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A CASE-BASED URBAN MICROCLIMATE VARIETY CLASSIFICATION PROCEDURE: FINISHING MATERIALS AND SHADING IN URBAN DESIGN

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Abstract: This research work focuses on the study of microclimate conditions of two squares of Madrid, a city with a considerable Urban Heat Island. The process includes field measurements of the surface and radiant temperatures of materials on buildings façades, pavements and urban furniture. Air temperature, relative humidity and wind speed and direction were also measured. A virtual 3D model was used for sun exposure and solar radiation simulations. The urban microclimate regulation capacity of the finishing materials and shading are numerically defined. Considering the results obtained from measurements and simulations, a procedure for open spaces' microclimate variety classification and identification is proposed: An approach to describe the thermal level for open spaces, in order to help the urban designers and planners to provide high microclimate variety for the users to meet their difference thermal demand. This is as a key element to identify environmental quality and to obtain thermal comfort

Keywords: Urban design; finishing materials; shading; outdoor microclimate; microclimate variety mapping.

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INTRODUCTION

This case-based research reveals empirical and theoretical insights into the relation between urban design and microclimate (Berry and Bollay, 1945). Atmospheric changes associated with urbanisation began to be analysed in the 19th century (Howard, 1833). Although the bioclimatic technique and research into the microclimate and its relationship with urban design gained importance 50 years ago (Givoni, 1998; Olgyay, 1963), in mid-20th century, with the first active conditioning systems, both architecture and urbanism became disassociated from climatic environmental conditions.

The influence of environmental elements on the modification of the urban microclimate, has been analysed throughout the last 20 years (Adolphe, 2001; Erell, Pearlmutter and Williamson, 2010; RUROS Project, 2004). More recently, studies on urban microclimate have focused on the surface and atmospheric Urban Heat Island (UHI) and climate change (Landsberg, 1981; Oak, 1973; Owen, Carlson and Gillies, 1998), and its mitigation (Brown, 2011), and on its effects on public health (Couts and Harris, 2013). Considering the more and more frequent heatwaves (IPCC, 2007; Luber and McGeehin, 2008), the strategies to adapt to climate change in the cities represent a challenge to improve quality of life, avoid diseases and reduce mortality associated with heat strokes (EC, 2017; Smargiassi et al., 2009; Showalter and Lu, 2010; Loughnan, Nicholl and Tapper, 2010).

Thermal comfort of the inhabitants in outdoor spaces determines the quality and livability of urban space, as well as the economic, social and leisure activities carried out therein. Madrid is a city with very variable and extreme weather conditions that determine the use of outdoor spaces. Two squares of the historic City Centre of Madrid were chosen for this study, which has the following objectives:

(a) To determine by field measurements the differentiated thermal behaviour of the artificial and natural materials of the squares, both in the sun and in the shade, and their influence in the microclimate variety of open spaces.

(b) To identify the hygrothermal differences of two traditional spaces, which, although morphologically are very similar and located in the same area, have very different urban designs.

(c) To develop a simple microclimate variety classification and identification procedure for outdoor spaces based on field measurements and simulation results. It will be representative of the inhabitants' thermal location options in the open space.

GEOGRAPHICAL CONTEXTUALISATION

Madrid has a Mediterranean Continental climate, with cold winters and very hot summers. There are high temperature contrasts: up to 30 ºC between winter and summer, and day-night differences up to 17 ºC in August and 7 ºC in winter. According to the Köppen Hagen classification, it is a Csa climate: warm climate with dry and hot summers.

Although there are numerous cold months, from mid-May to mid-October Ta will surpass comfort temperatures. Months with highest global horizontal radiation are those with maximum air mean temperatures (Tmax): 31.16 ºC in July, with average global horizontal radiation of 8.6 kW/m^2 per day. Mean relative humidity (RH) is low, with a minimum of 39 % in July, and a maximum of 74 % in December. In the hours when open spaces are in use the most (from 8am to 10pm), the RH is below 40 % for most of the year, and even below 20 % in summer.

Mean air temperature (Tm) in Madrid has had an upward trend over the last 135 years (1881-2015) of approximately 1.5 ºC, both in terms of average annual values and monthly values. This increase has been especially noticeable since 1950 (**Fig. 1**).

Madrid is located in Southern Europe, on the interior of the Spanish mainland, where the effects of climate change will be highly accused (EEA, 2012). The city is especially vulnerable to heatwaves (Smid et al., 2019) due to its size, manifold artificial surfaces, high percentage of risk population and its regional weather conditions. It has a clearly defined urban climate with a large number of days with very intense UHI (Fernández et al., 2016). There is a maximum temperature difference between the centre and the periphery of 5 to 6ºC (Núñez, 2017). Madrid's UHI has not changed in intensity since 1988, but the area affected by UHI has increased.

