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Thermal Perception in the Mediterranean Area: Comparing the Mediterranean Outdoor Comfort Index (MOCI) to Other Outdoor Thermal Comfort Indices

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Abstract: Outdoor thermal comfort is an essential factor of people's everyday life and deeply affects the habitability of outdoor spaces. However the indices used for its evaluation were usually developed for indoor environments assuming still air conditions and absence of solar radiation and were only later adapted to outdoor spaces. For this reason, in a previous study the Mediterranean Outdoor Comfort Index (MOCI) was developed, which is an empirical index able to estimate the thermal perception of people living in the Mediterranean area. In this study it was compared numerically (by using the data obtained through a field survey) with other selected thermal indices. This comparison, performed in terms of Spearman's rho correlation coefficient, association Gamma, percentage of correct predictions and cross-tabulation analysis, led to identify the MOCI as the most suitable index to examine outdoor thermal comfort in the interested area. As a matter of fact it showed a total percentage of correct predictions of 35.5%. Good performances were reported even in thermophysiological indices as the Physiological Equivalent Temperature (PET) and Predicted Mean Vote (PMV). Moreover it was revealed that adaptation and acclimatization phenomena tend to have a certain influence as well.

Keywords: outdoor thermal comfort; thermal adaptation; MOCI; PMV; PET; statistical analysis; field survey; comfort range

1. Introduction

Currently more than half of the world population lives in cities [1] and this has brought researchers, engineers, architects, urban planners to focus their attention on the urban microclimate and outdoor thermal comfort. Over the last decade the number of studies on these topics in order to understand how people perceive and interact with the surrounding thermal environment has been progressively increasing. A city planned properly with an accurate selection of the materials used for outdoor spaces [2–4] can improve thermal living conditions, with a decrease in the potential thermal stress and a reduction of the Urban Heat Island (UHI) effect. The result is an increase of outdoor activities and the exertion of means of transport as walking or cycling. Even if some studies focused their attention on natural ventilation in indoor environments [5–7], it should be also underlined how an accurate planning of outdoor spaces is one of the most effective measures to reduce the energy consumption caused by the air-conditioning in buildings [8,9] (in particular in the Mediterranean cities during summertime). Outdoor spaces which are thermally comfortable become gathering areas which in turn leads to a higher amount of time spent outside, hence a lower level of exertion of air-conditioners and other electronic devices. Moreover the energy demand decreases also thanks to an accurate selection of the materials [10,11]: as a matter of fact planning outdoor spaces by using "cool" materials on surfaces with a high sky view factor determines a decrease in the mean radiant temperature, air temperature and heat flux transferred to indoor spaces.

Although it was previously outlined that carrying out an accurate evaluation of outdoor thermal comfort has positive implications, it must be specified that this is a relatively new field in the world of research. Hence people's thermal perception has been often examined through indices and models which were meant for indoor spaces, whose parameters do not include shortwave radiation and assume still air and steady-state conditions. This is why sometimes they were adapted to outdoor spaces which present a more complex environment. For example, this was possible for the Predicted Mean Vote (PMV) [12] after the parametrization of the radiative fluxes performed by Jendritzky et al. [13]. Even indices created for outdoor spaces were realized by keeping in mind the assumptions made for indoor spaces: the Physiological Equivalent Temperature (PET), suggested by the German standards in urban and regional planning [14], assumes a thermal clothing insulation of 0.9 clo and a metabolic rate of 80 W which must be added to the basal metabolic rate.

However thermal comfort is not affected only by operative and environmental variables. To make the prediction of thermal perception harder, other factors such as physiological adaptation to the local climate conditions (acclimatization), behavioral and social adaptation (rules, norms and values) [15], expectations and preferences occur. This leads to different thermal perceptions and requirements among people adapted to different climates. From this point of view, Nikolopoulou and Lykoudis [16] examined outdoor thermal comfort in seven different European cities (Athens, Cambridge, Fribourg, Kassel, Milan, Sheffield and Thessaloniki) noticing that the neutral air temperature trend follows the profile of the respective climate temperatures on a seasonal basis. In other cases, some differences were reported by comparing, in different cities, neutral PET values [17–19] and the corresponding comfort ranges [19]. While taking into consideration these discrepancies, other studies tried to calibrate the limits of various scale indices [20,21] and make an evaluation of different calibration methods [22].

Differently further studies analyzed the indices performances. Tseliou et al. [23] examined three indices (PET included) and tried to improve their predictive abilities by taking into consideration the average climate temperature. Through another study, Pantavou et al. [24] analyzed a high number of indices by evaluating the possibility to quantify thermal perception in Athens (Greece). The result was that most of the indices simulated with success about 35% of the thermal sensation votes. Different conclusions were then reported by Ruiz and Correa [25]: they examined six thermal comfort indices (including PMV and PET) and found predictive abilities which were lower than 25%.

A different approach was adopted by Köppe and Jendritzky [26] and Blazejczyk et al. [27]. The former, in order to consider the acclimatization caused by short time intervals of exposure, added to each limit value of the thermal comfort scale one third of the difference between the index daily value and the corresponding limit. On the other hand the latter analyzed a global dataset, synoptic datasets from Europe and local scale data from special measurement campaigns of COST Action 730 to evaluate the ability of some indices to represent certain climates, micrometeorological conditions and place.

To reach this goal and consider the influence on thermal perception of expectation, preference and acclimatization, over the last few years there has been a tendency among researchers to create empirical indices. An example can be found in the correlation, through multiple regressions, between subjective thermal perception and the micrometeorological variables measured.

These analysis are usually preceded by field surveys where interviewees are asked to judge their thermal perception through an appropriate scale. The vote given by the interviewees will be used as a dependent variable, whereas environmental and/or operative variables as independent variables.

This kind of studies, hence empirical indices as well, were developed in the whole world covering different climates and cultures [28–34].

