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Addressing thermophysiological thresholds and psychological aspects during hot and dry mediterranean summers through public space design: The case of Rossio

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ABSTRACT

Within the contemporary city, the effects of urban climatology are increasingly elucidating the need for further climate responsive environments. So far however, and as global climate studies often present limited local specificity for urban planning and design, there has been a growing interest for complementary bottom-up perspectives which describe how efforts of adaptation can be locally initiated. Accompanying this interest, and orientated at a specific case study, this article presents the results of an empirical analysis that was undertaken during July of 2015 within one of Lisbon's iconic historical public spaces, Rossio. The study was built upon two foundational interrogations: (1) What are the principal microclimatic risk factors within the square that can affect pedestrian thermal comfort thresholds?; and, (2) How can the identified risk factors be translated into opportunities for public space design?

In order to obtain an initial understanding of thermal comfort conditions, Computational Fluid Dynamic (CFD) and Shadow Behaviour Simulations (SBS) simulations were undertaken to establish six Points of Interest (POI) within the square. Subsequently, ambient temperature, surface temperature, relative humidity, wind speed, global radiation and Sky-View-Factor (SVF) were measured with on-site meteorological handheld equipment. In order to complement these examinations, Pedestrian Based Response (PBR) interviews were also conducted. Finally, through the application of the biometeorological RayMan model, the Physiologically Equivalent Temperature (PET) index was used in order to: (i) obtain approximations of diurnal physiological stress around the square; and subsequently, (ii) propose conceptual public space design solutions to improve existing thermal comfort conditions in the square.

1. Introduction

With the arrival of the climate change adaptation agenda, local decision makers and designers are continually focusing upon the implementation of measures to address local 'risk factors' [19]. This maturing bottom-up perspective is one that enables an exploration into how the sphere of urban design can improve the bioclimatic conditions within local scales. Thus, this developing bottom-up perspective is one that explores how the spheres of urban design and climatology can tackle meteorological implications through modifications of the urban public realm [10,31,46,49,66]. Used as a means to evaluate such modifications, numerous recent studies have incorporated the use of biometeorological studies to examine thermal comfort conditions as part of the public space design process of (e.g., [1,9,16,32,35,42,62,70]).

When considering the specific case of Lisbon, it is already recognised that urban planning and design need to adapt to future possible aggravations of climatic conditions which are presently raising implications upon its public realm [5,8,39]. Thus far, such studies have focused upon general bioclimatic conditions within the public realm (e.g. [11,57]), effects and intensities of UHI's (e.g.

Abbreviations: C, Cycle; CD, Crown Dimension; CFD, Computer Fluid Dynamics; ETCS, Ephemeral Thermal Comfort Solution; FP, Functioning Period; GP, Group Plantation; H/W, Height-to-Width ratio; IPCC, Intergovernmental Panel on Climate Change; JJA, June, July, August; KG, Köppen Geiger; LM, Limitation Mechanism; LP, Linear Plantation; MEMI, Munich Energy balance Model for Individuals; NC, No Clouds; NH, Nozzle Height; PBR, Pedestrian Based Responses; PCZ, Physiological Comfort Zones; PET, Physiological Equivalent Temperature; PL, Planting Layout; POI, Point Of Interest; PP, Pump Pressure; PS, Physiological Stress; RH, Relative Humidity; SBS, Shadow Behaviour Simulation; SW, Surface Wetting; SVF, Sky View Factor; TH, Tree Height; TP, Thermal Perception; UHI, Urban Heat Island; clo, cloud cover; Kamb, Change in Ambient temperature.

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[3,5,38]), wind studies (e.g. [7,37]), and, the integration with planning policy (e.g. [6,8]). In addition, and inherent to the developing climate change adaptation agenda, studies relating to potential future climate change impacts upon the urban realm have also been disseminated (e.g. [4]).

Also located in Lisbon, this study presents the results of a bioclimatic analysis within one of the city's oldest civic spaces, Rossio. Based upon accessible meteorological equipment, and easy-to-use models/software for urban design and planning professionals, the study concludes a set of public space design solutions which were based upon the square's microclimatic risk factors. Undertaken in the summer of 2015, the empirical aims of the study were to: (i) identify the microclimatic risk factors within different areas of Rossio; (ii) to propose conceptual interventions that could potentially improve pedestrian thermal comfort during periods of annual higher climatological stress (i.e., JJA) in Rossio. Notwithstanding, the more encompassing objective of this study is to determine the lessons that the case of Rossio can bring in an era where urban climatology is becoming a continually important factor for local scale decision making and design.

2. Method

2.1. Study area

Lisbon is located close to the western coast of Portugal at 38°42′N and 9°08′W, with a climatic Köppen Geiger (KG) classification of '*Csa*' which implies that it has a Mediterranean climate with dry and hot summers [59]. During the year, and as presented by Refs. [48] and [15], the city witnesses: (i) between 10 and 20 'very hot days' with ambient temperatures above 35 °C; (ii) between 100 and 120 'summer days' where maximum ambient temperatures exceed 25 °C; and lastly, (iii) up to two annual occurrences of ambient temperatures surpassing 32 °C for at least 16 days, corresponding to an urban heatwave. In terms of wind regimes, N and NW wind directions are the most common during the year, especially during the summer [2].

