Real and theoretical evaluation of human thermal comfort in urban areas

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Abstract

The objective of this study was to evaluate the thermal comfort of humans in urban areas. As far as urban design parameters are concerned, height-to-width ratio and orientation of buildings may strongly affect thermal conditions in the cities. Physiologically equivalent temperature (PET) is a thermal index derived from the human energy balance and is preferred to other thermal indices as its unit (^{o}C) makes results more comprehensible to urban and regional planners and can be shown graphically or as climate maps. Meteorological parameters are required such as air temperature, air humidity, wind speed solar radiation and sunshine duration. The present study focuses on thermal comfort issues of humans in urban areas and provides estimates of PET based on long term data through RayMan model. RayMan among other models has the ability to create hypothetical buildings with different heights, widths and orientation (according to the under examination case). In the present study two buildings were added and their characteristics were altered in order to examine the variability of PET and sunshine in an urban area like University campus of UOA in 2013.

Keywords: RayMan, PET, thermal human balance, urban areas

Introduction

Many indices have been used in order to evaluate and quantify the thermal component of different climates and the effects of the thermal environment on human beings. These are also known as bioclimatic indices and they are based on the co-evaluation of meteorological parameters such as temperature, humidity, solar radiation and sunshine. We can classify bioclimatic indices in two categories according to two temperature conditions a) Indices that refer to cold environmental conditions, where air temperature and velocity are combined b) Indices that refer to warm environment, where air temperature and humidity are combined in order to study the evaporation occurring in human body. Indices that apply to warm environments are particularly interesting for the Greek region since thermal stress usually occurs from high ambient temperatures rather than low temperatures (Matzarakis 1995). Energy consumption has increased unintentionally at the building level because of climatic modifications, which has led to a remarkable demand on urban energy resources (Abreu-Harbich etal. 2013). The motivation for developing a thermally desirable or neutral outdoor environment has implications beyond the requirements of urban design and the design of climate-adjusted buildings. To re-establish thermally acceptable or neutral conditions, both indoors and outdoors, it is important to specify standards of how urban spaces can be structured and arranged according to the existing climate conditions within a region (Abreu-Harbich etal., 2013). Due to urbanization the phenomenon of urban heat island constantly spreads and results in the rise of temperature in urban areas where most of the population resides. Human perception of thermal conditions varies in relation to age, personality, education, climate experience, living conditions and heredity. Different human reactions could be generated by thermal change, for example, a sudden drop in temperature could cause from slight cold stress to extreme cold stress in different populations. Such climate parameters and their combination characterize the bioclimatic indices and determine the degree of biological wellness. The quality of life in an urban or rural environment is influenced significantly by bioclimatic conditions, both in short-term and long-term. There has been extended biometeorological research indicating the impact of urban bioclimate on human morbidity (Schwartz et al. 2004; Nastos and Matzarakis 2006; Michelozzi et al. 2007), mortality (Curriero et al. 2002; Analitis et al. 2008; Baccini et al. 2008; Hajat and Kosatky 2010; Almeida et al. 2010; Nastos and Matzarakis 2012), tourism potential and decision making (de Freitas 2003;Didaskalou and Nastos 2003; Hamilton and Lau 2005; Lin et al. 2006; Matzarakis and Nastos 2011), and urban planning (Carmona et al.2003; Nikolopoulou and Steemers 2003; Nikolopoulou and Lykoudis 2006; Thorsson et al.2004; 2007). Over the last years, many attempts have been made to formulate a reliable and user-friendly index for the assessment of the physiological thermal response of the human body to climatic conditions (d'Ambrosio Alfano et al. 2011), but only physiological equivalent temperature (PET) and Universal Thermal Climate Index (UTCI) seem to meet these requirements.

