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Assessment of thermal indices applicability in Cyprus

PANTAVOU K., GIALLOURIS G., LYKOUDIS S. and NIKOLOPOULOS G.*

Medical School, University of Cyprus, P.O.Box 20537, Nicosia, Cyprus

*corresponding author:
e-mail: nikolopoulos.georgios@ucy.ac.cy

Abstract Thermal indices are commonly used to assess outdoor thermal environments. This study aims to examine the applicability of popular thermal indices for the assessment of thermal sensation in Cyprus. Field surveys were conducted in outdoor public sites in five districts of the Republic of Cyprus. The surveys involved environmental monitoring and questionnaire-based interviews of pedestrians. The pedestrians reported their thermal sensation using a nine-point scale, the actual thermal sensation (ATS). Thermal sensation predicted by Discomfort Index, Heat Index, Humidex (HU), Physiologically Equivalent Temperature (PET), Predicted Mean Vote (PMV), Standard Effective Temperature, Universal Thermal Climate Index, and Wet-Bulb Globe Temperature (WBGT), was compared to ATS. Spearman's rho, Goodman and Kruskal's gamma, percentage of correct predictions, and distribution of indices' predictions per category of ATS were used to assess indices' applicability and find the index that best predicts thermal sensation. The analysis was performed for participants living in Cyprus (locals) and for visitors (non-locals). The indices predicted successfully a low percentage of ATS ranging in locals between 9.6% (HU) and 20.7% (PMV), and in non-locals between 13.9% (WBGT) and 29.9% (DI). Overall, PET performed better predicting successfully 16.8% of ATS in locals and 27.3% in non-locals.

Keywords: thermal index, thermal sensation, index evaluation, field survey, Mediterranean climate

1. Introduction

Thermal indices are models used to predict people's assessment of thermal environment. They integrate multiple meteorological variables, such as air temperature, relative humidity, solar radiation, wind speed, and often subjective variables, such as clothing insulation, activity, gender, and age, to assess thermal sensation or stress. They are commonly used for urban planning, energy conservation, tourism, and public health interventions.

Over the last decades, several thermal indices have been developed (de Freitas and Grigorieva 2017) raising a debate on their applicability and performance in different applications and climates. The most widely used indices are the Physiologically Equivalent Temperature (PET), the Predicted Mean Vote (PMV), the Standard Effective Temperature (SET*), and the Universal Thermal Climate Index (UTCI) that are considered universal (Potchter et al. 2018); the Heat Index (HI), Humidex (HU) and the Wet-Bulb Globe Temperature (WBGT) that are operational and they are used by weather services around the globe; and finally, the Discomfort Index (DI) that is one of the first indices introduced in 1959 to assess thermal conditions. This study aims to examine the performance of commonly used thermal indices in the climate of Cyprus.

1. Materials and Methods

2.1. Field surveys

Field surveys on thermal sensation were conducted in three seasons (summer and autumn 2019, and winter 2020), in five districts of the Republic of Cyprus (Nicosia, Limassol, Larnaca, Paphos, and Famagusta). The surveys were carried out in popular squares, pedestrians' streets, and promenades so as to monitor common visiting sites of people living or visiting Cyprus. Meteorological conditions were monitored on site using a mobile weather station and pedestrians were interviewed using a questionnaire.

Air temperature, relative humidity, wind speed, and grey globe temperature (PVC sphere 40 mm diameter) were recorded at the height of 1.1 m and were stored at 1 min intervals on a CR1000 Campbell Scientific data logger. The collected data were used to estimate the following thermal indices: DI, HI, HU, PET, PMV, SET*, UTCI, and WBGT. In the interviews, the pedestrians were asked to report their thermal sensation using the nine-point scale: -4, *very cold*; -3, *cold*; -2, *cool*; -1, *slightly cool*; 0, *neutral*; +1, *slightly warm*; +2, *warm*; +3, *hot*; and +4, *very hot*.

2.2. Statistical analysis

Thermal sensation reported by the pedestrians (i.e., actual thermal sensation, ATS) was compared with thermal sensation predicted by the thermal indices. This comparison was performed using four criteria: *(a) Spearman's rho, (b) Goodman and Kruskal's gamma, (c) the percentage of correct predictions*, and *(d) the distribution of indices' predictions per category of ATS*. The estimates of criteria *a*, *b* and *c* were normalized with respect to the maximum value per criterion and summed to produce an aggregate measure of indices' performance, i.e,

predictability score (PS). The statistical analysis was conducted for both participants living in Cyprus (locals) and visitors (non-locals) using Stata v.16 (Stata Corp., USA).

3. Results

Data of 2,616 interviews (male participants: n=1,388, 53.1%) were included in the analysis. The median age of the participants was 33 years (mean ± standard deviation: 38.0±18.4). About 82.6% (n=2,150) were living in Cyprus (locals) and 17.1% (n=447) were visitors (non-locals). The thermal conditions during the field surveys are presented in Table 1.