When considering the site of Rossio, although located just north of Lisbon's Tagus River (Fig. 1B), the square is located in the city's historical district which witnesses the strongest effects of UHI within the city [11], and often the highest ambient temperatures during the summer [6]. In addition, and within this district, most canyons present relatively high H/W ratios (i.e., of ≈1.66) (Fig. 1D), yet in the case of Rossio, this ratio is considerably lower (i.e., of ≈0.21) (Fig. 1E) thus increasing the susceptibility to microclimatic variables such as solar radiation during the summer. Such susceptibility of canyons with low H/W ratios has also been considered a high priority for thermal sensitive urban design (e.g. [52]), which in turn, summons the opportunity for public space design [23]. (■ See Appendix A.1/2 for Project Data Sheet).

2.2. Initial computer simulations

In order to establish the locations for the on-site meteorological measurements, two types of preliminary computer simulations were undertaken in order to: (i) identify areas that were more prone to microclimatic risk factors; and, (ii) validate the simulation results with subsequent onsite measurements. The selection of these two simulations were focused upon obtaining a synoptic comprehension of wind patterns, and radiation fluxes which: (i) are the most influenced by morphological and physical properties of the urban environment [42]; (ii) have proven to be the strongest parameters upon urban thermal comfort [12,16,34,35,72]; and, (iii) are often overlooked in top-down climatic assessments [41].

The first simulation was established to provide an initial indication of summer wind currents within the square through the use of Computational Fluid Dynamic (CFD) studies. In order to calibrate the wind tunnel study, four parameters were introduced into the CFD simulation: predominant wind direction, wind speed, horizontal height of the simulation plane, and lastly, sufficient 'contextual roughness' around the square.

As a starting point, and based upon data from the Portuguese Institute of Sea and Atmosphere (IPMA), wind rose studies indicated that the predominant wind direction for the July period varied between 315°–337.5°, i.e., ranging between NNW and NW (Fig. 1C). Such data was also utilised in numerous studies that explore wind regimes in Lisbon (e.g. Refs. [2,6,38]). When considering such implications upon the case of Rossio, it was noted that orientation of '*Avenida de Liberdade*' (Fig. 1A/B) aligned with the predominant wind direction for the summer period (i.e., JJA). Such an alignment raised an initial concern that this could generate a wind tunnelling effect, and propagate very strong wind speeds upon northern region of Rossio. When deciding upon the appropriate wind speed for the simulation, it was noted that mean values at street level are often considerably lower than those presented by meteorological stations [58]. Thus, and based upon previous studies that identified summer daily wind regimes within Lisbon for this time of year (e.g. [7,38]), a maximum wind speed of 5 m/s was applied to the simulation.

As concrete pedestrian height has varied slightly amongst existing microclimatic studies (i.e., by ± 0.50 m) in the last decade (e.g. [21,35,61,65]), the simulation plane for the CFD study was established at a height of 1.50 m. Finally, and when considering the size of the simulation, in order to consider the influence of surrounding buildings and roads before the wind patterns reached the square with an area of 30,000 m^2, the total simulated area was of 185,000 m^2. Due to the calibrated wind direction, a particular interest was considering the impact of the possible wind tunnelling effect projected from the north.

The second simulation was directed at obtaining a basic understanding of solar radiation within the square through Shadow Behaviour Simulations (SBSs). Also through the introduction of a geo-referenced massing model, the solar path was used in order to obtain the behaviour of shadows that were cast by the squares built form. As building heights were very much uniform in the square (i.e., 5 storeys), a synoptic building height of 18 m was used within the massing model. Within each simulation, the calibration of the simulation was adjusted in order to obtain the desired temporal scope and required precision. The first study was regulated to present a complete diurnal analysis of shading hours around the square (i.e., 08:00–17:00). In order to obtain a more precise result (such as vegetative shadows cast upon adjacent sidewalks and façades), the simulation was configured to assess resulting shadow patterns every 15. Subsequently, two more simulations were undertaken to analyse maximum shadow extents in the morning (i.e., 08:00–12:00) and afternoon (i.e., 12:00–17:00).

2.3. On-site meteorological measurements

Through the use of handheld/portable weather instruments (■ See Appendix B.1/3 for Equipment & Measurements), five different types of measurements were undertaken, i.e., Wind Speed (V), ambient temperature (T_{amb}), Relative Humidity (RH), global radiation (G_{Rad}), and surface temperature (T_{surf}). Although more sophisticated equipment could yield more accurate results, the focus of the selected equipment was also their ease of use and portability. Established upon an analytical timeframe of 10 min (where measurements were recorded every minute for 8 min, and a subsequent 2 to allow for relocation and set up time) a total of six POIs were permitted in order to obtain enough mean results around the site