Evaluation of weather conditions in urban climate studies over different Madrid neighbourhoods: Influence of urban morphologies on the microclimate

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Abstract

Urban microscale data is crucial in the evaluation of a wide range of engineering applications. However, it is observed an outdated climate data files and an undetailed boundary conditions within the urban environment, triggering variations between real and simulated energy data. This fact is proved through the analysis of two accessible weather files (EPW and CTE) and an updated experimental climate datafile (EXP10). Then, there are characterized the albedo (α), the emissivity (ε), the sky view factor (SVF) and the Mean Radiant Temperature (MRT) for three representative urban structures, considered notable variables for the outdoor energy assessment.

The EXP10 data are warmer, drier and have intense and longer radiation than EPW and CTE files, showing an increase MRT values for all cases. Some MRT variations are also found between urban typologies. Dense-medium-rise areas with limited green-tree zones (DS_Usera) present a low-medium emissivity and SVF, being the MRT higher during the night. On the contrary, sprawl-high-rise areas with medium green-tree zones (OB_Cañorroto) have a high albedo SVF, graphing the lowest MRT during the night. Although tree crowed areas reduce the MRT along the day, they could increase these values during the night because of the possible low SVF in their canopy as it is shown in sprawl-low-rise areas with large green-tree zones (SH_Viso).

Keywords: climate change, boundary conditions, urban microclimate, urban typology, mean radiant temperature

1. Introduction

As a response to the growing urbanization, numerous neighbourhoods with different density and several building structures have been built around the cities. These neighbourhoods are characterized by a large number of low-rise to high-rise structures and autonomous buildings with different layouts/forms (Sharifi 2019), different geometries and public/private open spaces (Wang et al. 2016). The result of these changes in the physical characteristics of cities is an urban microclimate characterized by a set of twisted climatic conditions with multiple levels of humidity, temperature, and wind speed that prevails in an urban area (Jhaldiyal et al. 2018). It is generally accepted that urban microclimate conditions have major impacts on the variations of local weather variables (air temperature, wind flow, shortwave/longwave radiation etc.) (Javanroodi and Nik 2020). These facts impact on air pollution patterns (Castaldo et al. 2017), building’s energy performance (Soutullo et al. 2020; Sánchez et al. 2020), urban health (Linares, n.d.), thermal comfort (Lai et al. 2019), as well as the development of daily activities.

Climate change makes cities even more vulnerable to these urban microclimatic variations. In addition to the global rise of temperatures, it is expected extreme weather events more intense, frequent and long (IPCC, 2018). In an increasingly urbanized world, where most of the half of the population live in urban areas, it is crucial to define an accurate climate change adaptation plan to ensure the development of activities and health´s quality. According to the Agenda 2030, this framework must be based on sustainable principles, considering both humans and other living beings. However, some shortcomings seem to limit the development of resilient cities. A lack of updated climate files and an undetailed knowledge of the climate variation within the urban structures could cut down the effectiveness of frameworks designed to face the new climate scenarios.

To this end, this article proposes a methodology to quantify the incidence of macroscale climate conditions on

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urban structures by calculating different urban typologies through dynamic simulations. The main objectives proposed of this paper are: a) Quantify differences and climate trends for widely used climate data and an updated experimental climate data. b) Analyse different urban characteristics in the city and their influence in the urban microclimate. c) Study the diverse urban boundary conditions and their impact on the main microclimate variables.

2. From macroscale climate conditions to microscale urban climate

Urban structures modify the local climate conditions (macro level) within the city (micro level), changing the energy balances. This effect is known as urban microclimate and it is due to the substitution of the natural layer to buildings and paved surfaces. The urban microclimate variability can be assessed transforming the macroscale climate to urban microclimate through the local climate files, urban characteristics and their boundary conditions.

2.1. Climate files

The weather of a region is obtained from the treatment of the climatic variables registered by meteorological stations over long periods of time. There are multiple global climate classifications. Köppen-Geiger is one of the most known, however many of them only provide a general idea of the local climate but do not consider relevant factors for a specific location as the orography, green areas, mass of water, soil characteristics or the wind or insolation profiles. A common method to summarize the local weather conditions is the typical meteorological year (TMY), that must be based on long term weather variables records (at least 10 years), to ensure the natural climate cycles. Depending on the study, there are diverse methodologies to assess the TMY, varying the weight factor of the meteorological variables (Zarzalejo et al. 1995; Soutullo et al. 2020; 2017). Representative days or periods can be also useful to study the seasonal climate behaviour.

The urban or buildings energy simulation software, use the TMY files to feed their calculations. The EPW files are used by the Energy+ software or the MET files developed by the Spanish Building Code (CTE) for their standard simulation tool. Nonetheless, the use of these easily available files for the urban quantifications lead to high levels of uncertainties. These files are usually outdated despising the global warming. In addition, these files are commonly based on weather recording stations located out of the city, not considering the specific boundary conditions and the urban microclimate effect that modifies the local weather conditions in the city.

Updated climate data files from recent long-term experimental monitored campaigns should be considered integrating the climate change and its direct impact on our environment. Annual and seasonal averages of relevant meteorological variables should be assessed but also identify extreme weather events. Temperature and solar global radiation as well as relative humidity and wind are usually analysed.

2.2. Urban characteristics

Built environments present a varied range of buildings characteristics, materials properties or urban distributions, as a result of the evolution needs in the city´s growth. The urban aspects are linked to a specific period as the use of materials or constructive systems. Beyond this, flowering urban theories about how to understand the city or the socioeconomic conditions of the citizens had influence in the urban environment and its transformation. Examples of these facts are the role that have green or pedestrian areas of different neighbourhoods compared to the private vehicle, or the housing design for workers compared to higher-income population.

To gather the differences between urban conditions, it is used urban typologies classifications. They define the common parameters that group certain ways of designing and building. Through them, the global behaviour of an area could be estimated effectively. In addition, their top-down approach from an intermediate scale allows us to analyse common trends that are not generally considered in administrative divisions or at the building level.

Some urban classifications are developed based on urban indicators through the aerial image's analysis covering wide world´s areas. Corine Land Cover Classification (CLC), the Urban Atlas project or the Local Climate Zones (LCZ) (Stewart and Oke 2012) classify the areas in predefined categories, giving an urban pattern idea. On the other hand, more detailed urban classification methods are carried out specifically to a city or a region, considering the local urban conditions, codes, normative, culture or uses. The city of Madrid has different urban designation as the Regional Direction of the Spanish Cadastre (RDSC), the Statistical Institute of the Madrid Community (SIMC) or the General Urban Planning Plan (GUPP). Finally, World Urban Database and Access Portal Tools (WUDAP) try to combine both classification types over different approach levels.