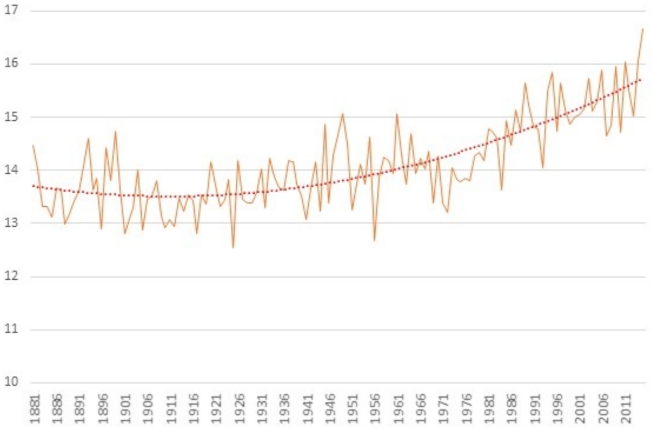

Fig. 1 Annual mean air temperatures of Madrid, 1881-2015. Prepared by the authors based on historical data. Source: State Meteorological Agency AEMET.

Thus, two daily use urban spaces located in the UHI's greatest intensity area (in blue) have been selected: 2 de Mayo square (2dM) and the Pedro Zerolo square (PZ). They are in the Centre District. Field measurements have been taken from Spring to Summer, when UHI intensity increases noticeably. From 2000, extremely hot days have increased in those months (Fernández et al., 2001).

METHODOLOGY

The following steps have been taken in the analysis and microclimate variety classification procedure definition process:

a) Physical characterisation of the squares and 3D drawing: morphology, materials, trees and benches.
b) Determination of solar radiation and shading using Autodesk Ecotect Analysis software, throughout the studied period.
c) Selection of field measurement locations: on pavements, façades and benches of sunny and shaded spaces.
d) Field measurements: Surface temperature (TC), long wave radiation of the materials, air temperature (Ta) and relative humidity (RH), and wind speed and direction, in April, May and June, from morning to night.
e) Processing of measurements and conclusions: microclimatic conditions of measurement points and materials behaviour.
f) Defining a procedure for microclimate variety classification and identification.

DATA COLLECTION

Physical characterization of the spaces

Both of the squares are located on the city centre of Madrid, in the Centre District, at a distance of 680m. Their orientation size and morphology are very similar, but their urban design is considerably different.

2 de Mayo square (2dM) acquired its current dimensions in 1869, 69m per 77m (5,313 m^2). Since then and until its current configuration, it has been reformed several times. The surrounding buildings are 2 to 7-storey high, the most common ones having 5 storeys, so the square's height–width proportion is between 1/4.8 and 1/4.3. 30.3 % of the square's pavement is pervious, natural soil where mature trees grow. Road paving only represents 8 %. 61.7 % of the paving is granite. There are 15 wooden and 8 granite benches.

The current dimensions of Pedro Zerolo (PZ) square are from 1848, 77m per 73m (5621m^2). Although, morphologically is very similar to 2dM, it is a much harsher square. Between 1999 and 2005 a refurbishment was carried out eliminating the existing gardens from 1950, and an underground parking was built. Most of the buildings facing the square are 6-storey high (height-width proportion between 1/4 and 1/3.85). The predominant pavement is grey granite, which represents 60 % of the square area. Pervious pavements only are the 8.5 % of the surface, with only a few small trees. There are occasional terrazzo pavements. The rest 25 % of the area are roads. There are 46 wooden benches in the square.

Solar radiation and shading: selection of field measurement locations.

A 3D model, defining the properties of the finishing materials and trees, was built. Autodesk Ecotect Analysis software[1] (Oregi, Roth, Alsema, et al., 2015) was used for the analysis of natural light and sky component, shading percentage and solar radiation of the squares. The measurement locations were selected based on maximum and minimum solar gain on pavements and façades and on resting zones and benches (**Fig. 2**).

Field measurements of the thermal environment

Ta, RH, wind speed and direction and TC of pavements, façades and urban furniture were measured in both squares from April to June at the pedestrian zones of the squares. The data were collected both in sunny and shaded locations on clear days, at three different times of the day: morning, afternoon and night (10 to 10.30 am, 6 to 6.30 pm and 10.30 to 11 pm). Given that in open spaces, the exchange of energy between materials and inhabitants happens at microclimate scale (Caballero, 2004), the measurements were taken 1.5 to 2 m above ground level.

A Testo 400 device with 3 sensors was used: Dry bulb air temperature (ºC) and relative humidity (%) probe, surface contact temperature sensor (ºC) and a wind speed (m/s) and air temperature (°C) thermal anemometry probe. In parallel, thermographies with FLIR thermal camera were taken to measure the long-wave infrared radiation and verify the correct choice of the measurement points.

