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Human thermal perception of Coastal Mediterranean outdoor urban environments

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A B S T R A C T

This research evaluates the perception of human thermal sensation in the Mediterranean climate in an attempt to calibrate the scale of human thermal sensation for this climate, by applying the Physiologically Equivalent Temperature (PET) index. A field survey was conducted in the city of Tel Aviv, Israel in several outdoor urban spaces during summers and winters of 2007–2011. Empirical data of climatic variables were collected by meteorological stations and accompanied by subjective thermal sensation questionnaires. The relations between the calculated PET values for the investigated sites and the Thermal Sensation Vote (TSV) were examined. Analytical results indicate that the "neutral" TSV range for the Mediterranean climate is between 20 and 25 °C PET, higher than that of the temperate climates and lower than that of the hot and humid climates. The PET boundaries for the cold classes of thermal perception in the Mediterranean are relatively high in comparison to Western/Middle Europe but are relatively low in comparison to Taiwan. However, the differences in PET boundaries for the hot classes of thermal perception decrease as the temperature values increase, toward an almost identical definition of "very hot" in Western/Middle Europe, the Mediterranean and Taiwan.

Introduction

People in urban environments are exposed to a large variety of thermal conditions during the seasons of the year, ranging from heat stress to neutral, comfortable conditions to cold stress. Since people use different urban environments (streets, plazas, urban parks) throughout the day with different microclimate conditions, even during the daytime hours they can be exposed to hot and cold thermal stresses. Assessment of the human perception of thermal comfort conditions in urban spaces is critical, as it bears major implications for the development of cities and the living conditions of urban residents. A broad understanding among urban planners, architects and urban climatologist exists regarding the climatic quality of outdoor urban environments and its contribution to the quality of life within cities (Givoni et al., 2003; Nikolopoulou & Lykoudis, 2006; Nikolopoulou & Steemers, 2003). Increasing research attention in the last decade has been dedicated to thermal comfort in relation to the outdoor urban environment (Hwang, Lin, & Matzarakis, 2011; Kántor, Égerházi, & Unger, 2012; Kántor, Unger, & Gulyas, 2012; Knez & Thorsson, 2006; Lin, 2009; Tseliou, Tsiros, Lykoudis, & Nikolopoulou, 2010; VDI, 1998).

Thermal comfort is defined as "the state of mind, which expresses satisfaction with the thermal environment" (ASHRAE, 2004). According to this definition, comfort is a subjective sensation. However, this definition is difficult to capture in physical parameters (van Hoof, Mazej, & Hensen, 2010). Based on the ASHRAE definition, the zone of thermal comfort is the span of conditions in which 80% of sedentary or slightly active persons find the environment "thermally acceptable" (ASHRAE, 1992). The zone of thermal comfort sensation represents an integration of a range of environmental parameter; radiation fluxes, air temperature, humidity and wind speed. According to Olgyay (1963, pp. 14–23), although the comfort zone does not have real boundaries, the zone of thermal comfort and acclimatization is subject to geography and seasonality. In hot climates, the comfort zone shifts toward warmer climate conditions, while in cold climates the comfort zone is lower than in the hot climates and during winter the comfort zone lies a little lower than the summer comfort zone. ASHRAE (1992) stated that in terms of climatic conditions, the acceptable ambient temperature of comfort would be slightly higher in the summer (23–27 °C) than in the winter (20–25 °C). However, this is a general

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statement and previous studies showed that the comfort range can vary from one geographic zone to another (Lin & Matzarakis, 2008).

Acclimatization and thermal adaptation plays an important role in the perception of comfort and discomfort. Acclimatization, which Shvartz (1973) and Sohar (1979) describe, takes a period of three weeks to complete and varies seasonally. In the short term, people's acclimatization is subject to hourly exposure to specific microclimate conditions (Becker, Potchter, & Yaakov, 2003). Strong evidence also exists for adaptation being a two-tiered process: physical (with seasonal variation in clothing and changes to the metabolic rate) and psychological (Nikolopoulou & Lykoudis, 2006). Thermal adaptation involves not only physiological and psychological factors, it is also influenced by behavioral factors, which play an important role in subjective assessment of thermal environments (Höppe, 2002).

Throughout the last century, much active research has attempted to define and assess thermal perception and to grade thermal stress. A large number of indices have been proposed and are being implemented worldwide. Epstein and Moran (2006) listed approximately 40 indices, and many others exist as well (Blazejczyk, Epstein, Jendritzky, Staiger, & Tinz, 2011). Tahbaz (2011) listed thermal indices appropriate for hot climates such as Wet Bulb Globe Temperature (WBGT) (Yaglou & Minard, 1957), Discomfort Index (DI) (Thom & Bosen, 1959), Index of Thermal Stress (ITS) (Givoni, 1963), Heat Index (HI) (Steadman, 1979), Humidex (HD) (Masterton & Richardson, 1979, pp. 1–45) and Tropical Summer index (TSI) (Sharma & Sharafat, 1986), while others better suite cold conditions, such as Wind Chill Index (WCI) and (WCET) (ISO/TR 11079, 1993). In the last four decades, a serious effort was made to develop universal indices, capable of evaluating both cold and hot conditions, such as the Standard Effective Temperature (SET) (Gagge, Fobelets, & Berglund, 1986), the Physiologically Equivalent Temperature (PET) (Höppe, 1999; Matzarakis, Mayer, & Iziomon, 1999; Mayer & Höppe, 1987), the Temperature Humidity Index (THI) (Kyle, 1994), Perceived Temperature (PT) (Staiger, Bucher, & Jendritzky, 1997), Outdoor Standard Effective Temperature (OUT_SET) (Pickup & de Dear, 2000) and Universal Thermal Climate Index (UTCI) (Jendritzky, Havenith, Weihs, & Batchvarova, 2009; Jendritzky, de Dear, & Havenith, 2012).