The index the authors wanted to evaluate in this study, the Mediterranean Outdoor Comfort Index (MOCI) [19], is an empirical index as well. It was determined through the results provided by an annual field survey carried out in Rome (Italy). It is based on the ASHRAE 7-point scale [35] and is able to predict the mean value of the votes Mediterranean people might give to judge the thermal quality of an outdoor environment. Its independent variables are: air temperature, mean radiant temperature, relative humidity, wind speed and thermal clothing insulation and it derives from a Best Subsets analysis. This index, specifically created for outdoor spaces, was developed in order to introduce an instrument able to both predict the thermal perception in the Mediterranean area and indirectly take into consideration phenomena as acclimatization, expectations and preferences.

In this study the MOCI was numerically compared with other commonly used thermal comfort indices: Actual Sensation Vote Europe (ASV_{EUROPE}) [36], Effective Temperature (ET) [37], Physiological Equivalent Temperature (PET) [38] and Predicted Mean Vote [12]. In order to perform this comparison, a transversal field survey has been conducted in Rome for 5 months (from June 2015 to November 2015) and 592 structured questionnaires (complying with the ISO 10551 [39]) were filled and combined with micrometeorological measurements. The interviewees answered to personal questions (gender, age, weight, height, clothing, activity, time of residency, time of exposure . . .) and were asked to judge 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)). While taking into consideration the environmental variables measured and the operative variables related to the questionnaires, a certain value of each evaluated index was associated to each questionnaire and to the vote given by the interviewee. This allowed to perform a numerical comparison between the indices studied through four different criteria (three of them were statistical whereas the fourth qualitative): Spearman's rho measure of correlation, symmetrical measure of association Gamma, total percentage of correct predictions and distribution of the correct predictions for each class (estimated through a cross-tabulation analysis). Further aspects concerned people's adaptation to outdoor conditions and the indices values varying with the changing of the season.

2. Study Area

The urban area where the field survey was carried out is Rome, Italy (41°55′N, 12°29′E) with 2,844,821 inhabitants distributed on an area of 1285.30 km^2 and a height ranging from 13 to 120 m above the sea level [40]. Rome is characterized by the typical Mediterranean climate (Table 1), with mild winters and hot summers. This can be considered a comfortable climate from April to June and from the middle of September to October. In August the daily maximum temperature often exceeds 32 °C, whereas the average maximum temperature in December is about 13 °C. Sometimes temperatures are below 0 °C [40]. For what concerns the wind speed, it presents an average value of 4.4 m/s at a height of 10 m above the ground level, whereas the average relative humidity reaches a maximum value of 81% during the cold months and a minimum value, 74%, in August.

Table 1. Average values of the air temperature and relative humidity in Rome [40].

Variables	Months											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
T_A (°C)	7.2	8.4	10.5	13.0	17.2	21.1	23.9	24.1	21.0	16.5	11.5	8.1
$T_{A\,MIN}$ (°C)	2.2	3.1	4.7	7.1	10.7	14.4	16.8	17.0	14.5	10.4	6.2	3.3
$T_{A\,MAX}$ (°C)	12.3	13.7	16.2	19.0	23.7	27.7	31.1	31.2	27.5	22.5	16.8	13.0
RH (%)	76	81	81	77	76	76	78	74	76	78	78	81

Given that the average temperature of the hottest month exceeds 22 °C, this climate belongs to the Csa category of Köppen-Geiger's climate classification [41]. Figure 1 shows how the field survey was performed at two sites of the Sapienza University of Rome: S. Peter in Chains' cloister (Faculty of Engineering) and campus outdoor areas.

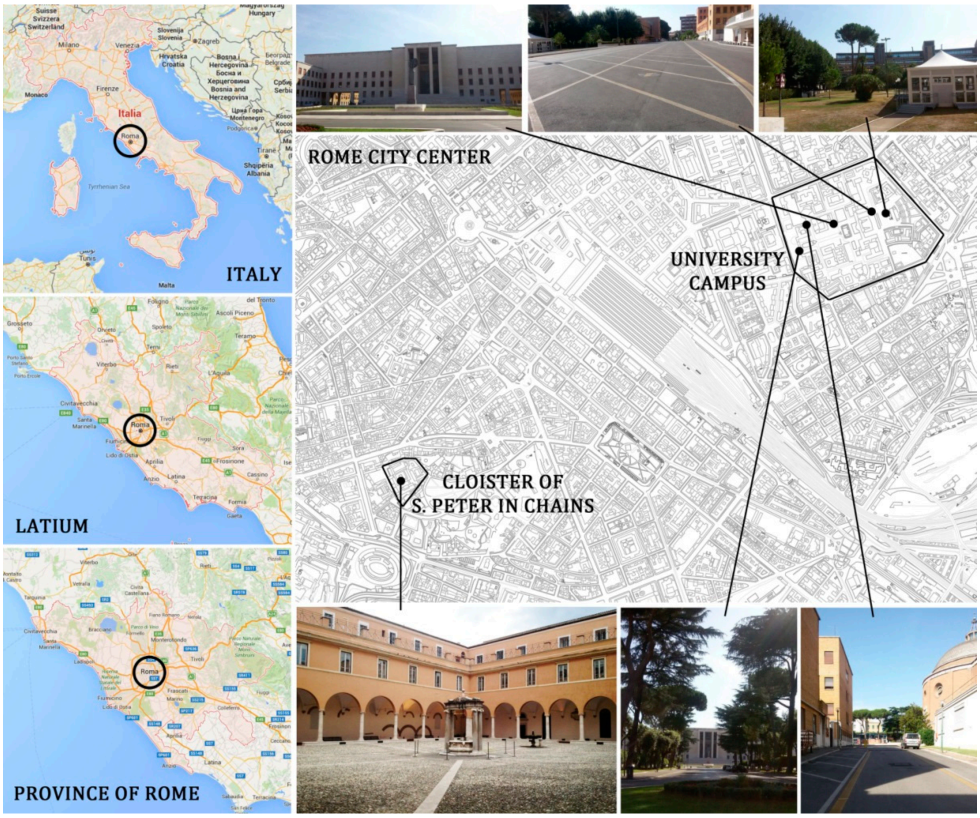

Figure 1. Map of the study area: position of Rome on the Italian territory with position and general views of the sites examined.