2.3. Boundary conditions of urban environments

The boundary conditions are a key factor in the physical behaviour modifying its climate environment. Some of European roadmaps as the Strategic Energy Technology plan (SET-Plan, 2018), point out the necessity to assess these boundary conditions deeply in order to ensure an optimized integration of an energy transition framework.

Their role it is crucial in the meteorological variables as temperature, humidity, wind and radiation values. They depend on a combination of factors as the albedo (α) and emissivity (ε) that refer to the material characteristics, while the Sky View Factor (SVF) is related to the morphology conditions. The albedo depends on the reflection capacity of the material and it is related to the colour and surface characteristics. The emissivity is defined as the capacity of surface materials to emit the heat as thermal radiation. The proportion of visible sky above a certain observation point determines the Sky View Factor. In urban areas, these factors are the result of the human activity and must be controlled in order to not reach more extreme climates conditions in urban areas, optimizing the distribution of the city network. The influences of the most significant variables in the city are:

- *Soil:* The colour, composition, porosity, thermal inertia, etc., impact on the climatology of the area modifying reflected solar radiation, thermal gradient or air quality.
- *Water:* The presence of water may act as a temperature stabilizer through evaporative exchanges.
- *Vegetation:* Plants notably affects shading factors, thermal gradients, moisture content and air quality.
- *Wind circulation:* The speed and direction of wind is strongly influenced by the orography, the water masses, etc., modifying the sensation of thermal comfort.
- *Urban environment:* Buildings, infrastructures or human activity have a dominant influence on the climate conditions of the city. The modification of the urban climate conditions depends on numerous factors such as the construction materials (absorptivity or reflection), the presence of green areas (elements of shade and humidity), the height of the buildings (solar accessibility or air circulation) or the conditioning systems (heat pumps, air conditioners, etc).

2.4. Microclimatic conditions, variability within the urban structure

The most influential meteorological variables on the urban microclimate are temperature and solar radiation. These variables regulate most of the urban energy exchanges, so their intensity, variability or hourly distribution are determining factors, influenced by the boundary conditions (Shahrestani et al. 2015). They are the main factors of the widely studied Urban Heat Island (UHI), that implies a global rise of temperatures in the built environment as a consequence of human influence (Oke T.R. 1982). However, other meteorological variables should be considered. The air humidity determines the use of different passive thermal conditioning strategies as evaporative and dehumidification cooling. The correct consideration of the preferential wind flows and the adequate distributions of urban structures are crucial to define urban areas with optimum thermal comfort and air quality.

Regarding the thermal comfort and consequently the urban health and the development of daily activities, other variables as the Mean Radian Temperature (MRT) represent a determinant factor. It is defined as the uniform temperature of an imaginary room in which the radiant heat transfer from the human body is equal to that carried out in a non-uniform real room. MRT depends on the heat emitted by the surrounding materials and it cannot be obtained directly. The MRT´s calculation is based on measures as the globe temperature (Tg) or six directions method (Marino, Nucara, and Polimeni 2018). However, the complex and limiting process, lead to the use of energy simulation tools as Envimet, Trnsys, Star CCM+ or SkyHelios, commonly used for the energy simulation.

3. Case of study: city of Madrid

The methodology proposed starts with the creation of a climate file, adapted to the current climate trends through a long-term experimental campaign (EPX10). The EXP10 data and two representative climate files (EPW and CTE) have been used to analyse the climate trends. Secondly, representative urban morphologies have been selected, studying their morphological and material properties. Thirdly, the interactions between urban morphology characteristics and weather variables of experimental and representative climate files have been assessed. Variations of albedo (α), emissivity (ε), Sky View Factor (SVF) and Mean Radian Temperature (MRT) at the urban microscale are studied for these urban morphologies by dynamic simulations. Finally, the city of Madrid is selected as a case of study. It is chosen by its urban complexity and its morphological and material diversity. In addition, Madrid is the biggest city in Spain, with diverse activities and socioeconomic profiles.

3.1. Quantifying the climatic trends

Madrid is characterized by temperate climate with dry hot summers and mild cool winters. It is classified as hot-summer Mediterranean climate in Köppen-Geiger classification; however as it is explained in section 2.1 this is a regional global classification that doesn't consider local deviations due to urban factors.

To quantify the urban energy performance representative meteorological years are needed. Two free available representative meteorological years of Madrid are used in this study: CTE and EPW. The CTE climate data is provided by the Spanish Ministry to obtain the certification of the energy performance of buildings (CTE 2015). The representative file EPW is provided by the Energy Plus website (EnergyPlus n.d.) and created by ASHRAE for energy calculations using the international weather format IWEC.

These files do not represent the climate change, so long-time series of meteorological measurements of the last years are recommended. To quantify the climate trends registered in Madrid during the last decade, an experimental campaign of 10 years (EXP10) has been carried out by CIEMAT (Sánchez et al. 2020)

3.1.1. Climate file comparisons (representative vs experimental climate files)

The comparison between the long-term experimental climatic file (EXP10) and the representative meteorological years (EPW and CTE), gives an idea of how the climate patterns have changed during the last years due to climate change. To this end, climate biases from using different data files have been done. Based on hourly data, it has been compared the mean values of the main meteorological variables through the annual mean values and the annual means of the standard deviations. Table 1 highlights the differences and similarities between them.

Both the mean temperature and solar radiation increase in the experimental database, as opposed to the observed decrease in the relative humidity. Therefore, an increasing trend has been observed over time towards warmer and drier climates. On the contrary, the value of the standard deviation remains similar in all the databases. In conclusion, historical-synthetic weather data show major differences from current real climate scenario that can be explained as a result of global climate warming effects.

Table 1. Main meteorological variables (annual mean and annual mean standard deviation values) for EPW, CTE and EXP

Climate data	EPW	CTE	EXP-10
Annual air temperature (Ta) + standard deviation (°C)	14.3 ± 8.6	13.6 ± 8.6	15.8 ± 8.2
Annual relative humidity (RH) + standard deviation (%)	62 ± 21.5	58 ± 16.6	51 ± 18.2
Annual global solar radiation (G) + standard deviation (kWh/m^2)	185 ± 235	178 ± 262	188± 256

The Box and Whisker methodology (Petruccelli et al. 1999) has been applied to identify trends, variances, symmetry and extreme values of the three climate files studied. A box plot has been created and represented in Figure 1 to evaluate the annual distribution of temperature (left side), relative humidity (middle side) and global solar radiation (right side). In these graphs the brown bars represent the EPW file, the red bars represent the CTE file and the blue bars represent the EXP10 file. The bottom and the top of this box represent the 25 and 75 percentiles respectively while the middle line represents the median value of the data series and the cross indicates the mean values. The extreme values have been calculated considering the inter-quartile range (IQR), the absolute difference between the 25 and 75 percentiles. Outliers values (out of the 1,5*IQR) are not represented.

