Can urban design mitigate the UHI effect?

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ABSTRACT

The Land Surface Temperature (LST) plays a key role in the generation of the Urban Heat Island (UHI), representing a determining factor of the radiation of the surface and the exchange of energy and control the distribution of heat between the surface and the atmosphere. The composition of the land covers is one of the main factors that influence the LST. The literature have highlighted that the different types of land cover materials, their albedo and roughness, degree of impervious as well as the quality and quantity of vegetation, can have a significant impact on the generation of the UHI. The overall objective of the paper is to investigate if urban design, on a detail scale, can mitigate the Urban Heat Island. The question is if the morphology of public space, especially the form and zoning of green areas and open spaces, influence surface (LST) and air (LSAT) temperatures and therefore in the UHI. The working hypothesis is that the morphology of public space plays a key role to control UHI. Thus, an adequate design of open spaces can help to increase the resilience of cities to Climate Change (CC). To prove the hypothesis, two case studies were chosen. The case studies are two urban expansion areas of city of Sant Cugat del Vallès (in the metropolitan area of Barcelona), the first one, called Parc Central and the second one, Coll Favà. Both have similar characteristics, but with a clearly differentiated public space design; while in Parc Central built-up area is structured around the open space, in Coll Favà, the vast majority of open spaces are located peripherally, surrounding the built-up areas. The research methodology consisted in: a) studying the urban and climatic parameters of selected areas; b) analyzing the spatial distribution of the LST using remote sensing technologies (Landsat 8); c) obtaining LST and LSAT through field work, during day and night time; and d) constructing a model of surface and air temperatures as a function of the different types of land cover, combining Remote Sensed data and in situ measurements, for each of the areas of analysis.

Keywords: Urban Heat Island, Green Areas, Cold Urban Areas, Planning, Urban Design, Climate Change, Morphology of Public Space

1. INTRODUCTION

"Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and sea level has risen." (IPCC 2014[1], page 30). "Each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850. The period from 1983 to 2012 was very likely the warmest 30-year period of the last 800 years in the Northern Hemisphere, where such assessment is possible (high confidence) and likely the warmest 30-year period of the last 1400 years (medium confidence)" (IPCC 2014[1], page 40). This temperature increase is distributed throughout the planet and is more pronounced in the higher northern latitudes. The terrestrial regions (Fig. 1) have warmed faster than the oceans. The variation of greenhouse gas (GHG) concentrations in the atmosphere and variations in land cover and solar radiation, alter the energy balance of the climate system. In this sense, the anthropogenic origin of the observed changes[2] seems today an equally incontrovertible fact. The global emissions of GHG due to the effects of human activities have increased, since the pre-industrial era, by 70% between 1970 and 2004. The result of the different models of the evolution of the temperatures of the earth's surface, show the prominence of anthropogenic forcing origin, with respect to those of a natural nature.

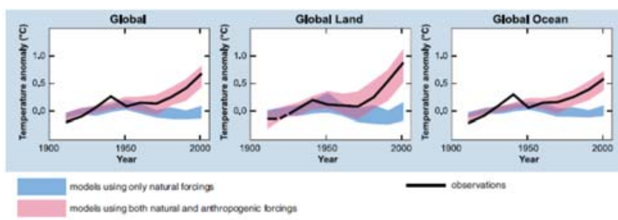

Figure n. 1: Evolution of temperatures (natural and anthropogenic forcing. Source: IPCC 2007[1]

There is a consensus on the fact that cities have a special role in the climate change. According to the Center for Human Settlements (UN-HABITAT), cities are responsible for 75% of global energy consumption, as of 80% of GHG emissions. The contribution of the urbanization to the climatic change is of double nature: on the one hand, by the urban generation of GHG, a factor that contributes in a decisive way to the global warming of the planet; on the other, by the radiation generated by the surface of the urbanized land, which determines a marked flow of sensible and latent heat according to the type of urban covers, as well as their degree of humidity.

Although the urban climate depends essentially on global and regional factors, local and micro-scale factors, such as the different characteristics of the urban structure, topography and surface of land covers, vegetation, anthropogenic heat generated by urban metabolism, among other factors, can modify the local climate on the urban scale.

There are significant differences between the climate of urban and rural areas: *the urban heat island* (UHI) describes the influence of urban surfaces on the patterns of temperature in urban areas as opposed to the surrounding areas. The sealed land and artificial materials (especially asphalt and concrete) used usually in urban areas are one of the main causes.

