when the mean radiant temperature, air temperature, wind velocity and clothing insulation were included (the order depends on their contribution) and only a lower improvement was given by relative humidity. The importance of the mean radiant temperature for the model is also showed by the fact that the corresponding coefficient of partial determination was 19%.

These results were confirmed by those provided by other studies [85,86] which showed how the mean radiant temperature was the variable affecting the most the energy balance of the human body. Such data are the result of the climate of Rome which is not windy: in fact in climates with higher wind velocity values, the air temperature becomes the dominant variable because it bestrides the convective heat exchange [19,28].

5.5. Correction of the Predicted Percentage of Dissatisfied (PPD) relation

It is necessary to consider that the MOCI (as the PMV) predicts the mean value of the thermal votes of a large group of people exposed to a given thermal environment and for this reason it could be useful to know the number of people perceiving a thermal discomfort under certain microclimatic conditions. From this point of view, the ISO 7730 [11] suggests the use of the Predicted Percentage of Dissatisfied (PPD) to determine the percentage of people experiencing a thermal discomfort and feeling too hot or cold; its numerical value can be calculated thanks to the PMV through a regression equation. However, as the PMV was based on the same 7-point thermal sensation scale adopted for the MOCI, this allowed the estimation of the goodness of fit, in reference to the Mediterranean climate, of the original formula of the PPD [11]. While taking into consideration Table 2 of the ISO 7730 [11], the thermal comfort was assumed to correspond to the range between −1 (slightly cool) to +1 (slightly warm), whereas the thermal discomfort was assumed to correspond to the votes +2 and + 3 when too hot and −2 and −3 when too cold.

Fig. 6 shows: the representative points of the actual PPD (determined through the results provided by the field survey for every PET bin), the curve of best-fit for these points (PPD Rome), the curve of the PPD estimated for the city of Glasgow (PPD Glasgow) [68] and the PPD curve calculated according to the ISO 7730 [11]. Table 9 shows the equations of these curves.

While examining Fig. 6 it can be noticed how, in correspondence of a neutral thermal sensation (MTSV = 0), the minimum PPD value obtained in this study was higher than the one provided by the PPD regression equation suggested by the ISO 7730 [11]. This can find an explanation in the higher variation of the thermal sensation votes for a given PET bin in an outdoor environment; this means a higher difference of the thermal sensations and leads to a higher number of people experiencing a thermal discomfort. Differently, when MTSV values are lower than −1.8 and higher than +1.8, the PPD characterizing the city of Rome is lower than the one suggested by the PPD ISO 7730. A possible explanation could be that when microclimatic conditions cause a high level of thermal stress, people are affected by the fact that they can't control the outdoor environment and tend to be more tolerant. For example, Yang et al. [63] found that in some hot climates the preferred temperature in outdoor environments was higher (0.7÷1.2 °C in their research) than the one people prefer in indoor and semi-outdoor environments; this proves the influence of expectations and how people in outdoor environments usually expect worse conditions.

Fig. 6 also shows how the curve PPD Glasgow [68] always presents a percentage of dissatisfied higher, MTSV being the same, than the curve PPD Rome. An explanation could be the influence of the wind velocity: the ranges of this variable, measured during the

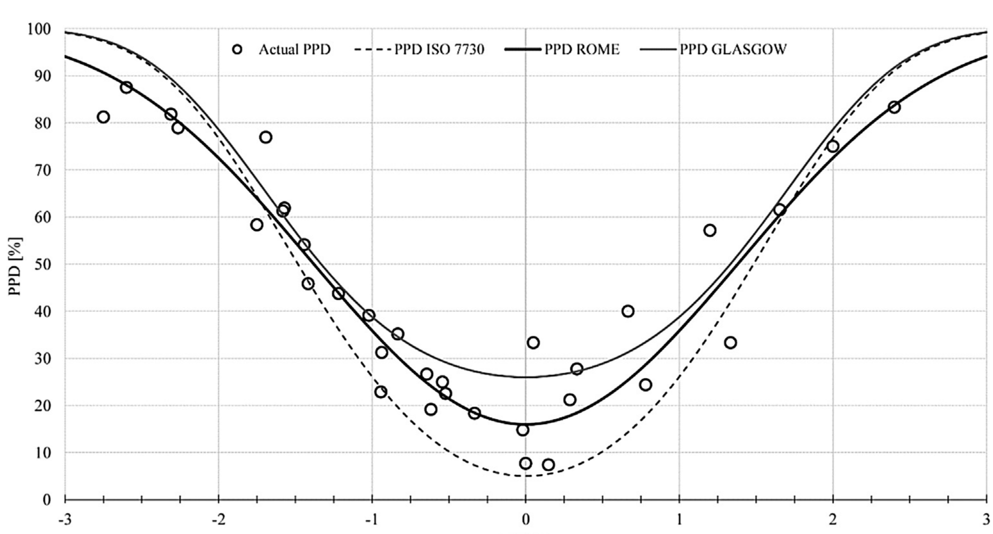

Fig. 6. Analysis of the Predicted Percentage of Dissatisfied (PPD).

Table 9
Adjusted regression equations for PPD.