Even though both sites belong to the Local Climate Zone LCZ 2_3 [42], such a decision allows to examine different areas in terms of local climate, topography and urban morphology. From this point of view, outside the campus there are: a parking space made of asphalt, a wide green area with trees, urban canyons and a yard with a fountain. Finally the cloister is characterized by a transitional space (indoor/outdoor), that is the portico.

3. Materials and Method

3.1. Field Survey

The field questionnaire survey was carried out together with micrometeorological measurements of air temperature, wind speed, relative humidity, globe temperature and global radiation and covered a transitional period, that is autumn, and summer. Rome, as previously stated, is a Mediterranean city whose pedestrians are subject to higher thermal stress during the hot season. Therefore the research was performed in 6 months: from June 2015 to November 2015. For what concerns the period of the day examined, the same method of Nikolopoulou et al. [16] was adopted. Hence the day was divided into morning (08:00 a.m.–11:59 a.m.), midday (12:00 p.m.–02:59 p.m.), afternoon (3:00 p.m.–5:59 p.m.) and evening (06:00 p.m.–08:59 p.m.). Sometimes the investigation concerned just one of these time intervals, whereas in other occasions an entire day was examined. The goal was to investigate and cover a wide variety of climatic conditions representative of the Mediterranean area.

For the micrometeorological measurements a pyranometer to determine the global radiation and a mobile microclimate control unit were used. The mobile microclimate control unit was connected to different probes: a PT 100 platinum resistance thermometer for the air temperature, a psychrometric probe with forced ventilation and distilled water tank for the relative humidity, a hot wire anemometer for the wind speed and a black spherical globe thermometer to measure the globe temperature

(150 mm diameter). For what concerns this instrument, it should be said that the spherical shape of the globe thermometer used gives the possibility to have a good approximation of the shape of the human body for those sitting [43]. On the other hand, this type of globe thermometer could provide a less accurate estimation for a person standing with respect to an ellipsoid-shaped sensor [44]. Still, Thorsson et al. [45] reported a good reliability of the spherical shape globe thermometer in mid- to high-latitude climates. However, a black-colored globe sometimes tends to overestimate the influence of the short-wave radiation [44].

Adopting the same procedures as Spagnolo and de Dear [46], the measurements were carried out at a distance which did not exceed 3 m with respect to the interviewee and, in accordance with the ISO 7726 [43], the probes were located at a height representative of the centre of gravity of the human body: 0.6 m for those sitting and 1.1 m for those standing. Then in order to have realistic values of relative humidity, air temperature, global radiation and mean radiant temperature, 3 measurements were performed during each questionnaire, followed by the assessment of their average value. It must be specified that to determine the mean radiant temperature from the globe temperature measured values the Equation (1) [43] was used:

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

This is the most common method to determine the mean radiant temperature. As Johansson et al. [47] stated, this methods was used in about half of the studies about outdoor thermal comfort. Moreover, Thorsson et al. [45] revealed slight differences among the results provided by both the globethermometer method and the more complex method based on integral radiation measurements and angular factor.

The approach was different for the wind speed: in this case its variability was also taken into consideration. This is why to the maximum value measured (WS_{MAX}) the standard deviation (sWS) of the three measurements performed during each questionnaire was added in accordance with the Equation (2) [48,49]:

$$WS = WS_{\mathrm{MAX}} + sWS \quad (2)$$

For what concerns the interviews, the structured questionnaire was organized in accordance with the ISO 10551 [39] and it was submitted to people selected randomly in the sites. It could be filled out in about 90 s and it was characterized by clear questions. One of them was to judge the thermal perception by using the ASHRAE 7-point scale (cold (−3), cool (−2), slightly cool (−1), neutral (0), slightly warm (+1), warm (+2) and hot (+3)) while further questions concerned personal aspects such as gender, age, weight, height, time of exposure, time of residency, clothing and activity. For what concerns the time of residency, it was used as a criteria of exclusion when its value was lower than 6 months. Then it should be treated with more detail the approach used to evaluate metabolic rate and thermal clothing insulation.

The ASHRAE Standard 55-2004 [35] suggests to consider the metabolic rate M as an average value and take into consideration the activity performed by the participant before the interview. Therefore it has been calculated from the metabolic rate (M_{ACT}) of each interviewee at the moment in which the questionnaire is being filled and her/his metabolic rate 0.5 h before according to the Equation (3) [50]:

$$M = 0.7 \cdot M_{\mathrm{ACT}} + 0.3 \cdot M_{0.5\mathrm{H}} \quad (3)$$

This value was added to the basal metabolic rate M_{B}, which was equally assessed for women and men, through the Equation (4) [51]:

$$M_{\mathrm{B}} = 0.0484 \cdot (19.7 \cdot \mathrm{FFM} + 743) \quad (4)$$

where FFM is the fat-free body mass (expressed in Kg). It was measured by subtracting the body fat (*BF*), assessed differently for women (Equation (5)) and men (Equation (6)) [52], from the body weight:

$$BF = 0.737 \cdot W - 5.15 \cdot H^3 + 0.37 \tag{5}$$

$$BF = 0.685 \cdot W - 5.86 \cdot H^3 + 0.42 \tag{6}$$

Moreover to determine some indices the software RayMan [53] was used which requires to adjust the metabolic rate for each person since the software demands it in Watt units. This is why the skin surface was assessed through the Equation (7) [35]:

$$\text{Dubois area} = 0.202 \cdot \left(W^{0.425} \cdot H^{0.725}\right) \tag{7}$$

where W is the weight in kg and H is the height in m.