Attending to the temperature values similar IQR is obtained for the CTE and EPW files (between 7°-20°C) being slightly higher for the EXP10 file (9°-22°C). The extreme values both upper and lower are higher for EPW and CTE, however, in the EXP10 database the median temperature is more centred with respect to the 1st and 3rd quartiles and the mean temperature is higher for EXP10 file (15.8°C) than EPW and CTE (14.3°C and 13.6°C).

The median relative humidity registered for the EXP10 file (51%) is lower than the other two files (62-58%). The IQR values for the EXP10 files are the lowest, reaching minimum extreme values. EPW files present the highest variability as is shown in its IQR and extreme values.

The annual median global solar radiation varies from 177W/m^2 (CTE file) to 188 W/m^2 (EXP10 file). The IQR and extreme values are slightly higher for the EXP10 files.

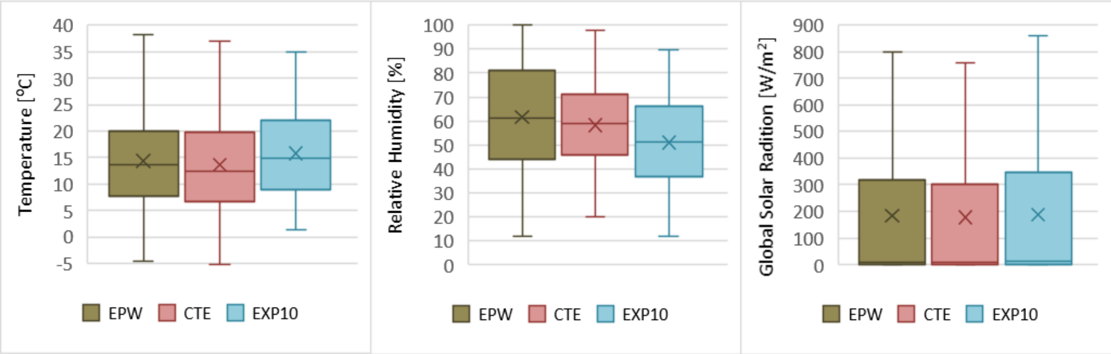

Figure 1. Annual statistical behaviour of temperature, relative humidity and solar global radiation registered by the representative file EPW (brown bars), representative file CTE (red bars) and experimental file EPX10 (blue bars).

3.1.2. Summer and winter representative days

The hourly climatic evolution throughout a representative day of a specific period allows identifying the quantity of the extreme values and when they take place. One winter and one summer typical days are calculated using the Hall methodology. This method calculates the absolute difference between daily and seasonal variables with the Filkenstein-Schafer statistics. The most representative day is selected as the minimal value of the weighted sum. The microclimatic variables have been weighted by the PASCOOL method (Soutullo et al. 2017). The summer representative day (SRD) and winter representative day (WRD) of each climate data file is shown in Table 2.

Table 2. Seasonal typical days obtained for the three climate files studied

Climate files	EXP10	EPW	CTE
Summer Representative Day (SRD)	25 July	15 August	5 August
Winter Representative Day (WRD)	29 January	3 February	30 December

Figure 2 graphs the summer and winter air temperature (Ta), relative humidity (RH) and global solar radiation (G) for the EPW (brown lines), CTE (red lines) and EXP10 files (blue lines).

The EXP10 climate file presents higher temperatures for the SRD and WRD. This fact it is especially significant for the SRD, where the EXP10 file has approximately 5°C above the EPW and CTE along the day. Generally, the SRD values are between 15°C to 35 °C. For the WRD the values of air temperature for the EXP10 are similar to the CTE and something lower for EPW. For the WRD the lowest Ta value is -3°C and the highest value is 11°C.

On the contrary, the humidity records for the EPX10 climate data is approximately 20% lower than EPW for the SRD, with values from 76-26 % for all climate files. The EXP10 data file for the WRD is slightly higher than the CTE climate file, but lower than the EPW data. The humidity variations range from 55-95% for the WRD.

Although the global solar radiation values are very similar for all climate data, the EXP10 file reaches slightly lower maximum values for the SRD. The maximum global solar incidence values are between 800 to 900 kW/m^2, while for the WRD the maximum values range from 300 to 400 kW/m^2.

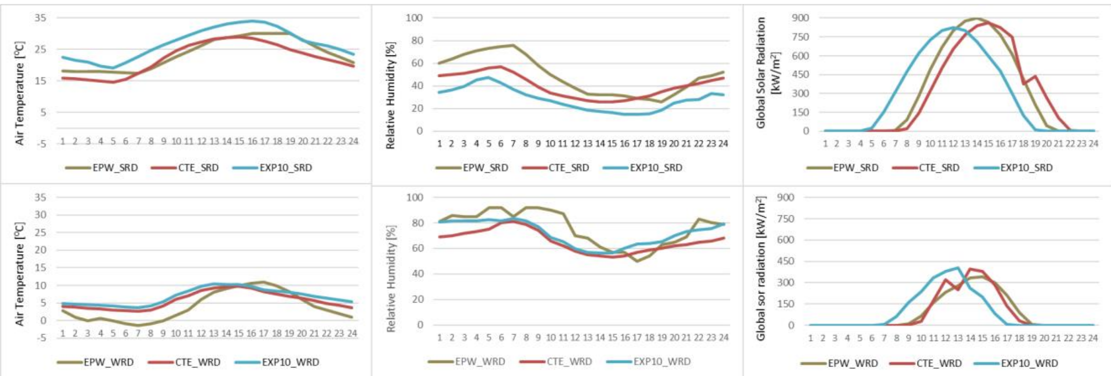

Figure 2. Meteorological values (Ta, RH and G) for summer and winter representative days for EPW, CTE and EXP10 files

All the graphs present small temporal deviations. This is due to the recording method and the generation of the representative meteorological year. CTE and EXP10 files are in solar data, while EPW data is in local time without considering daylight saving time. Also, the CTE records include an offset according to the equation of time.