Original PPD equation [11]	$PPD = 100-95\cdot EXP(-0.03353\cdot PMV^4-0.2179\cdot PMV^2)$	–	Eq. (16)
PPD Glasgow [68]	$PPD = 100-74\cdot EXP(-0.04\cdot MTSV^4-0.15\cdot MTSV^2)$	$R^2 = 0.80$	Eq. (17)
PPD Rome [present study]	$PPD = 100-84.02\cdot EXP(-0.003173\cdot MOCI^4+0.2668\cdot MOCI^2)$	$R^2 = 0.87$	Eq. (18)

field survey, were 0÷3.6 m/s for Glasgow and 0÷2.5 m/s for Rome. However, for what concerns Rome, it should be considered that 91% of the values measured was lower than 1.5 m/s. Such difference affects the percentage of people experiencing a thermal discomfort: thanks to a study carried out in Lisbon, Oliveira and Andrade [62] demonstrated how, for wind velocity values lower than 2.25 m/s, none of the subjects was experiencing a discomfort, whereas with values higher than 3.7 m/s, 40% of the subjects considered the wind excessive. Considering that the air temperature registered during the study of Oliveira and Andrade ranged between 16.6÷18.8 °C and 21.3÷23.5 °C, these results can be also extended to the research carried out in Glasgow where the air temperature values measured ranged between 7.9 and 21.9 °C, keeping in mind that temperatures lower than 16.6 °C might increase the number of dissatisfied people. Moreover, Glasgow was characterized by an average wind velocity of 4.8 m/s, similar to the one registered in Lisbon, 5.0 m/s [87]. The fact that these values are similar should exclude a different psychological adaptation, especially for what concerns both memory and expectations. To conclude, as showed in Table 3, the present study also measured air temperature values higher than 23.5 °C: with these conditions the wind velocity was experienced as a pleasant factor.

6. Conclusions

This research analyzed thermal perception and preference of the Mediterranean population through a case study carried out in Rome from February 2014 to January 2015.

Such study was a transversal field survey: 1009 questionnaires (941 valid) were filled by subjects chose randomly in areas outside the campus of the "Sapienza" University of Rome and the building of the Faculty of Engineering.

This questionnaire presented two parts: the first asked personal questions (age, gender, clothing, activity, time of exposure, etc …), while in the second part the interviewees identified their thermal perception through the ASHRAE 7-point scale (cold (−3), cool (−2), slightly cool (−1), neutral (0), slightly warm (+1), warm (+2) and hot (+3)) and their thermal preference through the McIntyre scale (cooler (−1), no change (0) and warmer (+1)). At the same time, right next to the interviewee, five microclimatic variables were measured: air temperature, mean radiant temperature, wind velocity, relative humidity and global radiation. This allowed to assign a PET (Physiological Equivalent Temperature) value to each interview.

Later, once the data were collected, the Mean Thermal Sensation Votes (MTSVs) and the regression lines between MTSV and PET in hot and cool seasons were estimated (with PET bins whose width was of 1 °C). These relations allowed the determination (with MTSV = 0) of the neutral PET values: 26.9 and 24.9 °C respectively for hot and cool seasons.

The same method was adopted for the air temperature: in this case the neutral value for the hot season was 27.2 °C and 22.1 °C for the cool season.

Even the answers provided by the interviewees about thermal preference were evaluated in correspondence of PET bins with a width of 1 °C; however they were correlated to the PET by using a logistic curve model with the probit function. This led to estimate a preferred PET of 24.8 °C for the hot season and 22.5 °C for the cool season and it proves that in Rome there is a sort of thermal adaptation through seasons.

Then an "optimal comfort range" was defined: the evaluation of the MTSV in correspondence of PET bins with a width of 1 °C was extended to the whole year. Hence one regression line only was determined, through which, by keeping in mind that the comfort interval should be −0.5÷0.5 of the ASHRAE 7-point scale, the PET comfort range was defined as being 21.1÷29.2 °C.

This research also determined an empirical index for the evaluation of outdoor thermal comfort of the Mediterranean population. This index, called MOCI (Mediterranean Outdoor Comfort Index), predicts the average vote (with reference to the ASHRAE 7-point scale) of a large group of people evaluating thermal comfort in an outdoor environment. The independent variables of the MOCI are: mean radiant temperature, air temperature, wind velocity, relative humidity and clothing insulation. They were obtained through the preliminary evaluation of the VIF (Variance Inflation Factor) followed by a Best Subsets analysis which identified the best model among those possible.

However the MOCI predicts a mean vote, hence it could be useful to know the number of people experiencing a thermal discomfort. This is why the relation of the Predicted Percentage of Dissatisfied (PPD), suggested by the ISO 7730, was adapted to the Mediterranean population.

For what concerns the application of the results provided by this study, they can be useful to architects, engineers, designers and urban planners in the predictive evaluation of the thermal behavior of outdoor environments and their level of habitability in the Mediterranean area. The results can also help in the choice of the materials that are going to form the urban texture (both while planning new public spaces and performing the renovation of urban sites). In other words, the relations suggested gave the possibility to make a numerical evaluation of how the choices made during the planning phase affect outdoor thermal comfort of a population adapted to the conditions of the Mediterranean climate. For example, through a software (i.e., ENVI-met [88]) able to simulate the microclimate of a specific area, different planning scenarios (in terms of morphological characteristics and/or materials used for outdoor surfaces) could be evaluated: for every scenario the values of the microclimatic variables could be obtained and they could be used as input data in the MOCI relation. Then the values of the MOCI could be used in the relation readapted to the Mediterranean population of the PPD. Hence, the MOCI and the readapted PPD relations would have a predictive character. Finally, the microclimatic variables could be also used to calculate the PET, which could be compared to the neutral PETs, the preferred PETs and the "optimal" PET comfort range determined in this study (these results could have a verification function).

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