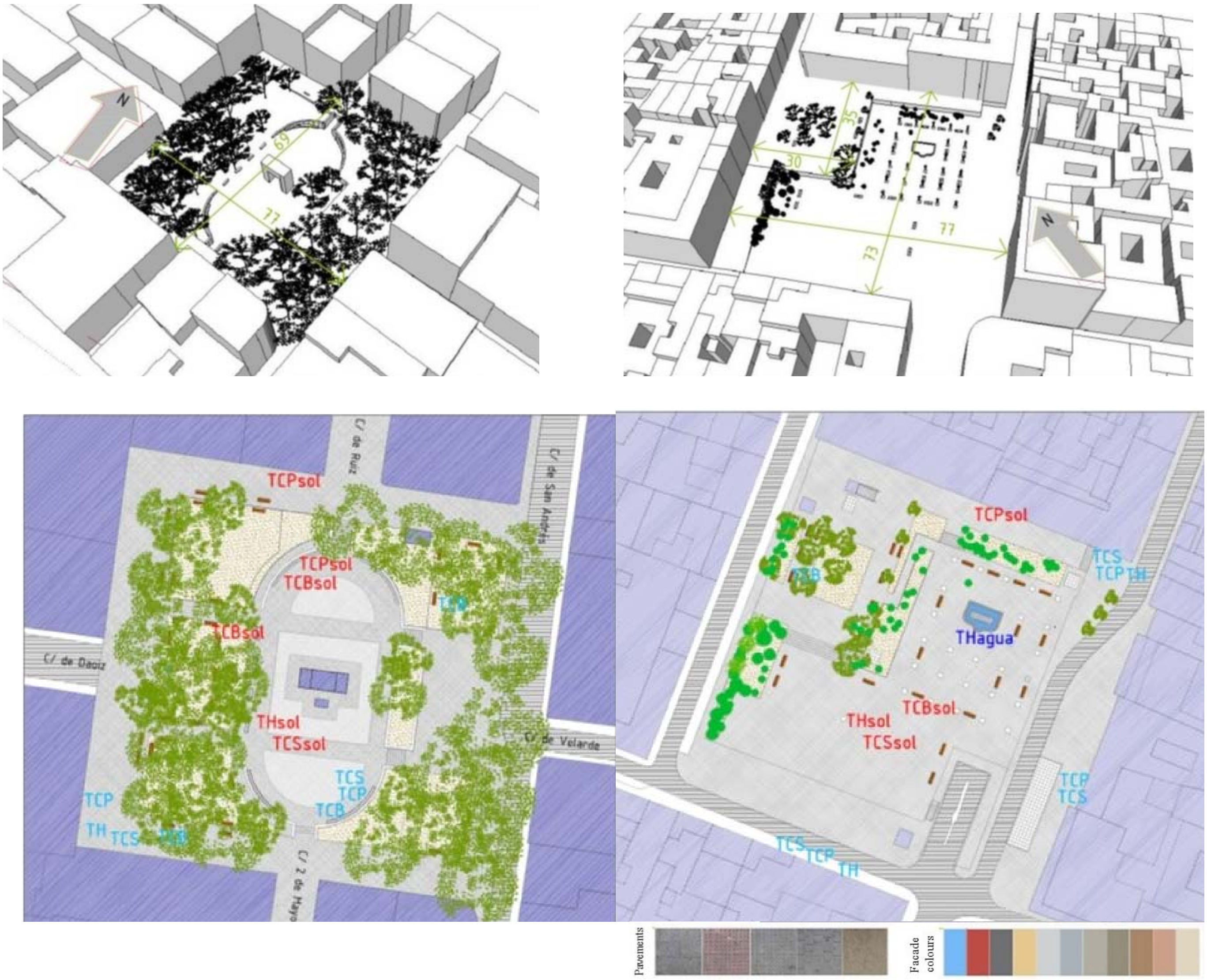

Fig. 2: 3D model of the squares and field measurements location, pavements and façades. 2 de Mayo and Pedro Zerolo squares. THsol: Ta and RH (sun), TH: Ta and RH (shade), TCPsol: façade´s TC (sun), TCP: façade´s TC (shade), TCSsol: pavement's TC (sun), TCS: pavement's TC (shade), TCBsol: bench's TC (sun) and TCB: bench's TC (shade).

RESULTS: FIELD MEASUREMENTS

The Ta of PZ are 1.5 to 2 ºC higher than Ta registered on 2dM during the day. However, at night, in the warmer months, PZ registered lower Ta. Maximum registered Ta is 33.6 ºC in 2dM and 35.9 ºC in PZ in June afternoon. On the other hand, Ta is considerably lower in shaded spaces than in sunny ones, especially in April, less so in June: 3.2 ºC less in 2dM and 5.2 ºC less in PZ in April and 1 ºC less in 2dM and 2.5 ºC less in PZ in June. Temperature differences between sunny and shady spaces are more significant in PZ (**Fig. 3**).

According to the updated UHI map (Núñez, 2017), there is a 2 ºC to 3 ºC Ta difference between the location of the nearest weather station in Parque del Retiro^2 and the squares. Field data confirms the UHI: Ta in PZ is 1 to 7 ºC higher comparing to the weather station Ta data, and 0.5 to 5.2 ºC in 2dM. PZ is hotter than 2dM during the day. At night, however, Ta difference between weather station data and square measurements is higher in 2dM (from 2.3 to 5.2 ºC) than in PZ (from 1.1 to 4.4 ºC).