Materials and methods

There is a strong demand in the field of applied sciences such as architecture, agriculture, and medicine for climatological and biometeorological methods that are easily understandable. The radiation and human-bioclimate model RayMan (Matzarakis et al. 2007) meets this demand. Despite its simplicity, RayMan provides good simulation results for radiation flux densities and thermo-physiologically significant assessment indices. Use of RayMan derived results in applied sciences has many advantages (Mayer 1993;VDI 1998;Thorsson et al. 2004; Johansson and Emmanuel 2006; Matzarakis et al. 2007). At first it was created to estimate the Tmrt (mean radiant temperature) parameter in urban environment and calculate indices like PET . RayMan model is used to predict long term events in a period of ten years and its use is applied mostly in urban environments. It takes a small amount of meteorological data as an input and provides a good illustration of radiation changes. Some of the required data concern the human and involve dressing, physical activity, body type, age, gender and body posture. Also meteorological data such as air temperature, wind speed and humidity can be used along with altitude, geographical coordinates, time and date data. Region geometry plays an important part and it should be described with fish-eye pictures or by drawing using the RayMan Pro. RayMan consists an implement of the MEMI mathematical model which is based on the human thermal balance (Matzarakis et al. 2007). PET index is considered as the most suitable index to evaluate bioclimatic conditions and human thermal stress outdoors (Lin and Matzarakis,2008). It is expressed in Celsius degrees which makes it more comprehensible to public who is not familiar with human biometeorological terminology, and that's why it is preferred against other alternative indices. PET results can also be presented graphically or as bioclimatic maps. It is an index that evaluates thermal conditions and it is categorized in different levels. It is necessary for the calculation of PET to determine all meteorological parameters important for the human energy balance. Those parameters should be determined at a human biometeorologically significant height(1.1 m above ground). Dominant meteorological parameters influencing the human energy balance include air temperature, vapour pressure, wind velocity and mean radiant temperature of the surroundings (Matzarakis A., Mayer H., 1999).

Table 1 :Ranges of physiological equivalent temperature(PET) for different grades of thermal perception by human beings and physiological stress on human beings; internal heat production 80 W, heat transfer resistance of the clothing 0.9 clo (according to Jendritzky et al.1990; Matzarakis and Mayer 1997) (Matzarakis A., Mayer H.,1999)

PET	Thermal Perception	Grade of Physiological Stress
	very cold	extreme cold stress
4 °C		
	cold	strong cold stress
8 °C		
	cool	moderate cold stress
13 °C		
	slightly cool	slight cold stress
18 °C		
	Comfortable	no thermal stress
23 °C		
	slightly warm	slight heat stress
29 °C		
	warm	moderate heat stress
35 °C		
	hot	strong heat stress
41 °C		
	very hot	extreme heat stress

Using the RayMan software two virtual buildings were created with height from 10m to 30m and their between distance values from 10m to 50m (canyon). In this way we extract results on sunshine and PET per month, per day and min and max per year and per month for the year 2013. Throughout this process the duration of sunshine was calculated in a canyon for a virtual continuous city blocks 600m long in a way to evaluate the impacts on human beings. The research was carried out in the University campus of the National and Kapodistrian University of Athens (23°47′ E, 37°58′ N; 257 m elevation). PET value was calculated at the geometrical centre of the building complex (Fig.1).

