Assessment of thermal indices for the operational evaluation of thermal conditions in Athens, Greece

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Introduction

The thermal indices combine several meteorological variables into a single value. This value can be assigned to a category of an assessment scale expressing the degree of human thermal perception (i.e., discomfort, sensation or stress; Fig. 1).

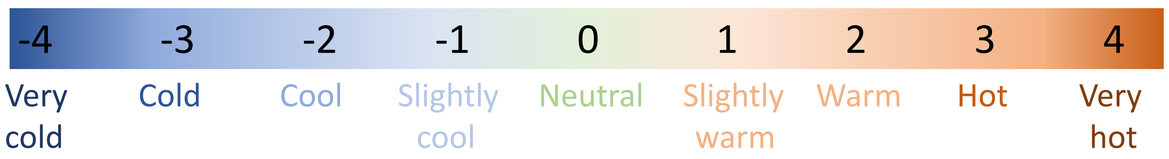

Figure 1. Example of the 9-point assessment scale of thermal sensation.

Thermal indices:

- ❖ valuable tools for assessing thermal environments for architecture, urban planning, tourism, energy conservation, and health purposes,
- ❖ numerous developed indices in the literature; the selection of a suitable one for a specific application is a complex issue.

Aim: to examine the effectiveness of commonly used thermal indices in quantifying the thermal environment for operational weather applications.

Methods

Data

Type: Hourly data of air temperature (Tair, °C), relative humidity (Rh, %), wind speed (WS, m/s) and global solar radiation (SR, W/m^2),

Location: Athens metropolitan area, Greece (Fig. 2),

Time period: 2010-2021,

Source: 15 weather stations of the Automatic Weather Stations Network, National Observatory of Athens (Fig. 2).

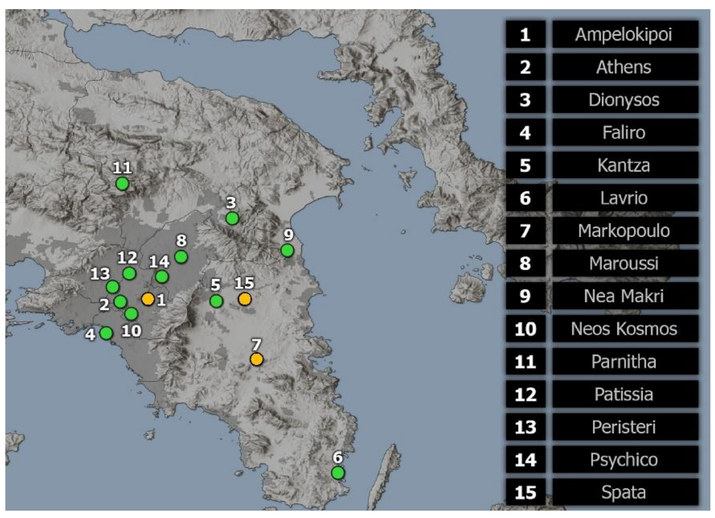

Figure 2. Stations operated by the Meteo unit, National Observatory of Athens in the Athens metropolitan area, Greece (stations with solar radiation sensors are in yellow).

Indices

Eight indices - six simple and two thermo-physiological.

Table 1. Summary of thermal indices examined for operational use.

Abbreviation	Index	Conditions applied	Variables considered
AT	Apparent Temperature	Warm	Tair, Rh, WS
HI	Heat Index	Warm	Tair, Rh
HU	Humidex	Warm	Tair, Rh
NET	Net Effective Temperature	All	Tair, Rh, WS
PET	Physiologically Equivalent Temperature	All	Tair, Rh, WS, SR
UTCI	Universal Thermal Climate Index	All	Tair, Rh, WS, SR
WBGT	Wet-Bulb Globe Temperature	Warm	Tair, Rh
WCI	Wind Chill Index	Cool	Tair, Rh, WS

All indices are measured in ◦C.

Statistical analysis

Step 1. Thermal perception was assigned to a common for all indices numerical scale (from -6 to 5) in line to the scale of each index.

Step 2. Criteria for effectiveness:

(a) sensitivity to variations of thermal environment, i.e.,
- ▪ frequency of the estimated categories,

(b) ability to reproduce occurrences of extreme thermal conditions in terms of Tair, i.e.,
- ▪ exceedances of the daily max or min Tair/thermal index from the respective 95% or 5% threshold in each station.

Step 3. Statistical test: two-sample test of proportions.

Results

- ➢ Indices' estimations extended to the entire range of their assessment scales except for AT (range: 0 to 2) and WCI (range: -1 to 0).
- ➢ NET (63%; -1 to -3) and PET (56%; -1 to -4) tended to classify often the thermal perception in the negative categories ($p<0.001$; Fig. 3).
- ➢ UTCI estimations in the negative categories (-1 to -5) were 25.8%.
- ➢ Most UTCI estimations were classified in the neutral category (53.1%; $p<0.001$; Fig. 3).