Ta near a fountain was also measured in PZ to evaluate the cooling and humidification effect of the water. During the afternoon, the reduction in Ta (0.5 m distance from water) is 1 to 3.5 ºC, while at night it is only 0.5 ºC. RH increased by 3.5 %.

RH is similar in both squares. RH is higher in shaded spaces than in the sunny ones: up to 8 % in April 4 % in June in PZ and up to 12 % in April and 4 % in June in 2dM. During the warmer hours, that difference drops to 2 to 4 % all months.

Wind direction and intensity varied throughout the months, and even on the same day. In 2dM square, wind varied from calm to a maximum speed of 4 m/s, with no recurrent direction. In PZ square, wind came from NE in April, while in May and June it came always from

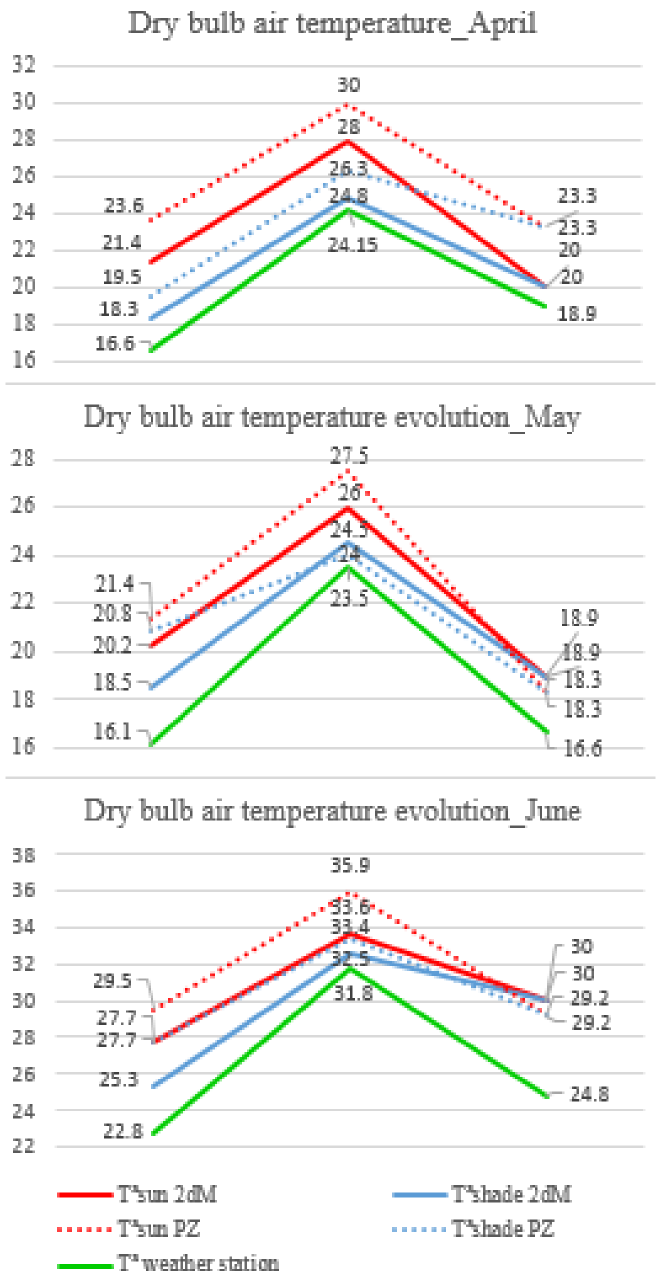

Fig. 3: Dry bulb air temperatures in the sun and in the shade and weather station measurements in ºC (8 to 8.30 am, 4 to 4.30 pm and 8.30 to 9 pm-UTC).

SW. These are the prevalent wind directions in Madrid. Mean wind speed was always slightly higher in PZ.

Pavement materials are natural soil, light grey and dark grey granite[3], white and red terrazzo[4], and there are whitewashed[5], solid red brick[6] and medium grey granite on façades. Benches are made of wood[7] and light grey granite. Construction materials influence both the heat balance and the water balance (Lee and French, 2009) of the urban space. Their thermal, hydric and optical properties, and mainly the albedo, absorptivity, thermal inertia, water permeability and texture, influence the energy balance with the environment, creating different microclimate conditions (Hernández, Fariña, Fernández et al. 2013; Santamouris, 2001). Not just the materials' properties influence the microclimate, but also the amount of material (Fokaides, Kylili, Nicolaou et al., 2016), their location in the public space and the spatial configuration of the area. UHI is closely related to construction materials (Hui, 2015), as traditionally, materials with great heat storage capacity have been used. While vegetation remains practically at air temperature (Ta), construction materials absorb, store, reflect and emit radiant energy influencing the near-surface air temperatures. It is in the Urban Canopy Layer (UCL) where this heating of the urban atmosphere becomes more evident (Oke, 1982).