3.1.3. Climate trends

To quantify the variability of the weather registered in Madrid during the last decade, climate indices have been calculated annually and seasonally for the CTE, EPW and EXP10 databases (Table 3). These indices have been provided by the European Climate Assessment & Dataset (ECA&D project).

The annual climate indexes are focused on the evaluation of the heat and cold trends. Generally, is found an increase of warm scenarios for the EXP10 climate data comparing to the EPW and CTE files, with higher maximum and minimum temperatures (SU and TR index). EPW is characterized by the highest temperature variability as it is graphed before (Figure 1). On the other hand, the seasonal indices are considered for the sunshine, humidity and wind tendencies. The sum of daily hours (SS) is the highest for the EXP10 file for summer and winter representative days and no significant differences exist between EPW and CTE climate files. The mean daily humidity (RH) is lowest in the SRD for the EXP10 database in summer, but the RH index is medium for the winter season. Finally, the FG index, associated to the mean wind velocity, present extreme values for the EPW and the CTE climate files, while the EXP10 data file has medium values for the summer and winter season.

Table 3. Annual and daily climate indices obtained for the EPW, CTE and EXP10 climate files.

Index type	Annual Climate Index. Definition		EPW		CTE		EXP10	
HEAT	ETR	Extreme temperature range considering daily maximum and minimum temperatures	45		42		33	
	SU	Number of days with daily maximum temperature above 25 °C	111		100		129	
	TR	Number of days with daily minimum temperature above 20 °C	8		19		29	
COLD	FD	Number of days with daily minimum temperature below 0 °C	0		2		0	
Index type	**Seasonal Climate Index. Definition**		**EPW**		**CTE**		**EXP10**	
			SRD	**WRD**	**SRD**	**WRD**	**SRD**	**WRD**
SUNSHINE	SS	Sum of daily sunshine duration in hours	15	11	15	10	19	14
HUMIDITY	RH	Mean daily relative humidity	49	76	40	66	28	72
WIND	FG	Mean daily wind strength	2,4	0,4	1,1	2,4	1,6	1,5

3.2. Urban properties of the representative neighbourhoods

In order to quantify differences between the urban typologies and their boundary conditions for a further urban microclimatic study, three representative neighbourhoods have been analysed. through the Statistical Institute of the Community of Madrid (SICM) classification. The SICM has been selected to be the most updated and tailored for this study. It revels the urban patterns according to Madrid´s urban evolution by 8 residential urban typologies. The three selected neighbourhoods are Usera, Cañorroto and El Viso, that belongs respectively to Developed settlements (DS), Open blocks (OB) and Single/semi-detached house (SH). They have been chosen because of their significant differences in their urban patterns and their representativeness within the city.

The Figure 3 shows these significant differences between DS_Usera (blue), OB_Cañorroto (green) and SH_El Viso (orange) through the urban distributions (left), urban materials (center) and building density and high (right).

The DS_Usera neighbourhood is characterized by having most of its public space destined to roads (30%) and the residential space for built areas (62%). Consequently, the main materials found in DS_Usera are asphalt and plaster. This area has a high density (about 3500 residential buildings/km^2) with a mean height of 9 m.

The public space (no residential) of the OB_Cañorroto neighbourhood is equally divided between roads and green areas (26 and 27 % respectively) while the private zones (residential) are occupied mainly by pavement (26%) and then by building area (16%). These facts mean that the material distribution in this urban typology is balanced between asphalt, concrete and grass; plaster surfaces are slightly lower. The building density is low (about 1500 residential buildings/km^2), however the buildings are taller (mean high of 12 m).

The no residential areas for the SH_Viso zone are employed mostly for roads in the (30%). The residential surfaces are occupied mainly by gardens, the printed building area and less notably by pavements (29, 26 and 8% respectively). The material surfaces are mostly grass, asphalt and plaster, being less representative the concreate. The quantity of buildings per surface are low (1700 residential buildings/km^2) with a low mean height (9 m).

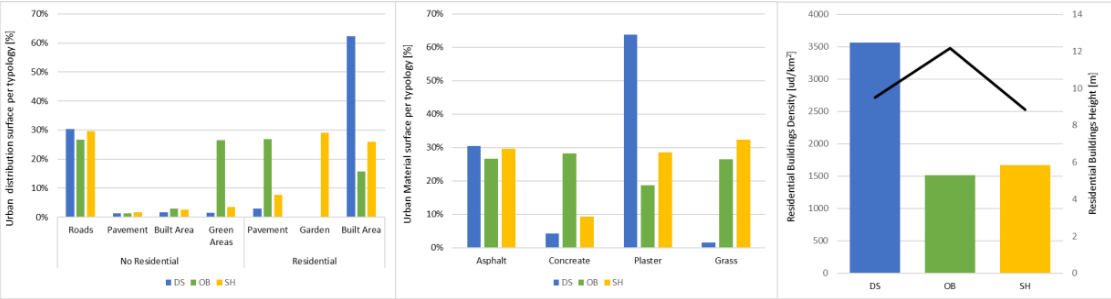

Figure 3. Mean urban characteristics for DS_Usera (blue columns), OB_Cañorroto (green columns) and SH_El Viso (orange columns). Urban distributions (left), urban materials (center) and building density and high (right).

For a better understanding of the urban typologies, their spatial distribution is represented in the Figure 4. It shows the diversity within neighbourhoods for the urban materials (1st row) building high and trees (2nd row) and urban perspective (3rd row). As it is described before DS_Usera is based on compacted-medium rise buildings with limited green and tree areas. OB_Cañorroto is defined by sprawl-high rise buildings with large public green areas and medium tree quantity. SH_Viso is identified by sprawl-low rise building with large private green and tree areas.