In order to obtain better agreement between indices and actual thermal sensation, some researchers focused on redefining the boundaries of the scales of the various indices. These adjustments require calibration that should be carried out using local subjective comfort data (Spagnolo & de Dear, 2003). Monteiro and Alucci (2006) tried to calibrate the scales of several indices so as to maximize the correlation between the indices and the actual recorded votes at Sao Paolo (Brazil). The necessity for observed data from field surveys regarding the perception of the subjective human thermal sensation in the outdoor environments has been recognized, so as to provide a broader perspective to assess thermal comfort in urban spaces (Kántor, Égerházi, et al., 2012; Kántor, Unger, et al., 2012; Lin, 2009; Nikolopoulou & Lykoudis, 2006). This understanding enlarged research on this topic in the last decade. Table 1 summarizes previous studies that assessed thermal sensation with different thermal indices. Some of the examinations were tested as in empirical studies, others were simulated experiments and others involved questionnaire-based field studies. Although the UTCI recently become very common, the most commonly applied index is the PET, which has been tested in field studies in different climate zones (Gulyas, Unger, & Matzarakis, 2006; Johansson & Emmanuel, 2006; Matzarakis, Rutz, & Mayer, 2007; Thorsson, Honjo, Lindberg, Eliasson, & Lim, 2007).

Originally, the Physiologically Equivalent Temperature (PET) index was applicable to Western/Middle Europe. Lin and Matzarakis (2008) have adapted the PET index scale in Taiwan. It is likely that some adjustments will be needed for different seasons and climate zones.

The present study provides empirical data from field surveys conducted in the city of Tel Aviv, Israel, in different outdoor urban environments during summers and winters of 2007–2011.

The research aims to evaluate the perception of thermal comfort conditions in varied outdoor urban spaces during the summer and

Table 1
Summary of studies that assessed thermal sensation with different thermal indices.

Authors	Location	Season	Thermal indices	Use of questionnaires (*N*)
Matzarakis & Mayer, 1996	Freiburg, Germany	Summer	PET	
Nikolopoulou et al., 2001	Cambridge, UK	Spring, Summer & Winter	PMV	1432
Becker et al., 2003	Yotvata, Israel	Summer	PMV	30
Spagnolo & de Dear, 2003	Sydney, Australia	Summer & Winter	TOP, ET*, PET OUT_SET*, PT,	1018
Gomez, Gil, & Jabaloyes, 2004	Valencia, Spain	All year	ID, PE, VINJE, WBGT	1500
Gulyas et al., 2006	Hungary	Summer	PET	no
Johansson & Emmanuel, 2006	Colombo, Sri Lanka	Hot & humid (tropical)	PET	no
Knez & Thorsson, 2006	Göteborg, Sweden, Matsudo, Japan	March & April	PET	106
Nikolopoulou & Lykoudis, 2006	Thessaloniki, Athens, Milan, Freiburg, Kassel, Shefield, Cambridge	All year	PET, THI, K	9189
Thorsson et al., 2007	Matsudo, Japan	Winter & Spring	PET	1142
Lin & Matzarakis, 2008	Sun Moon Valley, Taiwan	All year	PET	1644
Hussein & Rahaman, 2009	Malaysia	January	PMV, To	375
Lin, 2009	Taichung City, Taiwan	Summer & Winter	PET	505
Shashua-Bar, Pearlmutter, & Erell, 2010	Sede Boker, Israel	Summer	ITS	no
Tseliou et al., 2010	Athens, Thessaloniki, Milan, Fribourg, Cambridge, Sheffield, Kassel	All year	PET, THI, K	9189
Hwang et al., 2011	Taiwan, Huwei	All year	PET	1644
Johansson & Yahia, 2011	Ecuador, Guayaquil	Dry & wet season	PET	537
Kampmann, Bröde, & Fiala, 2011			UTCI, PHS WGBT,	Laboratory comparison
Novák, 2011		July	UTCI, NET, Humidex, PT(CHMI), HI	Laboratory comparison
Yang, Lau, & Qian, 2011	Shanghai, China	Summer	PET	no
Kántor, Égerházi, et al., 2012; Kántor, Unger, et al., 2012	Szeged, Hungary	Autumn & Spring	PET	967
Schreier et al., 2012	Kiruna, Sweeden, Hamburg, Germany, Messina, Italy	Several years data	UTCI	
Weihs et al., 2012	Germany	Summer & Winter	UTCI	Model work