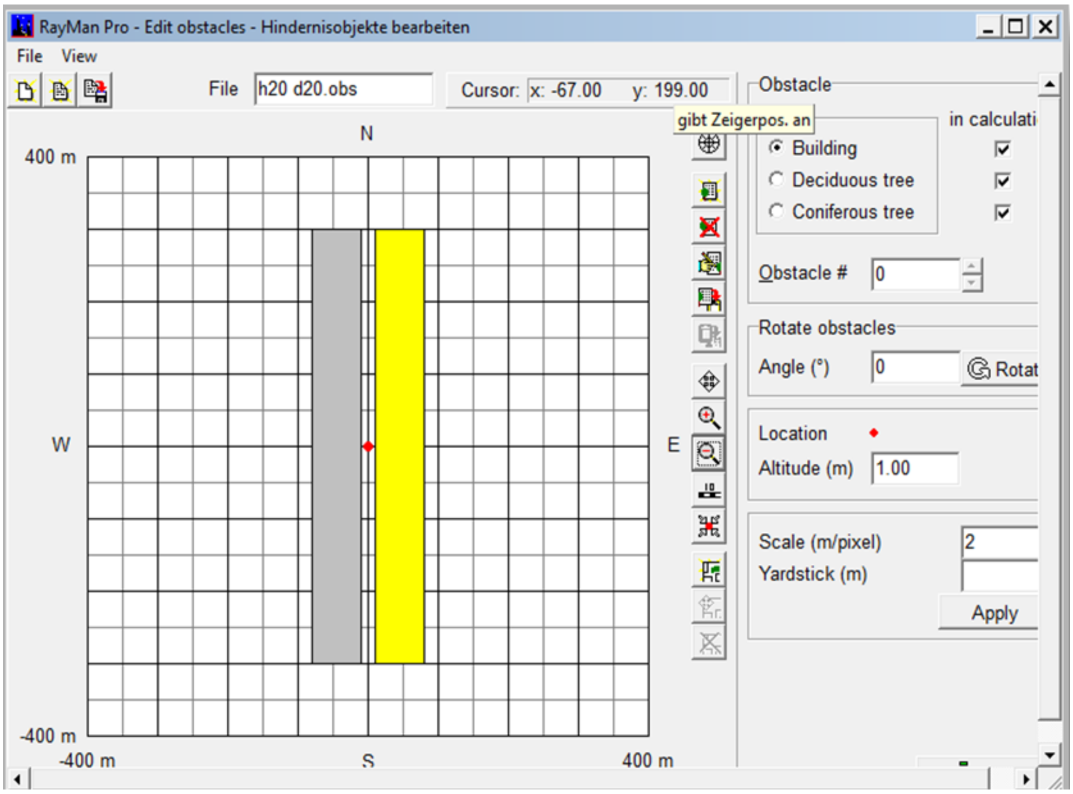

Figure 1 : Example of buildings input (plan view) in RayMan. The red spot is the location of the measurements.

Results and Discussion

The two parameters that we focused on were the height of the buildings and the distance between them. No major differences were observed upon varying these 2 different parameters from 10 to 30m of height and for 10 to 50m of distance. We did however observe a common tendency to obtain decreased mean PET values when increasing the inter-building distance for the colder months (e.g. January) while the opposite is true for the warmer months (e.g. August). In particular, for buildings of 10m height we obtained a decrease of 0.5 ^{o}C when increasing the distance from 10 m to 50m in January (4,9 ^{o}C – 4,4 ^{o}C) and an increase of 0.6 ^{o}C (26,4 ^{o}C –27 ^{o}C) in August (Fig. 2). For buildings of 20m height we obtained a 0.4 ^{o}C cooling effect of increasing the disctance for the coldest month (5,0 ^{o}C – 4,7 ^{o}C) and a warming effect of 0.7 ^{o}C (26,2 ^{o}C –26,9 ^{o}C)for the same distance change (Fig. 3). Similarly, the cooling effect was 0.3 ^{o}C in January upon increasing the distance of 30m tall buildings, while during August there was a warming effect of 0.6 ^{o}C (26^{o}C –26,6 ^{o}C) (Fig. 3). Proper architecture design optimizes the performance of certain factors which participate in the human thermal balance. By affecting values such as the orientation of the building and mainly its openings, shape of the building, ratio of compact components and openings, construction of shell and the heating method, ventilation and lighting, the researcher interferes in the thermal behaviour of the building. Key factor for the duration of solar activity and the amount of sunshine that the building receives is the orientation of compact and transparent components. Knowing the daily sun orbit during the year helps extracting valuable conclusions for the desining and the placing of the buildings compared to the the sunshine and heating required. A South frontage receives the maximum mean value of sunshine –heat which is ditributed throughtout the year in the most effective way. During the winter sun orbit is lower which results into a more vertical impingement of sunshine in the southern frontage and therefore is more effective. The South orientated frontage receives the higher amount of solar energy than any other orientated surface of the building. Contrary during the summer it receives the lower in heat despite high duration of solar activity. The frontages with the East and West orientation receive the maximun of sunshine from May to July and very small amount of heat during the winter.The North orientated frontages receive the sunshine only during the summer ,early in the morning and late in the evening. The distance between the two buildings with a height of 10m affects the sunlight in the canyon between them. In particular, the more we increase the distance between the two buildings the more the sunshine duration in the canyon reaches its maximum values during the summer. The orientation of the buildings also affects the sunlight in the canyon. The index PET is a useful tool in a structured environment for bioclimatic research and is considered to be the most appropriate for assessing bioclimatic conditions and thermal sensation of human outdoors.