TC of the materials vary based on their properties and their location in the space. According to measurements on sunned locations, the highest recorded TC are on dark granite and red terrazzo and the lowest on white terrazzo and light granite. There are differences of 7.5 ºC in April and 10.2 ºC in June between the most and least warm materials in the middle of the day. The difference in TC increases in the warmest months at the warmest times. In May and June, at night, granite still preserves the stored energy from the sun (TC is 3 to 5 ºC higher than in the morning).

Natural soil and vegetation TC is very similar to Ta, being just slightly higher (3 ºC maximum). At midday, TC of materials in the sun, except natural soil and vegetation, can rise to 8 ºC and up to 17ºC higher than Ta, having a considerable effect on comfort in open spaces (**Fig. 4**). The materials TC is lower in the shade than in the sun: in dark granites there is a 3 to 7 ºC difference in the morning and an 8.5 to 19 ºC difference in the afternoon. In terrazzo, the differences are somewhat less: from 1.5 to 4ºC in the morning and between 11.5 and 17.5 ºC in the afternoon from April to June. Focusing on the façades, and considering those that in the sun, granite façades reach the highest TC, up to 43.9 ºC in June. The ones that remain at lower temperatures are whitewashed walls, 8 ºC to 9 ºC less than granite. TC of reddish brick rises by approximately 11 ºC from morning to afternoon, while whitewashed walls rise 7.5 ºC maximum (**Fig. 4**).

TC of constantly shaded façades also increase from morning to afternoon, but more gently (from 2 to 7 ºC). Thermal behaviour of shaded granite and whitewashed walls is similar in the shade. Even if TC of wooden benches is higher during the early hours of the day, at the hottest hours, their temperature is lower than the one of granite benches (4º to 7 ºC less), reaching 47 ºC TC on granite and 43.1 ºC on wood. While granite benches still preserve part of the stored energy at night, the energy loss is faster on wooden seats, so, during the night, wooden benches remain practically at Ta. Noteworthy is the fact that TC of granite benches in the sun is 4.5 ºC to 15 ºC higher than in the shade. In wooden benches the difference on TC is of 5.5 ºC to 8 ºC. Shaded wooden benches remain at near-air temperature.