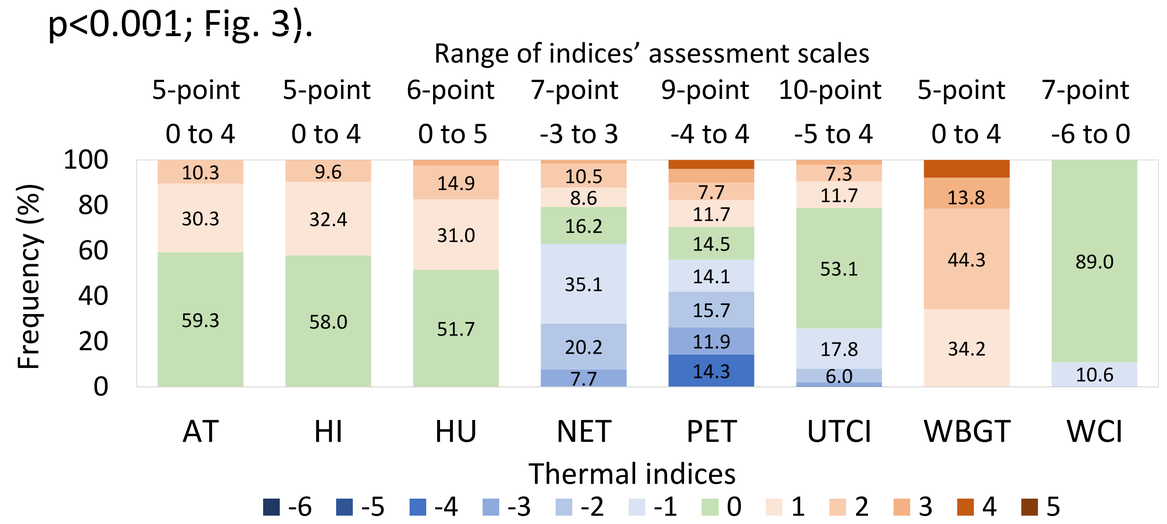

Figure 3. Distribution of indices' estimations in the categories of their assessment scales.

- ➢ AT, HI, HU and WCI thresholds for extreme thermal conditions were assigned in non-extreme categories of their scales (Table 2).

Table 2. Air temperature (Tair) and thermal indices' thresholds for the definition of extreme thermal conditions in summer and winter.

Index	Summer			Winter		
	Threshold	Category		Threshold	Category	
	(°C)	Number	Description	(°C)	Number	Description
Tair	36.2	-	-	0.4	-	-
AT	37.7	2	Heat symptoms possible[a]	-	-	-
HI	38	2	Extreme caution[b]	-	-	-
HU	42.6	3	Great discomfort	-	-	-
NET	29.1	3	Very hot	-13.3	-3	Very cold
PET	48.5	4	Very hot/Extreme heat stress	-7.9	-4	Very cold/Extreme cold stress
UTCI	43.1	3	Very strong heat stress	-23.6	-4	Very strong cold stress
WBGT	33.1	4	All training should be stopped	-	-	-
WCI	-	-		-4	-1	Low risk

[a] with prolonged exposure and/or physical activity; [b] avoid exertion

- ➢ Common with Tair occasions of extreme warm conditions in summer:
  NET ➡ 77.7% UTCI ➡ 64.4% PET ➡ 33.6%
- ➢ Common with Tair occasions of extreme cold conditions in winter:
  NET ➡ 51.3% UTCI ➡ 42.9% PET ➡ 77.9%

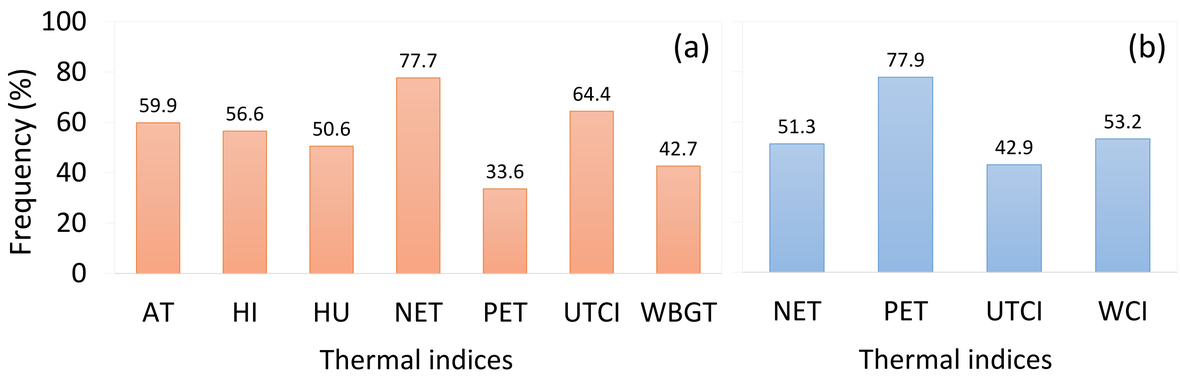

Figure 4 Occasions with extremely (a) warm conditions in summer and (b) cool conditions in winter identified jointly by thermal indices and air temperature.

Conclusions

- ❖ AT missed to classify perception in the highest category of its scale.
- ❖ HI and HU estimations in the extreme categories of their scales were scarce.
- ❖ WBGT reproduced poorly the extreme warm conditions in terms of Tair.
- ❖ WCI was unsuitable for the weather conditions of Athens (Tair<10°C).
- ❖ PET classified often perception in the cool categories and those with higher intensity of cold while underperformed at estimating warm extreme conditions.
- ❖ NET and UTCI were sensitive to variations of both cool and warm conditions and in good agreement with Tair for the estimation of warm extremes.
- ❖ NET and UTCI satisfy requirements for operational use sufficiently.

Acknowledgements

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