On the other hand for what concerns the thermal clothing insulation, each person had a clothing ensembles list provided in the questionnaire (adopting the method 1 of the ASHRAE Standard 55-2004 [35]). Once she/he had chosen the clothing ensemble, the corresponding thermal insulation value was calculated in clo. It must be specified that such value, called $I_{\text{CL INACTIVE}}$, was assumed to be valid for metabolic rates which were lower than 1.2 met. If it exceeded this value, the thermal insulation $I_{\text{CL ACTIVE}}$ was calculated through the Equation (8):

$$I_{\text{CL ACTIVE}} = I_{\text{CL INACTIVE}} \cdot (0.6 + 0.4/M) \tag{8}$$

3.2. Thermal Comfort Indices

The Mediterranean Outdoor Comfort Index (MOCI) [19] was meant for the evaluation of people's thermal perception in the Mediterranean area. While developing this index, the vote given by the interviewees about the thermal environment was considered as a dependent variable, whereas the independent variables were the environmental variables (mean radiant temperature T_{MR}, air temperature T_{A}, relative humidity RH, global radiation I_{G}, wind speed WS), the operative variables (metabolic rate M, thermal clothing insulation I_{CL}) and some personal factors (age, time of exposure). Age and global radiation were afterwards excluded through the analysis of VIF (Variance Inflationary Factor) and multicollinearity. Then a Best Subsets Analysis was performed which, through the assessment of the adjusted R^2 and the C_{P} statistic, determined the Equation (9):

$$\text{MOCI} = -4.068 - 0.272 \cdot WS + 0.005 \cdot RH + 0.083 \cdot T_{\text{MR}} + 0.058 \cdot T_{\text{A}} + 0.264 \cdot I_{\text{CL}} \tag{9}$$

This index is based on the ASHRAE 7-point scale but, depending on the local climatic conditions, could present values exceeding the range (−3)–(+3).

The Physiological Equivalent Temperature (PET) [38] can be defined as "the equivalent temperature of an isothermal reference environment with a water vapor pressure of 12 hPa (50% at 20 °C) and light air (0.1 m$\cdot$s^{-1}), at which the heat balance of a reference person is maintained with core and skin temperature equal to those under the conditions being assessed". It assumes a mean radiant temperature equal to the air temperature and refers to the Munich Energy Balance Model for Individual (MEMI) [38], a complete heat budget model of the human body based on the following Equation (10):

$$M + W + R + C + E_{\text{D}} + E_{\text{Re}} + E_{\text{Sw}} + S = 0 \tag{10}$$

where M is the metabolic rate, W is the physical work output, R is the net radiation of the body, C is the convective heat flow, E_{D} is the imperceptible perspiration, E_{Re} is the sum of heat flows to heat and humidify the inhaled air, E_{Sw} is the heat flow related to the evaporation of sweat and S is the storage heat flow for heating or cooling the body mass. M, being an energy gain, is always positive whereas W, E_{D} and E_{Sw} are representative of energy loss and are always negative.

The PET was evaluated by considering a thermal clothing insulation of 0.9 clo and a metabolic rate of 80 W (which must be added to the basal metabolic rate). It was examined in this study because its use is suggested by the VDI-guideline 3787 [14] and it is the most used index for the evaluation of outdoor thermal comfort [47].

In this paper the MOCI was also compared to the Predicted Mean Vote (PMV) [12], the second most used index for the evaluation of outdoor thermal perception [47]. At first it was developed for indoor environments examining the physiological response of the thermoregulatory system with the thermal sensation votes provided by 1565 people and then adapted to outdoor environments through the parametrization of the radiative fluxes of Jendritzky et al. [13]. This rational index predicts the mean value of the votes that a large group of people might give to judge a thermal environment and it was calculated through the Equation (11):

$$\text{PMV} = \left(0.303 \cdot \text{e}^{-0.036M} + 0.028\right) \cdot S \tag{11}$$

where M is the metabolic rate and S the storage deriving from the energy budget of the human body. The PMV, whose scale ranges between −3 (cold) and +3 (hot) where 0 is the thermal neutral value, could be determined once the metabolic rate and the thermal clothing insulation were estimated, and air temperature, mean radiant temperature, wind speed and relative humidity were measured.

A further index examined in this research was the Effective Temperature (ET) [37]. It was firstly introduced by Houghten and Yaglou [54] in 1923, whereas its mathematical formulation was defined in 1933 by Missenard [37] (Equation (12)):

$$ET = 37 - \frac{37 - T_{\text{A}}}{0.68 - 0.0014 \cdot RH + \frac{1}{1.76 + 1.4 \cdot WS^{0.75}}} - 0.29 \cdot T_{\text{A}} \cdot (1 - 0.01 \cdot RH) \tag{12}$$

This index allows to determine the temperature perceived by the human body based on certain values of air temperature, relative humidity and wind speed with normal atmospheric pressure and a body temperature of 37 °C. The Effective Temperature was introduced in this study since it is widely used in several countries (East Germany, Poland, Russia, etc.) [27]: as example, it is used in Germany to program the medical check-ups for employers exposed to intense thermal stresses, whereas in Hong Kong the weather service uses it as a warning system.

The last index here examined is the Actual Sensation Vote Europe (ASV_{EUROPE}) (Equation (13)) [36]:

$$ASV_{\text{EUROPE}} = 0.049 \cdot T_{\text{A}} + 0.001 \cdot I_{\text{G}} - 0.051 \cdot WS + 0.014 \cdot RH - 2.079 \tag{13}$$

It was developed by combining the models created for 7 different European cities (Athens, Cambridge, Fribourg, Kassel, Milan, Sheffield and Thessaloniki) during the project RUROS (Rediscovering the Urban Realm and Open Spaces) [36]. In each city the results provided by different field surveys were reported together with micrometeorological measurements obtaining simple linear models where air temperature, global radiation, wind speed and relative humidity were the independent variables (with Pearson coefficients ranging between 0.27 and 0.68).