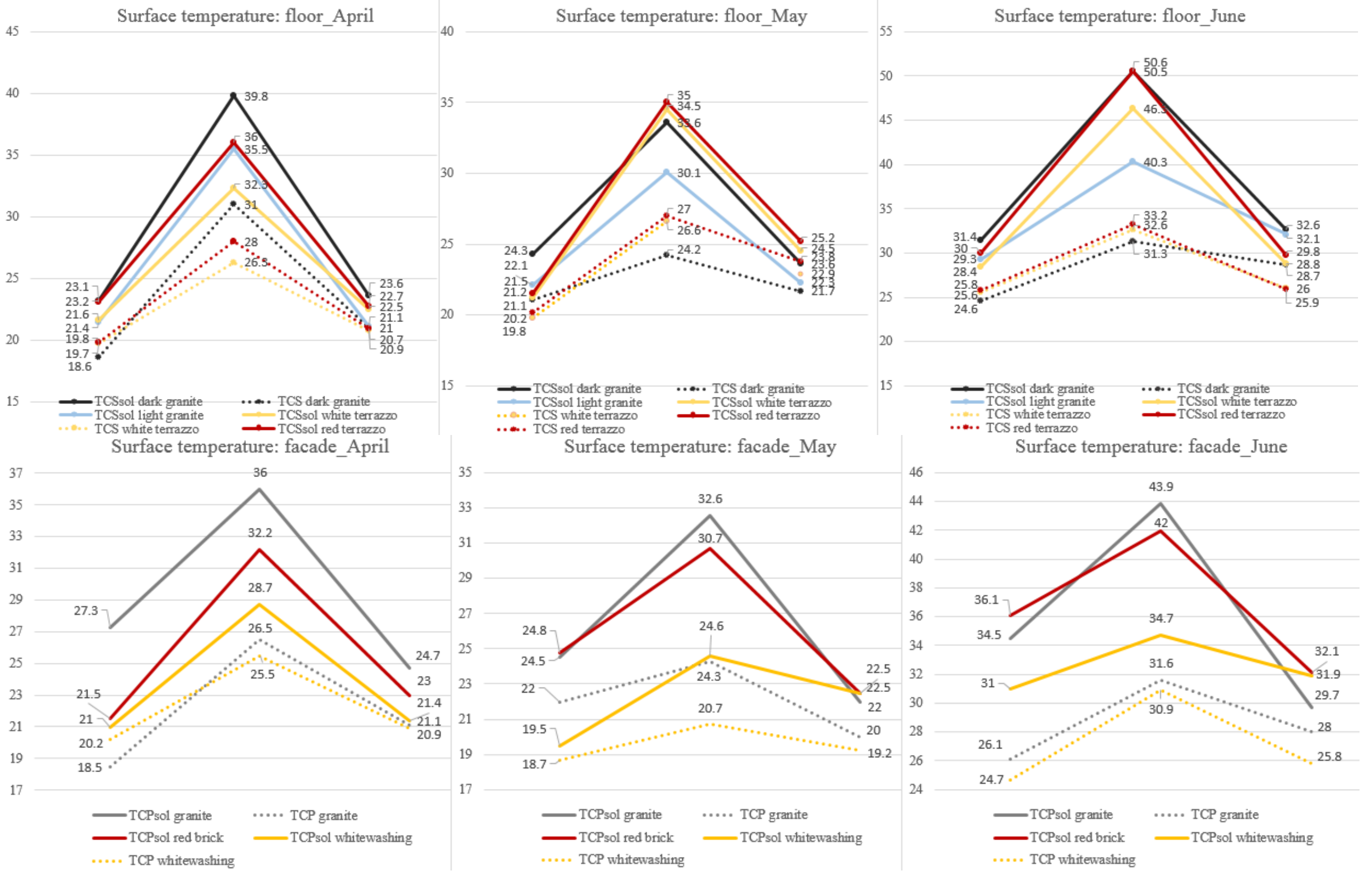

Fig. 4: Surface contact temperatures of paving and façades materials in the sun and in the shade (8 to 8.30 am, 4 to 4.30 pm, and 8.30 to 9 pm-UTC).

DISCUSSION ABOUT FIELD MEASUREMENTS: defining main parameters for a microclimate variety classification procedure

Summer in Madrid is extremely warm, even at night (30 ºC at 11 pm), and dry too (RH<30 %) during the day. Recorded Ta values are over the summer physiological equivalent temperature PET that people prefer in Madrid from 22 to 27 ºC, and it can lead to thermal dissatisfaction and heat stress (Fernández, Rasilla, Galán et al., 2008). PZ is a warmer square, with high energy storage capacity pavements (pervious pavements are just the 8%) and with an absence of shaded quality spaces to stay. However, PZ is a space that more easily loses the stored energy in its finishing materials, with lower Ta at night than 2dM. This may be due to its greater sky-view factor (SVF) (Oke, 1988) and greater wind speed. RH in 2dM in the morning is higher than in PZ, a square with more vegetation and many more mature trees, with more unpaved areas. However, in the afternoon and night, RH is practically the same in PZ, and even higher in the latter.

Ta reduction and RH increase in shaded spaces becomes evident, although the higher the outside temperature, the less effect it has. Materials' TC evolution is similar throughout the day both in the sun and in the shade, recording considerably lower TC in the shade. TC differences in same materials in the sun and in the shade are bigger in the afternoons and in June, reaching 17.5 ºC difference in red terrazzo. Shading is a very effective strategy to improve comfort at the warmest hours of the day.

During the daylight hours, when people use the most open spaces, finishing materials have a high TC. These spaces became even warmer places due to the radiant exchange that will take place, increasing near-surface Ta. In May, pavements and facades become heat sources for square users. Differences in the materials' thermal behaviour linked to their albedo, thermal inertia and density and shading have been identified. The albedo is a decisive property. Regarding granite, its TC is 3 to 10 ºC higher in the dark ones than in light ones. In addition, there is 0.5 to 4 ºC difference in red terrazzo comparing it to white one. As stated by manifold studies, paving materials with high albedo improve the urban thermal environment combined with a high SVF, reducing their TC, the near-surface Ta and the long-wave radiation emitted by the surfaces (Shooshtarian and Rajagopalan 2017), 2014; Kinouchi et al., 2003). Although the use of light-coloured surfaces does not always reduce the outdoor Ta, as it could happen on high albedo façades in urban spaces with low SVF (Al-hafiz, Musy and Hasan, 2017). On façades, those with a higher albedo also maintain lower TC. In June, the warmest month, the difference in thermal behaviour between terrazzo, less dense, and granite, denser, becomes noticeable. The latter's energy gain is slow, but they also cool down more slowly, while terrazzo paving gains energy more quickly, reaching lower TC than granite at night. Even if most of the materials lose gained energy at night, granite in June preserves part of the stored energy.

The hygro-thermal regulation capacity of water is local. It is only effective during daytime hours and at a distance of 0.5 to 1 m. The fountain is small and the water is not in motion.

In the measurements taken at locations surrounded by trees and with natural soil, a 4 % RH increase was registered in 2dM, although this parameter depends on the weather conditions (Kurbán et al. 2011). TC measurements have confirmed that pervious and natural pavements practically remain at Ta.

PROCEDURE FOR CLASSIFYING THE MICROCLIMATE VARIETY OF OPEN SPACES

A methodology is proposed to characterise open spaces' microclimate variety: open space's "micro-microclimates", the range of spaces with different thermal conditions. This aims to be a simple decision-making tool for stakeholders in urban design and open spaces refurbishment.