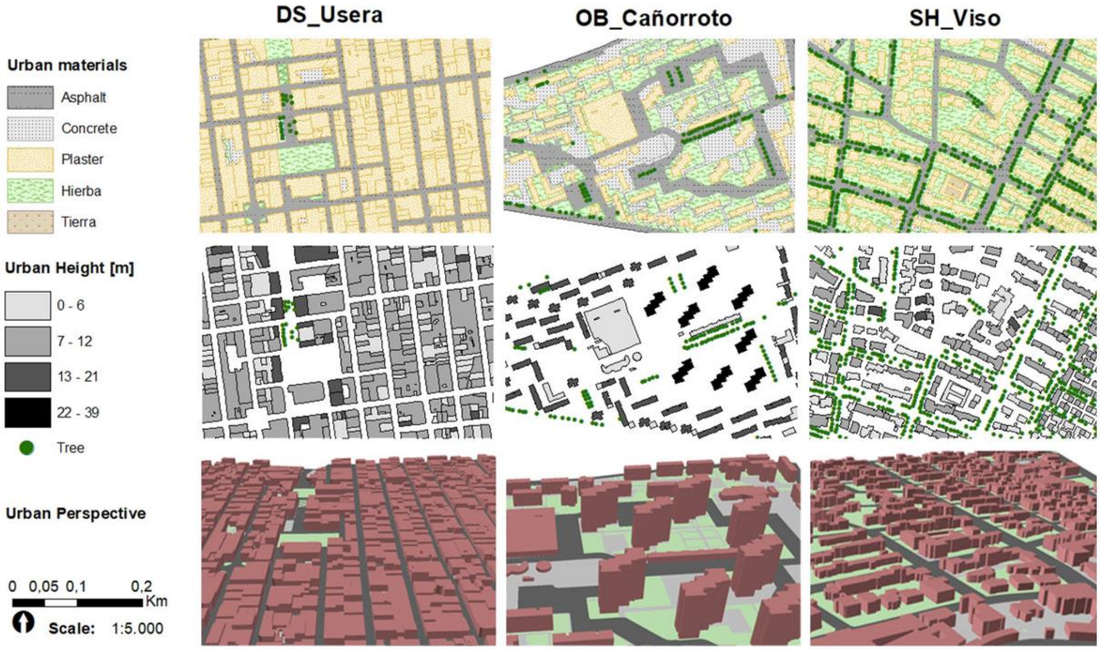

Figure 4. Spatial distribution of the urban characteristics for DS_Usera (left), OB_Cañorroto (center) and SH_El Viso (right). Urban materials (1st row) building high and trees (2nd row) and urban perspective (3rd row).

3.3. Simulation of boundary conditions and microclimate variables

The deep knowledge of the boundary conditions and the urban microclimate behaviour of the representative urban typologies are enabled through the SkyHelios Pro software (Fröhlich and Matzarakis 2018). It is a dynamic simulation program focused on the urban climate study that allows the calculation and visualization of continuous results for each point of a complex area. As each urban typology is gathered by their common urban morphologies and material patterns, they should have similar boundary conditions and urban climate behaviour.

The program has been fed in each studied neighbourhood by a) Hourly urban meteorological variables Ta, RH, Wv and G for the EPW, CTE and EXP10 climate files. b) Urban morphology through 3D representation and its material properties and trees (Table 4) through a Geographic Information System (GIS). Each urban model contains a 5 x 5 m calculation grid at the height of 1.1 m for each representative location to assess the variations during 24 hours for a summer and winter typical day. The grid´s pixels indicates the mean values for the 5 x 5 m area, being the total calculated points 25872 for DS_Usera, 7254 for OB_Cañorroto and 14536 for SH_El Viso.

Table 4. Material properties for the urban simulation

Material	Asphalt	Concrete	Plaster	Grass	Tree
Albedo	0.13	0.23	0.30	0.23	0.20
Emissivity	0.95	0.80	0.92	0.93	0.98
Transparency	1.00	1.00	1.00	1.00	0.90

3.3.1. Boundary conditions of the representative urban typologies

As it is shown in the Figure 5, the boundary conditions are assessed by the albedo (α), the emissivity (ε) and the sky view factor (SVF) for the representative urban typologies. The figure´s rows represent the spatial distribution of the albedo, the emissivity and the sky view factor values for the representative neighbourhoods (in columns). On the right side it is graphed the mean (strong colour) and the standard deviation (light colour). All the values are calculated for outdoor areas, not considering the buildings zones.

The Developed Settlements (DS_Usera) typology presents medium values of albedo (0.304 ± 0.003), low emissivity (0.923 ± 0.003) and a low-medium sky view factor (0.458 ± 0.162). This numbers are related to a high presence of buildings (plaster) and a lack of green areas and trees. The SVF values are explained by the relation between the width of the street and the buildings height. Slightly morphological and material variations are found, reflected in the low standard deviation for all studied variables.

The Open blocks (OB_Cañorroto) neighbourhood has high values of albedo (0.305 ± 0.006), medium emissivity (0.926 ± 0.007) and high sky view factor (0.566 ± 0.1654). The equal materials distributions can be associated to the no significant albedo and emissivity properties and standard deviation, that only change in the center of the spatial representation due to the tree's presence. The open spaces between buildings rise the SVF.

The Single-semidetached Houses (SH_Viso) have a low albedo (0.301 ± 0.007), high emissivity (0.936 ± 0.012) and a medium sky view factor (0.497 ± 0.168). The high presence of grass and tress is linked to this albedo and emissivity. The mix of tree and no tree areas trigger a higher values variability (standard deviation). Although the relationship between high buildings and width street is low, the street trees blocks the sky visibility (SVF)

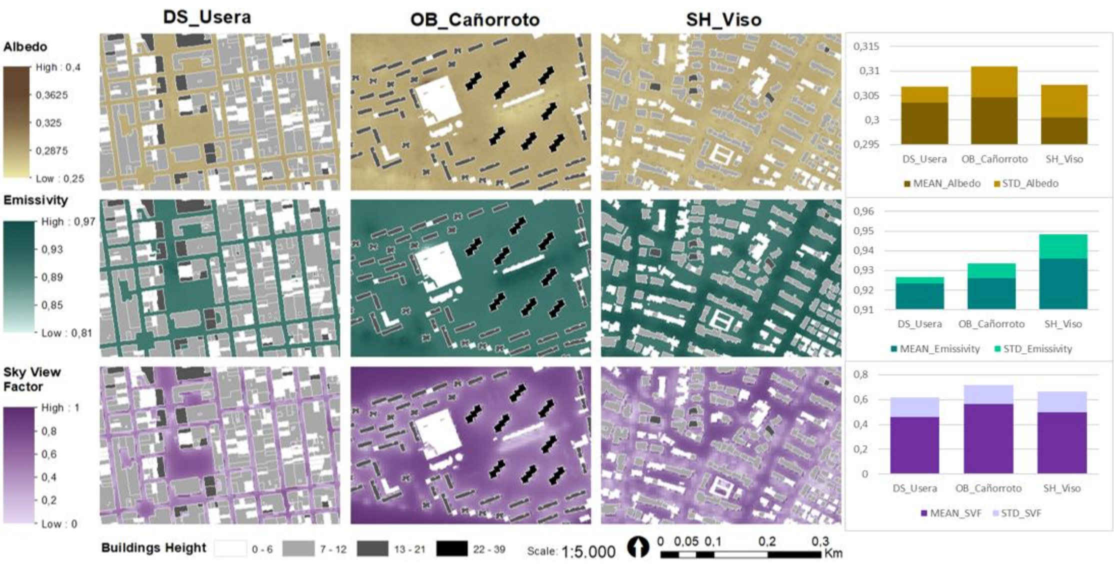

Figure 5. Spatial distribution mean and standard deviation of the boundary conditions for DS_Usera (left), OB_Cañorroto (center) and SH_El Viso (right). Albedo (1st row), emissivity (2nd row) and sky view factor (3rd row).