This index was part of this study because the ASV_{EUROPE} can be considered one of the first empirical indices obtained through field surveys carried out in different cities.

3.3. Data Analysis

The aim of this research was to evaluate the Mediterranean Outdoor Comfort Index (MOCI) comparing its performances with those of other commonly used biometeorological indices. This comparison, according to what done in other studies [22,24], was performed through three statistical criteria [20] and a qualitative one. The first one was the Spearman's rho measure of correlation. It can be considered a non-parametric measure of the dependence between what predicted by the indices and the votes of the interviewees asked to judge their thermal perception. This coefficient made an evaluation of how the relation between the two variables could be expressed through a monotone function with the advantage that it is not very sensitive to the extreme values (outliers). The second criterion was the symmetrical measure of association Gamma. It makes an evaluation of how the classes predicted by the indices (Table 2) change according to the votes of the interviewees. Therefore it measures the association when both variables are measured at an ordinal level. The third criterion examined the total percentage of correct predictions, whereas the fourth criterion studied them in reference to the classes through a cross-tabulation analysis. The first two criteria explored how sensitive the indices were, whereas the last two focused on their performances.

Table 2. Thermal perception votes and corresponding categories of the indices.

Thermal Perception Votes (−)	ASV_{EUROPE} (−) [A]	*ET* (°C)	MOCI (−)	PET (°C)	PMV (−)	Classes of the Indices [B]
−3	<−1.08	<1	<−2.5	<4	<−2.5	−3
−2	−1.08–−0.82	1–9	−2.5–−1.5	4–8	−2.5–−1.5	−2
−1	−0.82–−0.45	9–17	−1.5–−0.5	8–18	−1.5–−0.5	−1
0	−0.45–−0.08	17–21	−0.5–+0.5	18–23	−0.5–+0.5	0
+1	−0.08–+0.23	21–23	+0.5–+1.5	23–35	+0.5–+1.5	+1
+2	+0.23–+0.61	23–27	+1.5–+2.5	35–41	+1.5–+2.5	+2
+3	>+0.61	>27	>+2.5	>41	>+2.5	+3

Notes: [A] Assessment scale calibrated through probit analysis [22]; [B] With reference to Figure 2.

While taking into consideration what Pantavou et al. [22,24] did, it must be specified that evaluation scales focusing on thermal stress were modified according to the study of Epstein and Moran [55]; as a matter of fact they analyzed thermal sensations together with their physiological effects. On the other hand scales based on thermal comfort were not subject to variation because, as showed by Nicol [56], a potential interviewee tend to use a thermal sensation scale or a thermal comfort scale in the same way.

Finally in order to understand whether the newly developed Mediterranean Outdoor Comfort Index (MOCI) led to an improvement in the prediction of outdoor thermal comfort, the values assumed for each index by the correlation coefficients and the total percentage of the correct predictions were normalized by taking the maximum value as the reference value. The three normalized values were summed to obtain an objective parameter of comparison.

4. Results and Discussion

Table 3 reports the correlation coefficients with respect to those values predicted by the indices and the votes given by the interviewees; the total percentage of correct predictions was also reported.

Table 3. Total percentage of correct predictions and correlation coefficients with respect to the values predicted by the indices and the votes given by the interviewees.

Index	Coefficients		Percentage of Correct Predictions (%)
	Spearman (−)	Gamma (−)	
ASV_{EUROPE}	0.405	0.470	21.1
ET	0.444	0.487	29.6
MOCI	0.497	0.549	35.5
PET	0.494	0.493	29.6
PMV	0.505	0.536	32.3

In this study the PMV presented the higher Spearman coefficient (0.505), whereas the average value of the same coefficient was 0.469, about 0.13 units lower than what Pantavou et al. [24] determined. For what concerns the symmetrical measure of association Gamma, the highest value was determined for the MOCI (0.549); even in this case, there was a decrease in the average value with respect to the study carried out by Pantavou et al. [24]. From this point of view it must be specified that in the other case the field survey investigated, besides summer and autumnal seasons, winter season as well, with air temperature values ranging between 7.1 °C and 39.3 °C. On the other hand in this paper, the analysis did not focus on the cold season and this might be the reason why there were an inferior correlation and a lower average value in both coefficients. However Rome is in the *C*sa category of Köppen-Geiger's climates classification [41] and most intense thermal stresses occur in summertime. In wintertime low temperatures are rarely registered and people can control their exposure to microclimatic conditions by increasing the level of the thermal clothing insulation. Hence a proper approach, while planning outdoor spaces which are thermally comfortable, must take into consideration these factors adopting an index able to ensure the highest number of correct predictions, especially in hot conditions. From this point of view, the MOCI seems to be the best index in terms of performances, being able to determine accurately 35.5% of the votes given by the interviewees. In particular, it works very well in the thermal perception range (−1)–(+1) (Figure 2) (these are the categories which Table 2 of the ISO 7730 [57] assumes to be representative of thermal comfort).