The proposal is based on the theory that well-being in urban open spaces is founded, in addition to physiological parameters, on the human parameter (Nikolopoulou, Baker and Steemers, 2001) and on the inhabitants' option to choose the urban microclimate that best adapts to them and their activities. The definition of thermal comfort has evolved from a purely quantitative perspective towards a qualitative approach (Shooshtarian, Rajagopalan and Sagoo, 2018). Unlike the quantitative indices, in adaptive models, comfort is based on the interaction between people and the environmental thermal conditions. Citizens react based on their physiological and psychological situation. Thus, people with more options to choose and adapt their medium will be prone to feeling comfortable (Fountain, Brager and De Dear, 1996; Brager, Paliaga and De Dear, 2004; Humphreys, 1981). Choosing options will improve and increase liveability, public space users and outdoor activities. Tsi

Microclimate variety identification and classification procedure's steps are as it follows:

First: Based on the simulations and measurements made, key urban design variables for thermal regulation (solar gain, heat storage and radiation) were defined for dry climates with cold winters and very hot summers. These variables have been already analysed in several research studies (Chatzidimitrioua and Yannas, 2016; Salata et al., 2015; Tsitoura, Tsoutsos and Michailidou, 2016; Sangkertadi and Syafriny, 2016):

(a) Shading: main condition to avoid solar energy gains and Ta increase.
(b) Paving materials: energy storage and radiation capacity.
(c) Existence of trees: shading element, non-energy radiating element and HR increase.

Second: Definition of continuously sunned and shaded areas. Shading is the main factor to gain energy. Two main areas are defined: warm areas (sunned, 5 and 4 in **Table 1**) and cool areas (shaded, 3, 2 and 1 in **Table 1**).

Third: Combination of first and second steps. Five zones have been distinguished. Thus, a preliminary map of microclimatic diversity over the period studied was created in which five zones with different microclimatic conditions are differentiated (**Table 1**):

a) Microclimate 1: very warm without shade or greenery, paved in energy accumulating materials.
b) Microclimate 2: warm without shade nor greenery, paved in light or permeable materials.
c) Microclimate 3: slightly cool space with shade, paved in energy accumulating materials.
d) Microclimate 4: cool space with shade and greenery, paved in light or permeable materials.
e) Microclimate 5: coolest space with shade and greenery, paved in light or permeable materials.

Fourth: Graphic representation of thermal zones (**Fig. 5**). For geometric simplicity, instead of isolines, a reticulated frame has been chosen. The frame scale must be adapted to the geometry of each space. It is noteworthy that, if this zoning were spread throughout the whole year, two main periods should be distinguished using the bioclimatic technique: period of the year when solar radiation is mainly needed to reach thermal comfort outdoors, and period when shading is presumably necessary.

Fifth: Identification of microclimate variety (**Fig. 6**). Microclimate variety of each one of the spaces is easily identifiable by placing the different "micro-microclimatic" areas. The greater variety of 2dM square becomes evident, offering several possibilities of location in the public space with different thermal nuances. This square offers citizens the possibility of selecting the area in the square where they feel comfortable.

Table 1. Microclimates' properties. Legend. X: property existing in each microclimate; (X): microclimate with one of the two properties; In grey color: No pedestrian areas.

Microclimates		Shade	Trees	Low energy storage pavement
Warm areas	🟥 5			
	🟨 4			X
Cool areas	🟦 3	X		
	🟦 2	X	(X)	(X)
	🟪 1	X	X	X

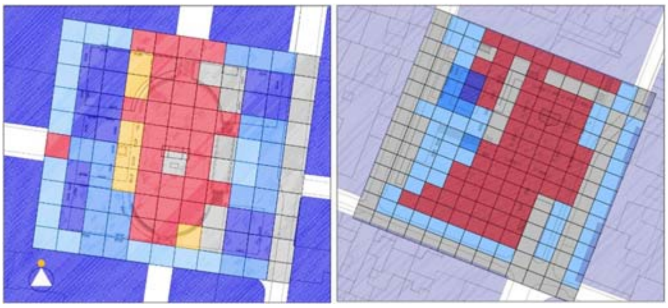

Fig. 5: Studied spaces' microclimate variety mapping.

In PZ square, although it is possible to have access to both sunny zones and shaded zones at the studied period, it lacks thermally different areas. 55 % of the sunned zones are very warm: very dense pavements and sun exposure throughout the whole day (50.5 ºC TC recorded). This is where the majority of the benches are located. There are few shaded zones and just for a few hours a day and there are practically no trees or non-energy storing pavements. This square offers users few possibilities of selecting the location they find most comfortable.

This methodology has been completed with the study of people's location in these open spaces, identifying activities they carry out and crossing these data with other urban design variables in addition to climatic variables. Due to its dimension, this study will be the subject of another publication.

CONCLUSIONS

This work establishes a methodology to characterise the microclimate variety of open spaces, in addition to analysing the thermal behaviour of finishing materials of two spaces of the historical centre of Madrid, using field measurements complemented with simulations. The study defines the capacity of materials and of shading in the creation of spaces with different climatic nuances.