3.3.2. Microclimatic variables, Mean Radiant Temperature (MRT) of representative urban typologies

The behaviour of the Mean Radiant Temperature (MRT) within the urban structures is selected as a relevant microclimate variable because it is crucial in the thermal urban comfort evaluation. The hourly MRT is simulated for the whole representative typologies and the different climate data for the SRD and the WRD. The Figure 6 represents the SRD and WRD hourly MRT for the climate files EPW (stripped line), CTE (dotted line) and EXP10 (simple line) separately for each urban typology. The hourly TMR values refer to the hourly mean of TMR for the whole neighbourhood´s outdoor areas, not considering the buildings areas.

For all urban typologies the MRT values present a high variability between day and night for both SRD and WRD, being even more significant in summer (higher than 50 ºC). The records for the SRD go from 8.6 to 13.3 ºC during the night (no solar radiation) but raising to the highest values about 14:00 pm (local hour) with values from 56.20 to 62.35 ºC. In winter, similar behaviour is found but lower values are obtained. The TMR values for the WRD on the night range from -10.14 to -2.36 ºC; in the afternoon are achieved records from 22.49 to 31.20 ºC.

Relevant differences are found for the experimental climate data (EXP10) being for almost all urban typologies higher than the available TMY data (EPW and CTE). This significant pattern is more relevant for the SRD with upper approximated higher values of 4 to 6 ºC throughout the day.

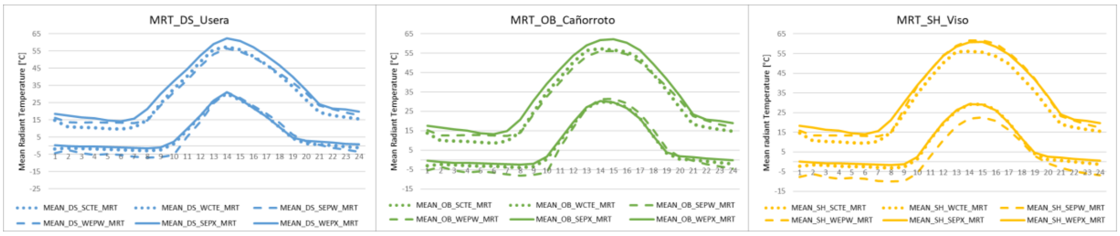

Figure 6. Hourly MRT for EWP, CTE and EXP10 climate data for DS_Usera (left), OB_Cañorroto (center) and SH_Viso (right)

With the aim of quantifying the differences between urban typologies, it is represented in the Figure 7.a the hourly MRT values for the SRD and WRD for the experimental climate data (EXP10). The widely range of MRT during the night and day, difficult the comparison between urban typologies. In that sense, it is graphed for the conducted values of the EXP10 climate data the gradient between the mean hourly MRT for all urban typologies within a representative day and the simulated hourly MRT for each urban typology. The Figure 7.b represents the ΔMRT values for the SRD (upper) and WRD (bottom).

For both SRD and WRD it is observed during the night high values of MRT for DS_Usera, followed by SH_Viso and OB_Cañorroto. During the day these records are inverted being lower for Developed Settlements (DS) and higher for Open Blocks (OB) and Single/semidetached houses (SH), except the central hours of the day. At this time of the day, the only shadowed areas are found under the tree canopy due to the vertical solar radiation. This fact shows the highest MRT values for DS zones followed by OB and SH neighbourhoods.

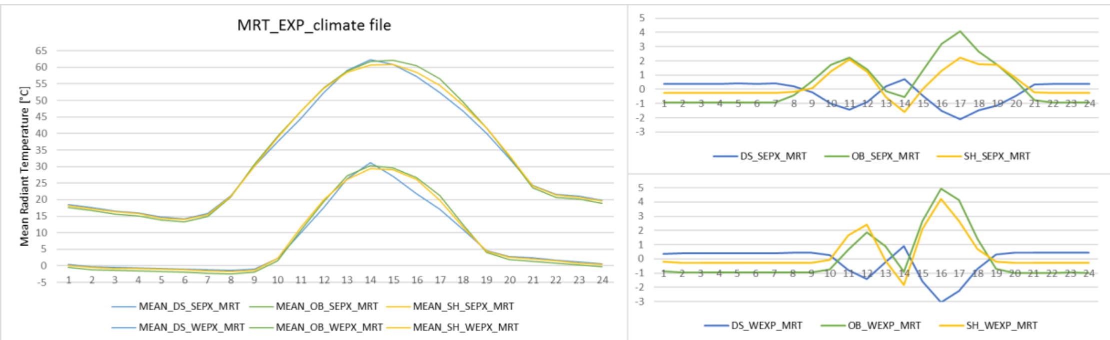

Figure 7. MRT associated values for EXP10 climate data for DS_Usera, OB_Cañorroto and SH_Viso. a) Hourly MRT values for SRD and WRD. b) MRT gradient for SRD (upper) and WRD (bottom)

Finally, a spatial representation of the MRT for the representative typologies is developed in order to study the variability within the urban structure. Using the SRD and WRD of the EXP10 climate file, Figure 8 represents a daily MRT behaviour for DS_Usera, OB_Cañorroto and SH_Viso at different hours. These daytimes belong to the night, hours after the sunrise, central day hours and hours before the sunset.

The spatial image of the Figure 8 shows the influence of the solar radiation in MRT values because of the urban morphologies and materials. Although the intensity of the MRT is higher and longer for the SRD both SRD and WRD behaviours are analogous. During the night the MRT values are the lowest and similar for all the zones, only a slightly higher records are found in below the tree surfaces. In the first hours of the day (8:00 - 10:00) the sun radiation start introducing in the urban structure. At that point, the cool areas found during the nigh are still cold, but a flip behaviour starts warming rising up the TMR values. The increase velocity of the TMR depends on the capacity of sun rays to penetrate in the city (no shadow areas and a high value of SVF foster this process), the albedo of surfaces (low albedos foster the process) and the emissivity of materials (low emissivity foster this process). In the central hours of the day (14:00) most of surfaces achieve the highest MRT values, only reduced by the trees or building tiny shadow areas. Low sky view factors, low albedos, and low emissivities increase the TMR in the noon time. Finally, during the sunset (17:00 - 19:00) the TMR records become to decline. At this moment surfaces with a high shadow level, high sky view factor, high albedo and high emissivity carry out this process faster and having the lowest TMR records during the night.