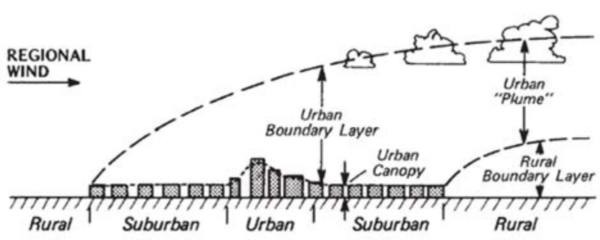

Figure 2. Urban Canopy & Urban Boundary Layers. Source: Oke (1987)[3]

The effects of the UHI manifest in different scales. Two types of UHI can be distinguished: the "canopy layer heat island" and the "boundary level heat island" (Fig. 2). The first depends on the roughness of the soil generated by the buildings and the canopy of the trees, with an upper limit located just above the level of the roofs of the buildings. In this layer, air flow and energy exchanges are governed by microscale processes that depend on the specific characteristics of the surface. The second is situated above the first, with a lower limit subject to the influence of the urban surface. In the urban boundary layer, which is the part of the atmospheric boundary layer above the level of the buildings whose characteristics are affected by the presence of the city, the UHI operates in a different way, in the case of a mesoscale local scale phenomenon, controlled by processes that operate on a larger spatial and temporal scale.

There is a wide consensus that *Land Surface Temperature* (LST) plays a key role in the generation of the Urban Heat Island, representing a determining factor in terms of surface radiation and the interchange of the energy[4], in addition to controlling the distribution of heat between the surface and the atmosphere[5].

The composition of land covers are one of the main factors that influence the LST. Specialized literature has emphasized that built up area and the pervious surface (occupied areas provided with vegetation) and impervious surface (paved and built areas) have a significant impact on the generation of a UHI[6]. In this sense, the reduction of vegetation affects not only in an increase of the LST, but also the reduction of precipitation and evapotranspiration[7,8]. The relationship between the LST and the Normalized Difference Vegetation Index (NDVI) is especially well-documented.

Remote sensing provides spatially continuous information that allows obtaining the LST at scales from tens of meters to kilometers. The satellites provide data on characteristics and land uses that make it possible to quantify the UHI using various indicators[9]. Remote sensing has made possible the generalized study of the LST and, consequently, of the UHI at local and regional scales. At present, there are several operational sensors that allow to measure the LST: MODIS, Advanced Spaceborne Thermal Emission and Reflection (ASTER), Landsat-7 ETM +, Landsat-8 TIRS, Geostationary Operational Environmental Satellite (GOES), NOAA Advanced Very High Resolution Radiometer. AVHRR), Indian National Satellite System (INSAT), Geostationary Meteorological Satellite (GMS) as well as the Meteorology Satellite (Meteosat), among others[10].

Although the LST can be easily measured by remote sensing, the UHI has been commonly studied through the air temperature in the atmospheric surface layer, usually at a height of 2 m above the ground (*land air surface temperature*, LSAT). The air temperature, measured in the weather stations, is one of the observations most frequently recorded, with great precision and temporal resolution[11].

The air temperature, despite its lower climatic relevance in relation to the LST, has an essential role at the scale of human comfort. It is the temperature that people perceive, and in relation to which the exchange of energy works with the environment. However, there are usually few meteorological stations, which in general terms means that the data obtained from the stations do not efficiently represent the spatial variation of the air temperature at the intra-municipal or neighborhood level. For example, at the RMB (Metropolitan Region of Barcelona) there are only 33 weather stations.

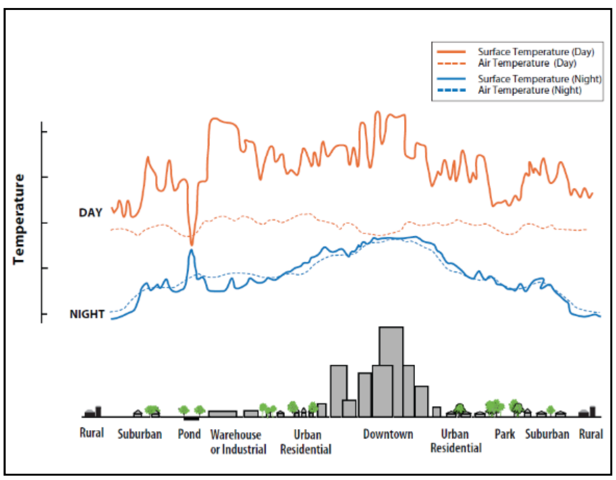

Figure n. 3: LST & LSAT, Day & Night time. Source: Environmental Protection Agency (2008)[12]

The urban heat island (UHI) has an impact on the health and well-being of the citizens, especially worrisome when there are extreme episodes such as *heat waves*. In recent years we can highlight the episode of August 2003 in Western Europe, in which between 22,000 and 45,000 deaths were related to the phenomenon. However, the 2003 heat wave was not an isolated case. In the last 15 years, climatic anomalies due to heat have exploded. A heat wave becomes especially significant when for three or more nights the air temperature does not drop below 25 degrees Celsius. Then, mortality shoots up.