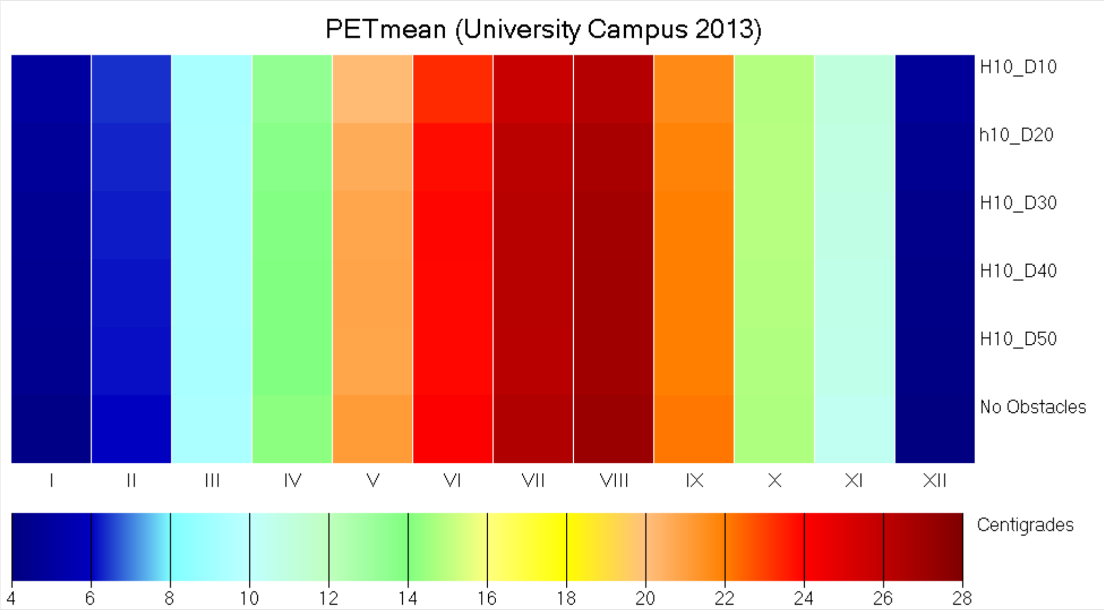

Figure 2: PETmean values for two buildings of 10m height and 10m to 50m distance between them(canyon).