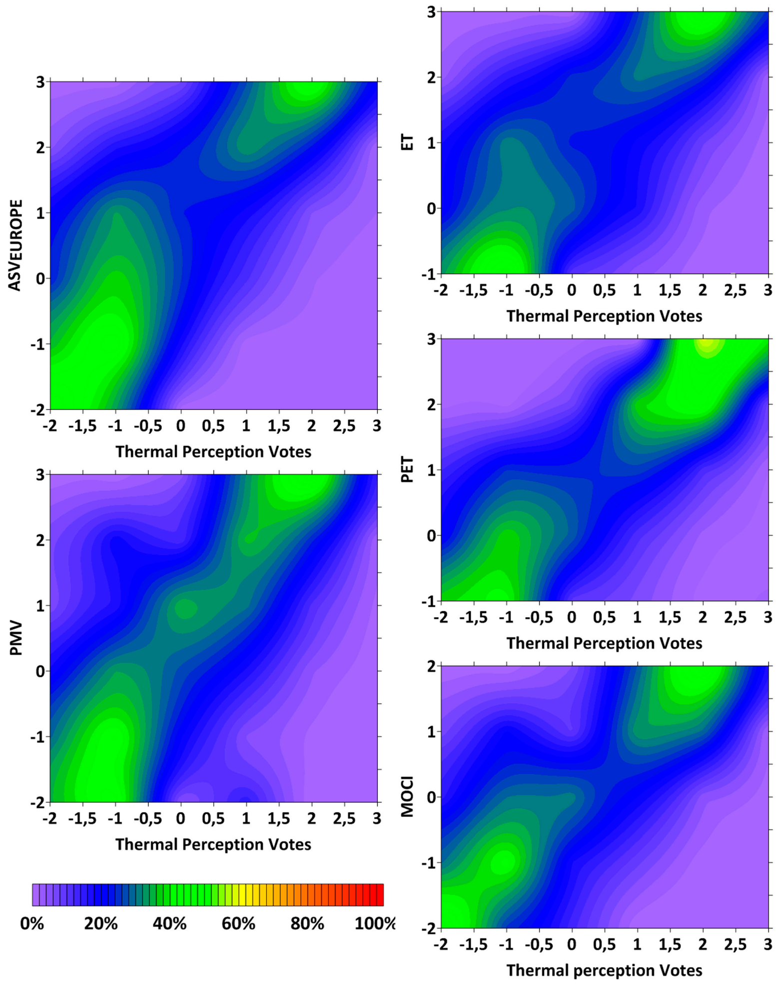

Figure 2. Relation between the classes predicted by the indices and the thermal perception votes.

In fact through a sort of cross-tabulation analysis, Figure 2 allows the evaluation of how the thermal perception votes given by the interviewees are distributed according to each class of the corresponding index. While examining this aspect, it must be considered that the sum of the percentage values of each class must be equal to 100%. The ideal situation would be the one where the votes are on the so called "identity line": that is the value 100% would be registered in the intersection of the category (−2) of the index and the thermal perception vote (−2), of the category (−1) and the vote (−1) and so forth. As a matter of fact in this case all predictions would be correct.

Obviously real conditions are different. As previously stated, for what concerns the MOCI good values of correct predictions were registered in the range (−1)–(+1). It should be also considered that the values concerning the intersections (−2)/(−2) and (+2)/(+2) must not mislead, since the results were affected by the reduced number of occurrences in the corresponding classes of the index.

As it could be assumed while analyzing the values of the correlation coefficient, the second index best simulating outdoor thermal comfort in the Mediterranean area was the PMV. It was characterized by a total predictive ability of 32.3% but, as reported in Figure 2, there was a good reliability around the votes (+2) and (+3). However, the investigations concerning these values, as for category (−2), were affected by the reduced number of people that chose them to give a vote to the thermal quality of the environment. For what concerns the assessment of this index, which was calculated through RayMan [53], some information was required such as weight and height of the interviewees (asked in the questionnaires). From this point of view it should be said that a study presenting a large scale validation [58] showed how most young women underestimate their weight of about 1.5 kg whereas old people overestimate their height of 2–4 cm. Hence, even this factor can affect the predictive ability of the PMV, though in a less extent.

A lower percentage of correct predictions was reported for the other indices examined: 29.6% for PET and *ET*, 21.1% for the ASV_{EUROPE}. These values find a proof even in the corresponding graphs reported in Figure 2. However, while taking into consideration the PET, the question would be why there is a predictive ability of 29.6% although it presents high values about the intersections (+2)/(+2) and (+3)/(+3). The answer in this case can be found in the fact that the occurrences in classes (+2) and (+3) of the PET were 13 and 5 respectively. For what concerns instead *ET* and ASV_{EUROPE} the situation is simpler: while examining Figure 2 it is possible to notice how the highest percentages were positioned on the left side of the "identity line". A possible explanation can be found in the fact that these last three indices, contrary to the MOCI and PMV, did not consider different thermal clothing insulation levels. If the PET assumed a constant value of 0.9 clo, this variable was not present in the relations of the *ET* and ASV_{EUROPE} (based solely on environmental variables).

It is possible to notice in Figure 3 how people living in the Mediterranean area tend to adapt their clothing to outdoor climatic conditions. Air temperature seems to be the most affecting variable with respect to the clothing insulation, whereas wind speed becomes the dominant variable when it assumes high values and at low temperatures (when it bestrides the convective heat exchange). In these conditions the effect of wind is not a positive factor and this is the reason why the wind-chill index was originally developed for arctic conditions [59] and is usually used in cold climates.

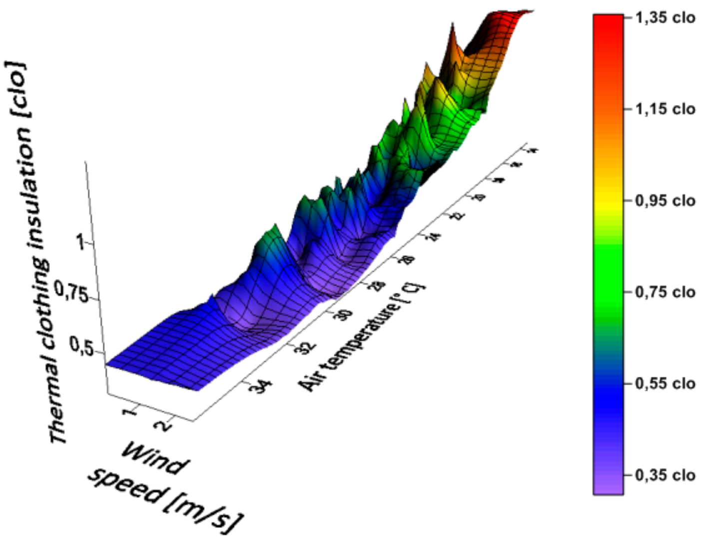

Figure 3. Values of the thermal clothing insulation with respect to wind velocity and air temperature.