The temperature at night has, therefore, a special role in the emergence of the UHI. The UHI manifests more intensely at night.

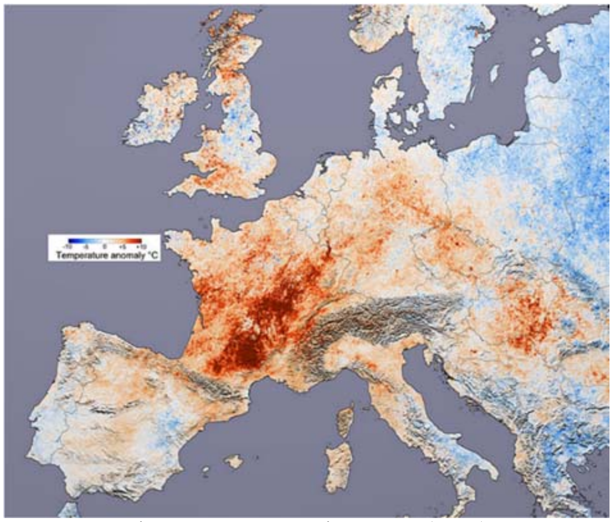

Figure 4. Heat wave in Europe (2003)

Urban planning has a fundamental transcendence to inform, coordinate and implement measures to improve the climate quality of cities in the face of global climate change[13]. There have been some initiatives to introduce methodologies, in the spatial planning, aimed at mitigating climate change. Especially on the "small scale", there is an extensive experience of urban bioclimatic design. In turn, at the building level there has been a significant effort in recent years to increase energy efficiency, with the aim of reducing the generation of GHG (Directives 2002/91 / EC and 2010/31 / EU of the European Parliament and the Council concerning the energy performance of buildings). On the "large scale", however, that of urban and territorial planning, there does not seem to be a parallel awareness, with few initiatives to adapt it in order to increase urban resilience to climate change.

The development of the so-called climatopes has become one of the most effective mechanisms for the introduction of climate in territorial and urban planning to the "large scale" (meso-scale, in climatic terms). The beginnings of this technique are found in the pioneering works developed by German researchers at the end of the 70's[14], which developed the new technique of the climatopes in the seminal researches of Baumuller et al. (1998)[15] and Scherer et al. (1999)[16].

Chao et al. (2010) have carried out a systematic review of the specialized research on urban climate analysis, called in the English-language literature, urban climatic maps (UCM), or more specifically local climate zones (LCZ). Highlights include work done for Tokyo[17], Berlin[18], Freiburg, Hong Kong[19], Lisbon or Vancouver[20].

Especially relevant, for the control of the UHI, are the urban green areas. Due to its abundant vegetation and its pervious surface, parks present a different behavior from the rest of urban spaces. The possibility of using parks as a strategy to reduce the UHI of cities has been studied. The specialized literature recognizes that vegetation is one of the main components of the urban space that causes cooling.

When there is a decrease in land surface and air temperatures due to the abundance of green areas, it is said that there is a *Green Cooling Island*[21], which consists of a cooling effect inside the green area and in its surroundings. Its influence is manifested in both the LST and the LSAT, and its effects occur both day and night, although the extent of its extension depends on the characteristics of the green space and the urban configuration of its surroundings[22, 21].

As a consequence of the aforementioned, the design of the urban parks as well as the public space represents a fundamental element in the regulation of the urban climate, and especially of the UHI.

2. OBJECTIVE OF THE RESEARCH

The general objective of the research is to study, using remote sensing techniques as well as "in situ" measurements, *how urban design affects in the generation of the Urban Heat Island*, as well as the urban microclimate in general. Specifically, this paper seeks to clarify whether the design of green areas can mitigate the UHI.

The case of study is the *Metropolitan Region of Barcelona* (figure 5), which includes 164 municipalities, with a population of 4.7 million people and an extension of 3,200 square kilometers. At this *metropolitan scale*, the spatial configuration of the UHI will be studied.

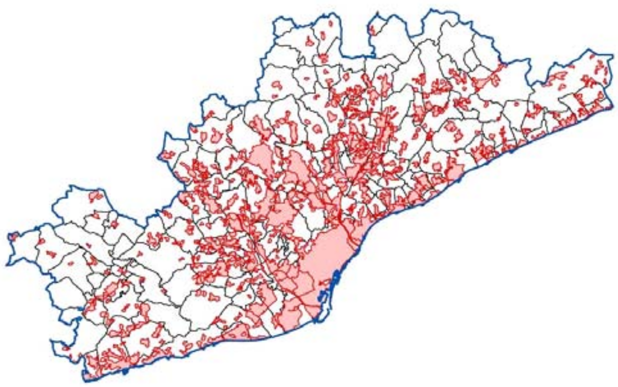

Figure n. 5. Metropolitan Region of Barcelona

At the *local scale*, we will study how the morphology of public space, especially of green areas and open spaces, affects surface temperatures (LST) and air temperatures (LSAT), determining the characteristics of the UHI.