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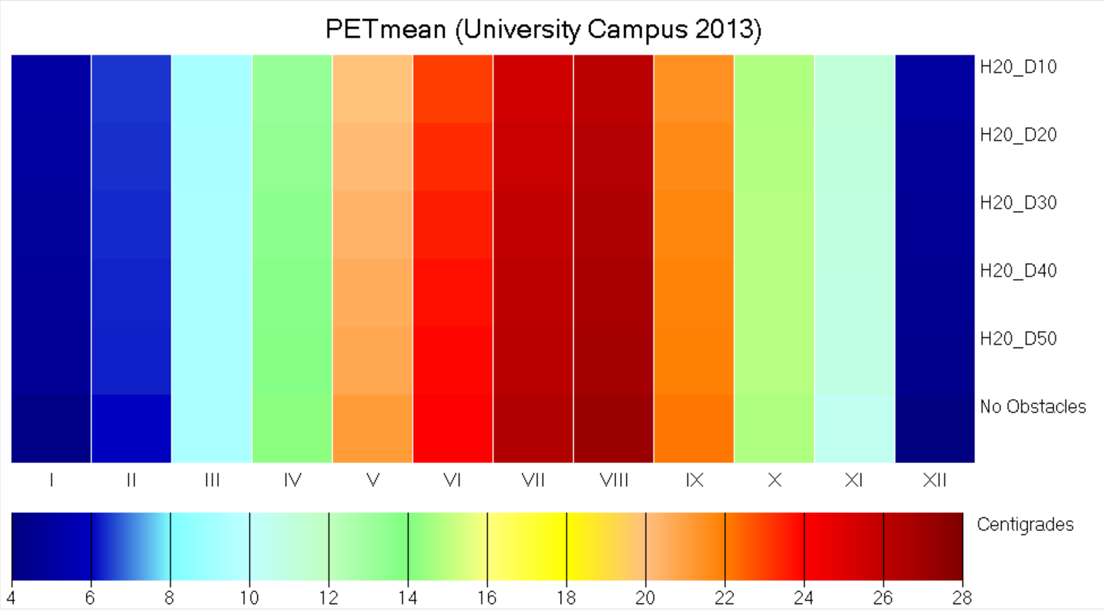

Figure 3: PETmean values for two buildings of 20m height and 10m to 50m canyon.

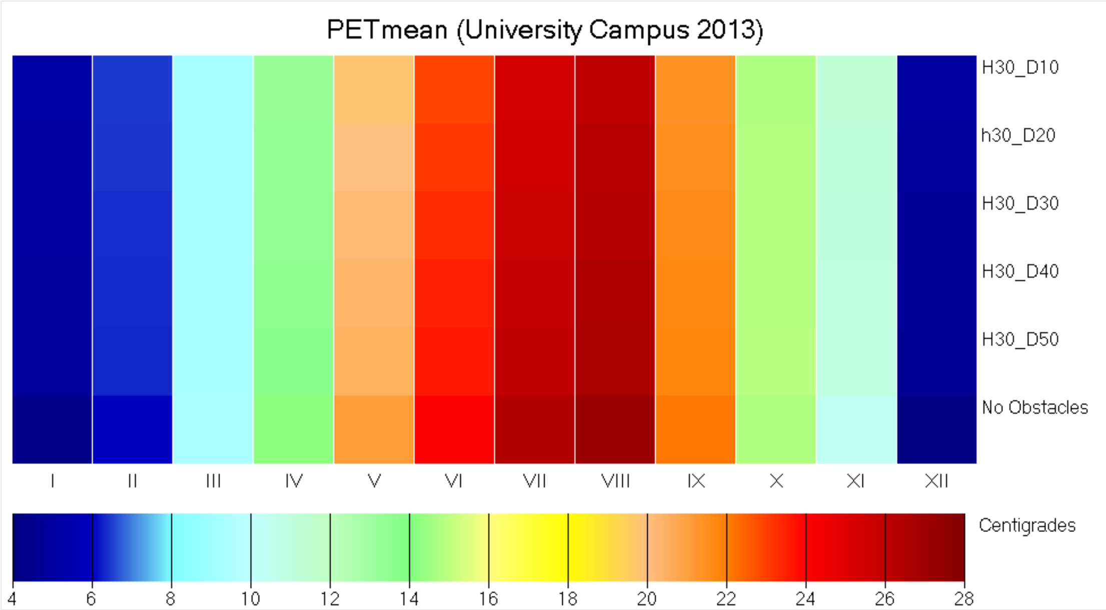

Figure 4: PETmean values for two buildings of 30m height and 10m to 50m canyon.

Conclusion

Depending on the height of the visual buildings and the distance between them no major differences were observed upon varying these 2 different parameters. In conclusion, a difference above or equal to 5 ^{0}C, which is the main prerequisite for changing grade of physiological stress, was not observed while altering the aforementioned parameters. However, the present study showed a common tendency to obtain decreased mean PET values when increasing the inter-building distance for the colder months, while the opposite is true for the warmer months. More bioclimate studies are needed to initiate and establish a biofriendly design of this area, so as to enhance the human thermal perception.

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