With respect to the analysis of the predictive ability of the indices, another aspect that should be examined regards the ASV_{EUROPE}. In this paper it was studied while taking into consideration an evaluation scale (Table 2) which was calibrated, through a probit analysis, after a study carried out in three different urban sites in Athens (Greece) [22]. Therefore for this index seven different intervals were defined and this explains the decrease in the percentage values of the central categories (Figure 2). The situation would have been different if the scale considered was the one not calibrated (reported in Table 4 by Pantavou et al. [22]): in this case the percentage of correct predictions would have been of 70.9%. However it is necessary to specify that this value was affected by the assumptions made. In the project RUROS (Rediscovering the Urban Realm and Open Spaces) [36] a 5 point-scale ranging from "very cold" (−2) to "very hot" (+2) was used. On the other hand in the present study the ASHRAE 7-point scale was used for the field survey and this led the votes (−1), (0) and (+1) (given by the interviewees) to be part of the category (−0.5)–(+0.5) of the non-calibrated scale of the ASV_{EUROPE} (with predictive ability values of this index in the central range of the scale exceeding 90%). For these reasons, performing a comparison was not possible but, as specified in other cases as well [47], this highlighted the importance of standardization (with respect to both evaluation scales, questionnaires structure together with measurement sites, type and location of the instruments, measurement of the mean radiant temperature ...) in analysis' procedures of outdoor thermal comfort and field surveys organization. Table 4 reports the correlation coefficient values and the total percentage of correct predictions normalized with respect to the maximum value presented by each criterion.

Table 4. Total percentage of correct predictions and correlation coefficient between the values predicted by the indices and votes given by the interviewees normalized with respect to the maximum value of each criterion.

Normalized Values				
Index	**Coefficients**		**Percentage of Correct Predictions (%)**	**Total**
	Spearman (−)	**Gamma (−)**		
ASV_{EUROPE}	0.80	0.86	0.59	2.25
ET	0.88	0.89	0.83	2.60
MOCI	0.98	1.00	1.00	2.98
PET	0.97	0.90	0.83	2.70
PMV	1.00	0.98	0.91	2.89

For example the highest Spearman coefficient was measured for the PMV and this is the reason why, in the corresponding category, the value was 1.00. Through the process of normalization of the evaluation criteria, the aim was to obtain a parameter as objective as possible to compare the performances of the indices. The highest total value corresponds to the index which, according to the three statistical criteria, best predicted the thermal perception in the Mediterranean area.

Hence Table 4 shows that the MOCI was the most suitable index to evaluate outdoor thermal comfort and the influence of urban materials [60–62] on microclimate in the studied area, followed by thermo-physiological indices as the PMV and PET. Lower total values were measured for the *ET* and ASV_{EUROPE}. This can be explained by the simplicity of the equations characterizing the models, where only micrometeorological variables occur. It must be stressed, once again, that for what concerns the ASV_{EUROPE} and its performances, the results were affected by the scale used.

Taking into consideration the study carried out by Tseliou et al. [23], it can be also interesting to focus on the relation between the thermal perception votes given by the interviewees and the corresponding values revealed by the various indices according to the season and air temperature. Hence for each of the five indices examined, the data revealed through the field survey were divided into two groups: summer season (in red, Figure 4) and autumnal season (green, Figure 4). Thus 10 subgroups were formed and it was possible to perform a second division of the data: they were categorized according to the corresponding thermal perception vote ((−3) and (+3) excluded due to the low number of occurrences). For each subgroup, the data were then graphed according to the index examined and the air temperature.

