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Examining default urban-aspect-ratios and sky-view-factors to identify priorities for thermal-sensitive public space design in hot-summer Mediterranean climates: The Lisbon case

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ABSTRACT

This study evaluates Lisbon's bioclimatic risk factors, and how such microclimatic considerations can be transferred into priorities for thermal sensitive Public Space Design (PSD) during periods of accentuated thermal stimuli. The examination was structured into three sequential stages to address how the often lack of meteorological information can be overcome to assess pedestrian thermal comfort thresholds within specific morphological configurations within the historical district of the city. Firstly, through the application of the human-biometeorological model RayMan, the monthly variations of diurnal Physiologically Equivalent Temperature (PET) and corresponding Physiological Stress (PS) fluctuations were examined to obtain an overall comprehension of annual thermal bioclimate conditions within Lisbon. Secondly, diurnal variations were analysed in more detail through hourly oscillations for July in order to obtain an understanding of how thermal comfort thresholds were influenced during one of the hottest months of the year. Thirdly, such results was subsequently cross examined within the constructed default urban Aspect Ratios (AR) and Sky-View-Factors (SVF) within the SkyHelios model to evaluate concrete hourly PSD priority for urban canyons with diverse morphological compositions.

Based upon the results obtained from the study, adaptations of the thermo-physiological index were tested/used, namely the modified PET (mPET), PET Load (PETL), and the cumulative PETL (cPETL) in order identify Thermal Attenuation Priorities (TAP) for PSD within concrete locations of the identified canyons during specific periods of the day.

1. Introduction

Since the early 1980s, examinations of Lisbon's urban climatic conditions have been undertaken in order to address the gap between the interdisciplinary spheres of urban planning/design with that of climatology and biometeorology. Commonly within southern Europe, many cities often present a significant lack of meteorological and climatological information that could otherwise inform design and decision making within the public realm. Considering the case of Portugal in particular, and as identified by Ref. [1], the analysis of 15 Masterplans of urban municipalities revealed that although climatic information was discussed in nearly all of them, the respective information often proved of limited use for local adaptation efforts. Such oversights have been suggested to be attributable to numerous reasons, namely to the fact that meteorological data from ‘classical’ stations used in the abovementioned municipal plans, were usually not applicable to meso, and microscales [2].

As a response from the scientific community, there has been a dissemination of studies that have made valuable contributions to comprehending the general bioclimatic conditions within the public realm (e.g., [3,4]), causalities of and intensities of Urban Heat Islands (UHI) (e.g., [5–7]), wind current studies (e.g., [8,9]), and, the combination

Abbreviations: UHI, Urban Heat Island; PSD, Public Space Design; AR, Aspect Ratio; SVF, Sky-View-Factor$_{(\#\ \text{respective region})}$; TAP, Thermal Attenuation Priority; KG, Köppen Geiger; HWE, Heat Wave Event; WMO, World Meteorological Organisation; PET, Physiologically Equivalent Temperature; MRT, Mean Radiant Temperature; PS, Physiological Stress; Oktas, Total Cloud Oktas; T_{amb}, Ambient Temperature; RH, Relative Humidity; WS, Wind Speed; T_{dew}, Dewpoint Temperature; $WS_{1.1}$, Wind Speed at height of 1.1m; G_{rad}, Global Radiation; CTIS, Climate Tourism/Transfer Information Scheme; (MR), Mid-Range value; NSO, North-to-South Orientation; WEO, West-to-East Orientation; M_{Sun}, Minutes Cast in the Sun; T_{surf}, Surface Temperature; mPET, modified PET; PETL, PET Load; cPETL, Cumulative PETL; BC, Background Conditions; DJF, December January February; JJA, June July August; SON, September October November; MEMI, Munich Energy balance Model for Individuals

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with planning policy (e.g., [10,11]). In addition, and as a result of the maturing climate change adaptation agenda, studies pertaining to potential impacts upon Lisbon's climate have also been published (e.g., [12–16]). Adjacently, and prospectively further invigorated by bottom-up approaches to climate adaptation within the past decade, there continues to be a growing interest (and demand) for application-orientated perspectives at local scales [17]. It is here where the concept of 'locality' gives origin to creative and design driven practices such as Public Space Design (PSD) in confronting urban climatological aggravations associated to hot-summer climates (e.g., [4,18–23]).

Based upon contributing to this bottom-up approach, this study conducted an application-orientated analysis of Lisbon's bioclimatic environment to identify physiological risk factors within Lisbon's public spaces by: (i) examining Lisbon's annual climatic oscillations of diurnal thermal stress, with a recording interval of 3 h between 09:00 and 15:00; (ii) constructing an hourly evaluation of July's climatic conditions between the diurnal hours of 09:00 and 18:00, with a recording interval of 1 h; and, (iv) assessing how such conditions were affected by the different modelled default urban Aspect Ratios (AR) and Sky-View-Factors (SVF). Once identified, the obtained bioclimatic conditions within the different open spaces were assessed through the application of different thermo-physiological indices in order to build upon Thermal Attenuation Priorities (TAP) for the interdisciplinary and 'locality' based practice of PSD.