Table 1. Descriptive statistics of thermal indices (°C) estimated by the meteorological variables recorded in the surveys.

	Mean	SD[1]	Median	Min	Max
DI	25.4	1.5	25.5	20.8	29.1
HI	30.6	3.1	30.5	20.0	39.7
HU	35.9	3.5	35.9	26.0	44.1
PET	25.5	7.2	26.5	1.9	43.1
PMV[2]	0.7	1.6	0.6	-5.5	5.6
SET*	23.8	5.7	23.8	3.3	42.2
UTCI	26.7	6.7	28.3	4.9	38.8
WBGT	29.2	2.3	29.1	23.0	34.7

[1]Standard deviation; [2]Dimensionless

3.1. Local participants

The estimates of the statistical criteria *a*, *b* and *c* and the predictability scores are presented in Table 2. The highest predictability score was estimated for PMV (2.83) followed by PET (2.68), SET* (2.61), and UTCI (2.53). The distribution of indices' predictions per category of ATS (criterion *d*) showed that the percentage of correct predictions for the categories 0 to +4 of thermal sensation in PET was higher than in PMV (Fig. 1a). Therefore, PET is considered to show the best applicability in Cyprus.

Table 2. Estimates of the criteria *a*, *b* and *c*, and the predictability score (PS) for participants living in Cyprus (locals).

	Spearman's rho	Gamma	Correct predictions [N (%)]	PS
DI	0.29	0.34	169 (11.2)	1.87
HI	0.31	0.22	223 (16.9)	1.94
HU	0.26	0.37	145 (9.6)	1.78
PET	0.45	0.43	354 (16.8)	2.68
PMV	0.43	0.44	435 (20.7)	2.83
SET*	0.41	0.41	373 (17.7	2.61
UTCI	0.46	0.48	204 (11.0)	2.53
WBGT	0.23	0.21	137 (9.1)	1.38

3.2. Non-local participants

The maximum score of criteria *a* and *b* (Spearman's rho and gamma) was estimated for UTCI (0.49 and 0.51), and of criterion *c* for DI (29.9%; Table 3). The maximum predictability score was estimated for UTCI (2.69), PET, and HU (2.66). The contingency table (Fig. 1b) showed that UTCI failed to predict the neutral and negative subscale (-4 to 0) of ATS and the percentage of correct prediction for each category of ATS was lower compared to PET. Moreover, PET had higher success rate prediction than HU in categories +2 and +3. Thus, PET seems to perform better for non-locals in Cyprus.

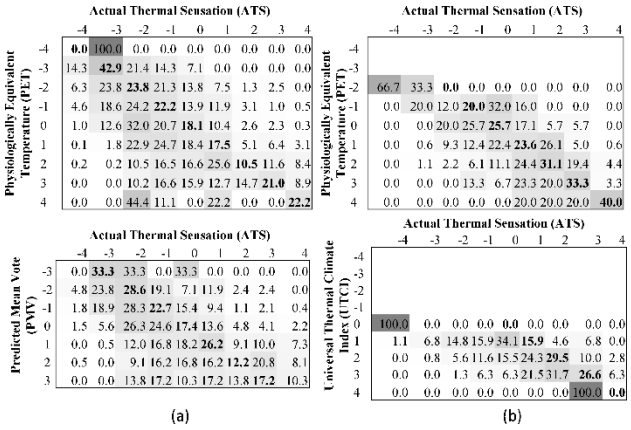

Figure 1. Distribution of predicted thermal sensation by the indices in relation to actual thermal sensation among (a) local and (b) non-local participants. Rows add to 100%, bold values indicate correct predictions, gradient shading darkens per 10%.

Table 3. Scores of the criteria *a*, *b* and *c*, and the predictability score (PS) for participants visiting Cyprus (non-locals).

	Spearman's rho	Gamma	Correct predictions [N (%)]	PS
DI	0.35	0.49[1]	114 (29.9)	2.49
HI	0.34	0.41[1]	85 (23.9)	2.14
HU	0.35	0.62[1]	108 (28.4)	2.66
PET	0.47	0.50	120 (27.3)	2.66
PMV	0.42	0.38	98 (22.3)	2.22
SET*	0.41	0.41[1]	81 (18.5)	2.10
UTCI	0.49	0.51	109 (26.0)	2.69
WBGT	0.36	0.28	53 (13.9)	1.64

[1] Non statistically significant (p>0.05)

4. Conclusions

The results showed a low predictability of thermal indices in participants both living and visiting in Cyprus. PET predicted thermal sensation better than DI, HI, HU, PMV, SET*, UTCI and WBGT, with a higher percentage of correct prediction of ATS in non-local than local participants.

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