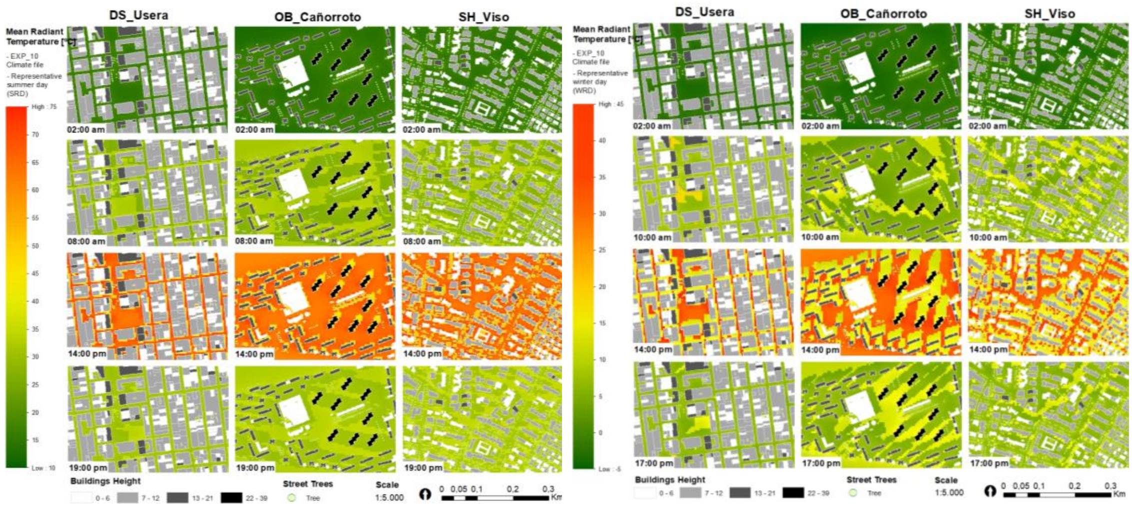

Figure 8. Spatial distribution of the MRT for the EXP10 data file for DS_Usera, OB_Cañorroto and SH_Viso. Daily behaviour for the SRD at 2.00, 8:00, 14:00 and 19:00 (left). Daily behaviour for the WRD at 2:00, 10:00, 14:00 and 17:00 (right)

4. Conclusions

This paper presents an approach to transform the macroscale climate conditions to microscale urban climate in order to aboard the warming and drier scenarios in cities due to the climate change and the urban microclimate effects. The city of Madrid is selected as a case of study, because of its morphologies and materials diversity.

To study the climate change effect in the city an updated experimental climate data file based on 10 years records data (EXP10) have been compared with two free available and representative climate files widely used (EPW and CTE) through different methodologies for the main meteorological variables. In addition, to obtain a better seasonal study the summer and winter representative days (SRD and WRD) have been calculated for all data files and the climate trends are studied by different climate indices. For all cases, the EXP10 data file shows approximately 2ºC warmer, a 10 % dryer values and a higher and longer solar radiation than the representative climate files (EPW and CTE). This comparison evidence the climate change tendencies and an urgent need to update the climate files used worldwide by simulation software (Energy+ is fed by EPW files) or normative applications (Spanish energy certification tools used by CTE files).

Then, the urban microclimate effect has been evaluated though the simulation of the boundary conditions and microclimatic variables by the SkyHelios Pro software for the previous climate data and different structures within the city. Three urban structures associated to prototype neighbourhoods have been selected by considering the most significant differences between urban structures and their relevant representativeness in the urban context. The selected urban typologies are: a) Developed Settlements (DS_Usera), dense-medium-rise areas with limited green or tree zones. b) Open blocks (OB_Cañorroto), sprawl-high-rise areas with public green zones and a medium ratio of trees. c) Single/semidetached Houses (SH_Viso), sprawl-low-rise areas with mainly private large green or tree zones. For all typologies, the roads (asphalt) represent between a third and a quarter of the total area.

The boundary conditions depend on the built environment characteristics. Because of this, the urban morphology and materials are assessed. The distribution of the buildings and trees are related to the sky view factor (SVF). Compacted and tree crowded areas have a lower value than sprawl and limit tree areas. The most significance material variations seem to belong to the green surfaces and more specifically to the tree area, characterized by low albedo (α) and high emissivity (ε). According to these properties the urban typologies present: a) DS_usera: SVF= low-medium, α=medium and ε =low. b) OB_Cañorroto: SVF=high, α=high and ε =medium. c) SH_Viso: SVF=medium, α=low and ε =high.

The influence of the boundary conditions in the microclimatic variables is proved by the Mean Radiant Temperature (MRT). The hourly MRT values have been generated for all climate data bases and urban typologies in the SRD and WRD. Low MRT values are graphed when there is no sunshine presence and they rise up to the highest values in the central hours of the day, when the solar radiation is maximum. A high MRT variability is found for SRD and WRD with differences between 40-50ºC during the night and day. The experimental data file (EXP10) has the highest records in all cases, being even more intense in summer with 4 - 6 ºC higher that EPW and CTE data, showing the impact of the climate change in energy simulations.

Regarding the hourly the TMR values between urban typologies, slightly differences are shown meanly during the night for summer and winter time. The DS_Usera TMR graphs a modest upper value throughout the night, followed by the SH_Viso records and the lowest values are for the OB_Cañorroto typology. This effect is associated to a low emissivity of the DS_Usera materials and a medium value of SVF (dense-medium-rise areas with limited green or tree zones), fostering that the absorbed heat during the day is emitted along the night finding some traps in this process because the urban structure. During the day this observed behaviour is thinly flipped, for the DS_Usera area, because of the structure shadows, except in the central hours, where only the tree shadows reduce the MRT. On the contrary, OB_Cañorroto due to their high albedo and medium emissivity materials and a high SVF value, present the lowest values during the night (sprawl-high-rise areas with public green zones and a medium ratio of trees). It should to be highlighted that although tree areas reduce the MRT values during the day because of their shadow and high emissivity, they also reduce notably the SVF, concentrating the heat in their canopy and increasing the MRT during the night, as it is occurred in the SH_Viso area. MRT differences could be even more notably if the neighbourhoods were simulated with real meteorological variables, instead of having a single climate data file for all typologies.