2. Methods

2.1. Site

Lisbon is located upon the western coast of Portugal at 38° 42′N and 9º08′W, with a climatic Köppen Geiger (KG) classification of '*Csa*', implying a Mediterranean climate with dry and hot summers [24]. As presented by Refs. [25] and [26], the city observes: (i) between 10 and 20 'very hot days' which are those that experience ambient temperatures (T_{amb}) above 35 °C; (ii) between 100 and 120 'summer days' where maximum T_{amb} surpass that of 25 °C; and lastly, (iii) frequent occurrences of Heat Wave Events (HWE), where T_{amb} sequentially surpass that of 32 °C during various days. With regards to wind patterns, N and NW wind directions are the most predominant during the year, particularly during the summer [2]. However, due to the proximity to the Tagus Estuary, estuary breezes reach adjacent urban areas on 30% of late mornings, and early afternoons during the summer [9]. Shown in Fig. 1, this study focuses mostly upon Lisbon's quarter around 'Baixa Chiado', which due to its morphological composition, often witnesses the highest intensities of UHI [3], and habitually the highest temperatures during the summer [10].

2.2. Data

In order to obtain the data required for this study, meteorological recordings were obtained from the World Meteorological Organisation (WMO) weather station with the Index Nº08535, located in Lisbon (at latitude of 38–43N longitude 009-09W, and an altitude of 77 m). Similar to existing studies (e.g., [2,27–32]), the extracted information from the station was subsequently processed through the RayMan Pro© model [33,34] in order to determine Physiologically Equivalent Temperature (PET) [35], Mean Radiant Temperature (MRT), and Physiological Stress (PS) levels. As presented by Ref. [36], PET is defined as the air temperature at which, in a typical indoor setting (i.e., without wind or solar radiation), the heat budget of the human body is balanced with the same core and skin temperature as under the complex outdoor conditions to be assessed. The reason for utilizing PET was twofold: (1) it is calibrated upon easily obtainable microclimatic characteristics; and, (2) it uses °C as the measuring unit to assess thermal comfort, it permits other professionals such as urban planners/designers to approach urban climatological aspects. Pertinent to the thermo-physiological assessments conducted in this study, the following microclimatic characteristics were initially introduced into the model: total cloud oktas (Oktas), T_{amb}, Relative Humidity (RH), and lastly, Wind Speed (WS).

With regards to the latter, once the values of WS were translated into ms^{-1}, a further adjustment was undertaken to account for the type of urban conditions discussed in this study. As suggested by Ref. [37], when considering speeds within beneath the Urban Canopy Layer (UCL), and within the streets themselves, modified WS values are often considerably lower than those presented by the meteorological station. As a result, and to determine the actual WS values upon the gravity centre of the human body as stipulated by Ref. [38], the obtained results from the station were adapted to a height of 1.1 m (henceforth expressed as $WS_{1.1}$). Similarly to the study conducted by Ref. [29], the formula presented in Refs. [38,39] was used (Eq. (1)):

$$WS_{1.1} = WS_h^* \left(\frac{1.1}{h}\right)^{\alpha} \qquad \alpha = 0.12^* z_0 + 0.18 \tag{1}$$

where: WS_h is the ms^{-1} at a height of h (10 m), α is an empirical exponent, depending upon urban surface roughness, and Z_0 is the corresponding roughness length.

Comparable to the morphological layout within the study of Ref. [29], Lisbon's denser downtown district with frequent open spaces also presented similar values of $z_0 = 1$ and $\alpha = 0.35$. In addition to these initial microclimatic variables obtained from the meteorological station, global radiation (G_{rad}) values were also introduced later in the study. Such data was retrieved from the authors through the use of the apparatus KKMOON SM206© with an accuracy of ± 10 and resolution

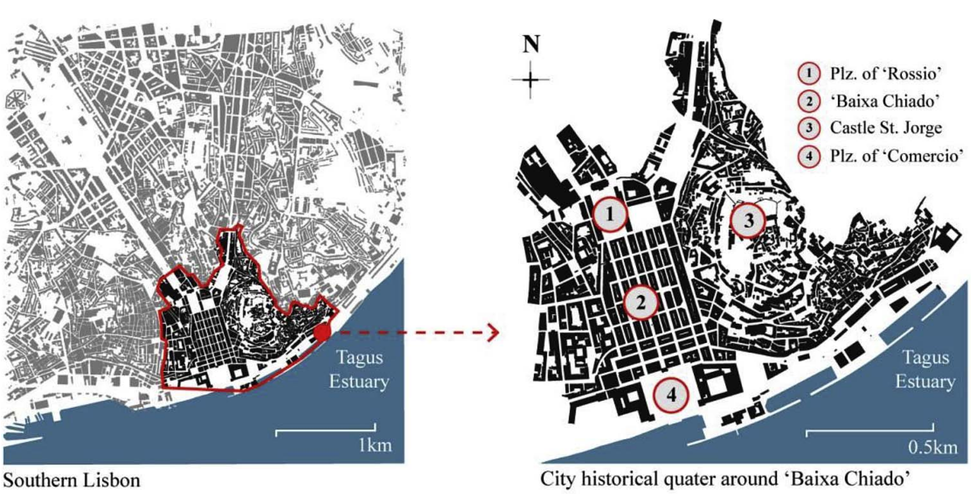

Fig. 1. Specific locations within Lisbon's historical quarter, surrounding context, and proximity to the Tagus.