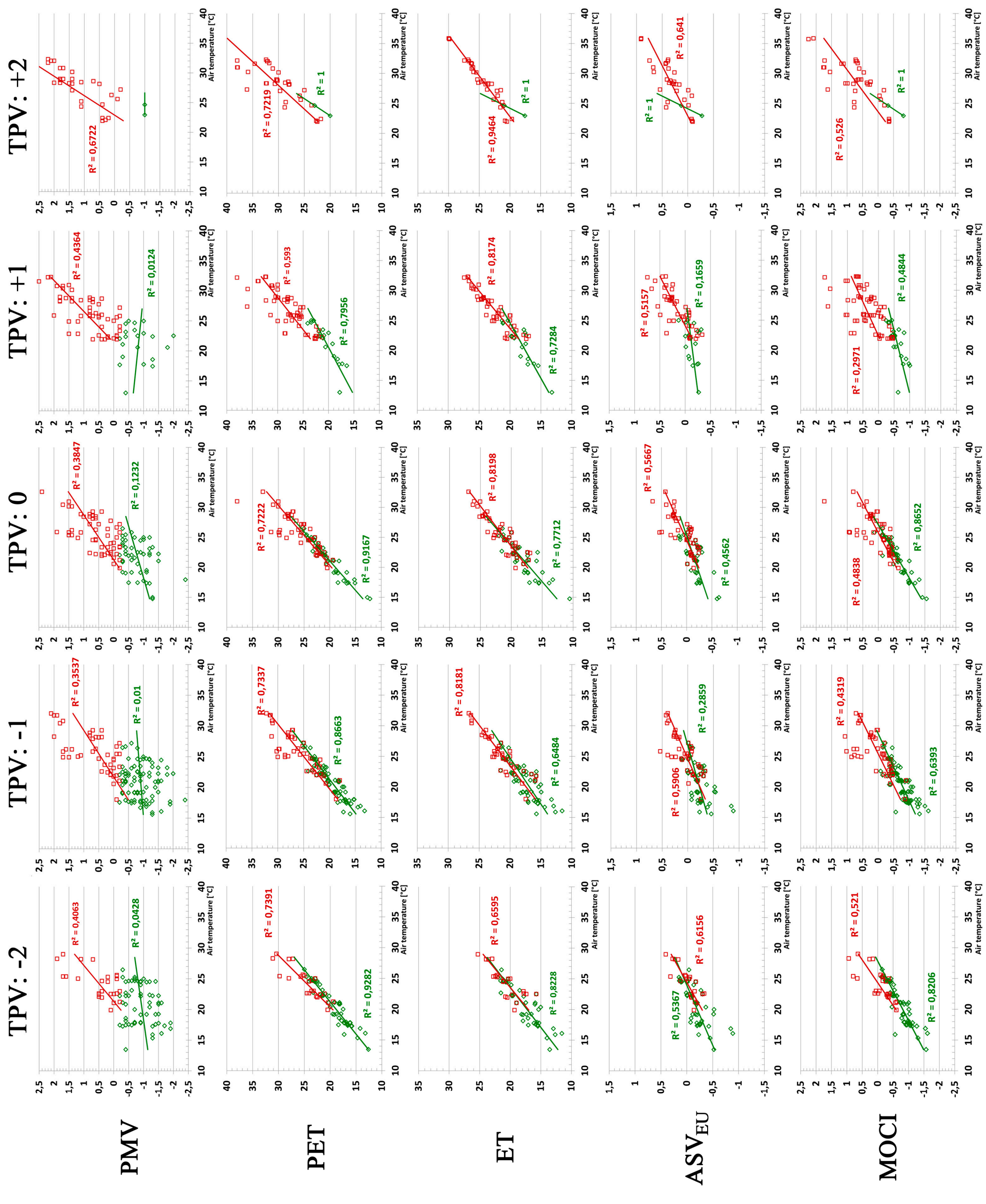

Figure 4. Seasonal dependence of the indices in function of the air temperature for the classes of thermal perception votes (−2), (−1), (0), (+1) and (+2).

An index used to evaluate outdoor thermal comfort should be able to describe the thermal perception of a human being in any climatic condition. Hence the indices should present a certain stability. With reference to Table 2, this means that if there is a thermal perception vote of −2, the corresponding PET values should be ranging between 4 and 8 °C, the MOCI values between −2.5 and −1.5 and so forth for all other indices and the votes given by the interviewees.

However this study showed that the indices were affected by the air temperature. This can be considered a consequence of those aspects connected to the adaptation and acclimatization processes which provoke some differences between the values predicted by the indices and the votes given by the interviewees. In particular, the slope of the regression lines allows to notice that the PET and

ET were deeply affected by the air temperature. With the exception of the PMV a tendency of the estimated values of the indices to shift towards neutral thermal sensations was also revealed, especially with thermal perception votes between 0 and −2. In these categories the indices showed a good level of stability for what concerns their predictions. Moreover it is interesting to notice how, with the MOCI and PET in particular, for positive thermal perception votes Mediterranean people tend to tolerate more hot conditions. In fact the data concerning summertime are systematically associated to indices' values higher that those concerning autumn (the category of the vote given by the interviewees remaining the same).

Finally the situation seems different with the PMV, which was characterized by a low level of predictive stability in correspondence of each category of thermal perception.

5. Conclusions

In this study the Mediterranean Outdoor Comfort Index (MOCI) was numerically compared to other 4 biometeorological indices: Actual Sensation Vote Europe (ASV_{EUROPE}), Effective Temperature (*ET*), Physiological Equivalent Temperature (PET) and Predicted Mean Vote (PMV).

In order to carry out this study a preliminary field survey was necessary. The sites of interest presented different characteristics in terms of microclimate, urban morphology and topography. The time interval was from June 2015 to November 2015, covering summer (which at the Mediterranean latitudes determines higher thermal stresses) and the transitional season of autumn. This was a transversal study and 592 structured questionnaires were filled while micrometeorological measurements of the air temperature, globe temperature, wind velocity, relative humidity and global radiation were performed. The questionnaire was structured in accordance with the ISO 10551 and was formed by two sections. In the first one the participants answered about personal questions, whereas in the second section they were asked to make an evaluation of 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)). This is the same scale used for the PMV and MOCI.

The vote given by the interviewees was related to the corresponding values of the thermal comfort indices that were calculated, according to the different models, through the personal data provided by the questionnaires and the measured values of the micrometeorological variables.

This comparison was performed through four criteria (three statistical and one qualitative): the Spearman's rho measure of correlation, the symmetrical measure of association Gamma, the total percentage of correct predictions, and, through a cross-tabulation analysis, the distribution of the correct predictions for each class of thermal perception. With respect to the first three criteria, the values reported by the indices were then normalized with reference to the highest value measured for that specific criterion.

This study revealed that the PMV and MOCI presented a good level of sensitivity, as showed through the correlation coefficients. These indices also confirmed their performances in terms of total percentage of correct predictions: the MOCI reports a value of 35.5% whereas the PMV of 32.3%.

Lower values were calculated for the other three indices. This might be a consequence of some factors determined by people's adaptation processes. In the models characterizing the MOCI and PMV there was a further factor which had an influence, that is the thermal clothing insulation (a variable not considered by the other indices). In particular the *ET* and ASV_{EUROPE} could be determined only thanks to the values of the micrometeorological variables. Therefore they seemed to be affected in a negative way by their apparent simplicity in terms of predictive ability, both for what concerned the total value and the one determined by the cross-tabulation analysis for their classes.

The sum of the normalized values led the MOCI to present a total value of 2.98, followed by thermophysiological indices as the PMV and PET with 2.89 and 2.70 respectively.

Finally the relation between the votes of the interviewees and the values of the indices was examined, evaluating the influence of season and air temperature. In fact this micrometeorological variable was the factor affecting the most the PET and *ET*. Then, with the only exception of the PMV (characterized by a low predictive stability), a tendency of the estimated values to shift to neutral thermal perceptions was registered. Even in this case the reason can be found in adaptation and acclimatization phenomena.

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Conflicts of Interest: The authors declare no conflicts of interest.

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