Suitable climate data considering the climate change and the boundary conditions and their influence in the microclimate variations within the city, should be recognize for further analysis. An updated and realistic microclimate behaviour will be decisive for future resilient strategies in urban environments fostering the habitability and wellbeing in public outdoor spaces, especially in most vulnerable neighbourhoods.

5. References

Castaldo, Veronica Lucia, Anna Laura Pisello, Ilaria Pigliautile, Cristina Piselli, and Franco Cotana. 2017. “Microclimate and Air Quality Investigation in Historic Hilly Urban Areas: Experimental and Numerical Investigation in Central Italy.” *Sustainable Cities and Society* 33 (September 2016): 27–44. https://doi.org/10.1016/j.scs.2017.05.017.

CTE. 2015. “Índice Objeto Clima de Referencia Climas de Referencia En Soporte Informático (MET).”

ECA&D “European Climate Assessment & Dataset.” n.d. Accessed May 5, 2020. https://www.ecad.eu/.

EnergyPlus. n.d. “Weather Data Sources | EnergyPlus.” Accessed August 26, 2020. https://energyplus.net/weather/sources.

Fröhlich, D., and Andreas Matzarakis. 2018. “SkyHelios - A Model for the Rapid Calculation of Spatially Resolved Micro Scale Climate Factors.” https://www.urbanclimate.net/skyhelios/.

IPCC 2018. “IPCC, 2018: Global Warming of 1.5°C.” https://www.ipcc.ch/sr15

Javanroodi, Kavan, and Vahid M. Nik. 2020. “Interactions between Extreme Climate and Urban Morphology:

Investigating the Evolution of Extreme Wind Speeds from Mesoscale to Microscale.” *Urban Climate* 31 (May 2019): 100544. https://doi.org/10.1016/j.uclim.2019.100544.

Jhaldiyal, Alok, Kshama Gupta, Prasun Kumar Gupta, Praveen Thakur, and Pramod Kumar. 2018. “Urban Morphology Extractor: A Spatial Tool for Characterizing Urban Morphology.” *Urban Climate* 24 (July 2017): 237–46. https://doi.org/10.1016/j.uclim.2018.04.003.

Lai, Dayi, Wenyu Liu, Tingting Gan, Kuixing Liu, and Qingyan Chen. 2019. “A Review of Mitigating Strategies to Improve the Thermal Environment and Thermal Comfort in Urban Outdoor Spaces.” *Science of the Total Environment* 661: 337–53. https://doi.org/10.1016/j.scitotenv.2019.01.062.

Linares, Cristina. n.d. “Cambio Climático y Salud: Impacto de Olas de Calor y de Frío.” https://www.miteco.gob.es/es/ceneam/grupos-de-trabajo-y-seminarios/respuestas-desde-la-educacion-y-la-comunicacion-al-cambio-climatico/2-cristina-linares-cc-salud_tcm30-486764.pdf.

Marino, Concettina, Antonino Nucara, and Erika Polimeni. 2018. “Outdoor Mean Radiant Temperature Estimation : Is the Black-Globe Thermometer Method a Feasible Course of Action ?,” no. February 2019. https://doi.org/10.1109/EEEIC.2018.8493714.

Oke T.R. 1982. “The Energetic Basis of the Urban Heat Island.” *Royal Meteorological Society* 108. https://rmets.onlinelibrary.wiley.com/doi/abs/10.1002/qj.49710845502.

Petruccelli, J.D., B. Nandram, and M. Chen. 1999. “Prentice Hall.” *Applied Statistics for Engineers and Scientists, Prentice Hall Nueva Jersey*.

Sánchez, M. N., S. Soutullo, R. Olmedo, D. Bravo, S. Castaño, and M. J. Jiménez. 2020. “An Experimental Methodology to Assess the Climate Impact on the Energy Performance of Buildings: A Ten-Year Evaluation in Temperate and Cold Desert Areas.” *Applied Energy* 264 (February): 114730. https://doi.org/10.1016/j.apenergy.2020.114730.

SET-Plan Working Group. 2018. “Europe to Become a Global Role Model in Integrated, Innovative Solutions for the Planning, Deployment, and Replication of Positive Energy Districts.” *SET-Plan Action No 3.2 Implementation Plan*, no. June: 1–72. https://setis.ec.europa.eu/system/files/setplan_smartcities_implementationplan.pdf.

Shahrestani, Mehdi, Runming Yao, Zhiwen Luo, Erdal Turkbeyler, and Hywel Davies. 2015. “A Field Study of Urban Microclimates in London.” *Renewable Energy* 73: 3–9. https://doi.org/10.1016/j.renene.2014.05.061.

Sharifi, Ayyoob. 2019. *Resilient Urban Forms: A Macro-Scale Analysis*. *Cities*. Vol. 85. https://doi.org/10.1016/j.cities.2018.11.023.

SICM “Statistical Institute of the Community of Madrid.” n.d. Nomecalles - Nomenclator y Callejero de La Comunidad de Madrid. Accessed August 26, 2020. https://www.madrid.org/nomecalles/.

Soutullo, S., E. Giancola, M. J. Jiménez, J. A. Ferrer, and M. N. Sánchez. 2020. “How Climate Trends Impact on the Thermal Performance of a Typical Residential Building in Madrid.” *Energies* 13 (1). https://doi.org/10.3390/en13010237.

Soutullo, S., M. N. Sánchez, R. Enríquez, M. J. Jimenez, and M. R. Heras. 2017. “Empirical Estimation of the Climatic Representativeness in Two Different Areas: Desert and Mediterranean Climates.” *Energy Procedia* 122: 829–34. https://doi.org/10.1016/j.egypro.2017.07.415.

Stewart, I. D., and T. R. Oke. 2012. “Local Climate Zones for Urban Temperature Studies.” *Bulletin of the American Meteorological Society* 93 (12): 1879–1900. https://doi.org/10.1175/BAMS-D-11-00019.1.

Wang, Zhi Hua, Xiaoxi Zhao, Jiachuan Yang, and Jiyun Song. 2016. “Cooling and Energy Saving Potentials of Shade Trees and Urban Lawns in a Desert City.” *Applied Energy* 161 (January): 437–44. https://doi.org/10.1016/j.apenergy.2015.10.047.

Zarzalejo, Luis, Felix Tellez, Elena Palomo del Barrio, and M R Heras. 1995. “Creation of Typical Meteorological Years (TMY) for Southern Spanish Cities.” In *International Symposium Passive Cooling of Buildings*.