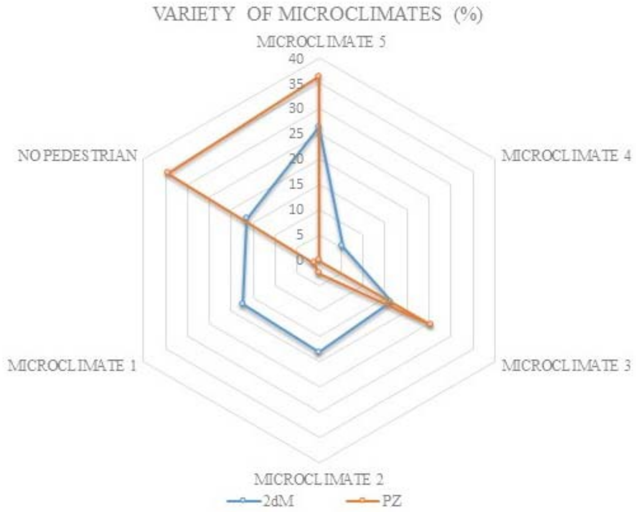

Fig. 6: Microclimate variety of 2dM and PZ squares (%).

An approach to urban design that contemplates climatic variables becomes essential, in order to design and locate pavements and resting spaces (Gaitani, Spanou, Saliari , 2011). The goal is the thermal comfort and the promotion of social relations in open spaces. Microclimate conditions of open spaces are difficult to generalise, lacking, in many cases, climate data at points close to the area of study (Rogora and Dessí, 2005). In bioclimatic and energy efficiency studies both at urban and building scale, average historical data are used[8] to establish the passive and active conditioning strategies. It is observed that the difference between field temperatures recorded and the historical Tm is even greater (Tm april: 11ºC, Tm may: 16ºC and Tm june: 20ºC) than those registered in the closest weather station. Thus, new studies on energy efficiency and thermal comfort are now focusing on including UHI in energy simulations (Santamouris, 2014; López et al., 2015; Bouyer, Inard and Musy, 2011). Furthermore, Tm of weather stations, which are used to work on the bioclimatic design, include the coldest hours of nights, when open public spaces are not practically in use.

Bearing these difficulties in mind, a procedure to discover and classify microclimate characteristics of the space is proposed considering just three factors. These are decisive in terms of thermal comfort and radiant exchange of the space with human body in dry Mediterranean Continental climate.

In open spaces, we are exposed to outdoor climate conditions. These are seasonal and variable, so parameters that are difficult to control are used in studies aimed at designing comfortable spaces (Shi et al., 2016). Furthermore, these spaces must be adapted to all kinds of people, with different perceptions of comfort, carrying out different activities, with different metabolic intensities. Thus, the objective of any urban designer wishing to create comfortable urban spaces should be to offer a space with varied microclimate situations. An urban space with high microclimate variety will allow a wide range of activities that citizens want or need to carry out throughout the whole year.

Conflict of interest none.

Notes

1. The aim is not to exactly define the solar gains, but to obtain approximate values to select the field measurement points.

2. Data taken from the National Agency of Meteorology, AEMET, for the measurement period of this study. Madrid Retiro Station. URL: https://opendata.aemet.es/centrodedescargas/productosAEMET? (2018-08-11).

3. Light grey granite (reflectance (R): 0.60) and dark grey granite (R: 0.25). Density (þ): 2500-2700 kg/m^3, water vapour diffusion coefficient (η) 10 000, specific

heat (cp) 1000J·kg−1·K−1, emissivity (ε) (20 ºC) 0.45, absorptivity (α) 0.45, thermal conductivity (λ) 3.5 W/Mk. Source: Spanish Technical Building Code. URL: https://itec.cat/cec/ (2018-07_01).

4. White (R: 0.80, α: 0.65) and red (R: 0.45, α: 0.85) terrazzo. Both with þ: 2000kg/m^3, cp: 1000J·kg−1·K−1, ε (0-200 ºC): 0.96, λ: 0.09W/m K. Source: Spanish Technical Building Code. URL: https://itec.cat/cec/ (2018-07_01).

5. Whitewashed: Þ: 1300 kg/m^3, R: 0.85, η: 10, cp: 1000 J·kg−1·K−1 y ε (24 ºC): 0.92, α: 0.26, λ: 0.53 W/m K. Source: Spanish Technical Building Code. URL: https://itec.cat/cec/ (2018-07_01).

6. Red brick: Þ: 2300kg/m^3, R: 0.35, η: 10, cp: 1000J·kg−1·K−1, ε (21 ºC): 0.93, α: 0.7, λ: 0.814W/m K. Source: Spanish Technical Building Code. URL: https://itec.cat/cec/ (2018-07-01).

7. Average density pine (500 kg/m^3), R: 0.29, η: 20, cp: 1600J·kg−1·K−1, ε (70 ºC): 0.94, α: 0.92, λ: 0.148 W/m K. Source: Spanish Technical Building Code. URL: https://itec.cat/cec/ (2018-07_01).

8. Climate files .MET of the Technical Building Code (URL: https://www.codigotecnico.org/index.php/menu-documentoscte/133-ct-documentos-cte/ahorro-de-energia.html) and Energy Plus Weather Data .EPW. URL: https://energyplus.net/weather (2018-08-11).

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