Two case studies will be analyzed and compared in the municipality of Sant Cugat del Vallés (SCV, figure 6): the urbanizations of *Parc Central* (PC) and *Coll Favà* (CF), which have similar urban characteristics, but which have clearly differentiated design aspects in terms of public space. Buildings in Parc Central are "built around open space", while in Coll Favà, the vast majority of open spaces are located peripherally, surrounding the buildings.

Figure n. 6. Sant Cugat del Vallès

The hypothesis is that the morphology of public space is a significant element in the generation of UHI. In particular, the design of the public space, their morphology as well as the quality of their vegetation determine the degree of cooling of the urban green areas, delimiting the extent and size of the Green Cooling Island.

3. METHODOLOGY

The methodology used in this paper combines the use of remote sensing technologies, of medium resolution (30 meters / pixel), with the taking of measurements "in situ". The combination of both approaches, remote and data collection "in situ", allows to validate in a more robust way the hypothesis of research related to the key role played by the design of the public space, and especially of the green areas, in the regulation of the UHI.

Specifically, the research methodology[23] is developed in the following steps:

I. *Remote sensing analysis*:

a. The daytime LST will be obtained from LANDSAT 8, at resolution scale of 30x30 meters / pixel. The measurement of the resulting LST will allow an initial comparison between the study cases (Parc Central and Coll Favà, located in Sant Cugat del Vallès), evaluating which of the two developments (PC and CF) shows a less pronounced effect of the daytime “land-surface” UHI.

b. The nighttime LST will be obtained from MODIS, at 1 km^2 for pixel. Due to the low resolution of MODIS, the results of the night LST do not allow a detailed analysis at the local level. However, the nighttime LST obtained through MODIS allows us to know the configuration of the nocturnal UHI at the metropolitan scale.

c. Daytime and nighttime temperatures, obtained by remote sensing in the previous sections, allow to make a detailed approximation of the UHI of the Metropolitan region of Barcelona.

d. The information obtained through the satellites allows knowing, together with the LST, some indices that affect the UHI, such as the NDVI or the NDBI. Particularly the NDVI helps to know the effect of the tree canopy and the quality of the vegetation in the UHI of the MBR, as well as of the cases of study at SCV.

II. *“In situ” Analysis*:

a. The previous information will be completed by obtaining day and night “in situ” LST in the two study cases. This second approach will allow contrasting the results obtained through remote sensing. The greater level of detail of the field data will help to ratify the hypothesis of research.

b. In addition, day and night LSAT measurements will be taken in the two study cases. This information will help us to confirm the hypothesis of the microclimatic effect of public space and green design (both during daytime and nighttime) in the perspective of human perception. Particularly, at nighttime, if the air temperature reaches the 25 degrees Celsius that represent the "torrid" nights.

c. Finally, the urban design of both study cases and its green infrastructure will be analyzed.

4. OBTAINING LST

The method used to obtain the LST using information from LANDSAT consists of converting the numerical coding (Digital Number-DN) of the thermal band (infrared heat) facilitated by the satellite in physical units, i.e. in Celsius degrees. As such:

- The *DN* is transformed into *spectral radiance*.
- *At-sensor brightness temperature* is calculated. This temperature does not take into account the type of material or land that emits the energy captured, it would therefore be equivalent to the temperature emitted by a black body.
- The final step for obtaining the LST is to correct the numerical value obtained in the previous steps, by introducing the emissivity of the soil materials. In this case, the emissivity has been obtained from the NDVI (normalized difference vegetation index). The use of the NDVI with respect to other alternatives, such as land use classification has two main advantages: 1. both, temperature and vegetation index come from the same moment in time, and 2. the immediacy involved in the calculation of this index.

The used image (LC81970312015176LGN00) was in the summer of 2015 (an extremely hot year). Specifically from June 25. LANDSAT 8 image with the following bands: 1 = Coastal; 2 = Blue (30 m); 3 = Green (30 m); 4 = Red (30 m); 5 = Close-up infra-red (30 m); 6 = SWIR 1 (30 m); 7 = SWIR 2 (30 m); 8 = Pan (15 m); 9 = Cirrus; 10 = TIR 1 (100 m); 11 = TIR 2 (100 m).

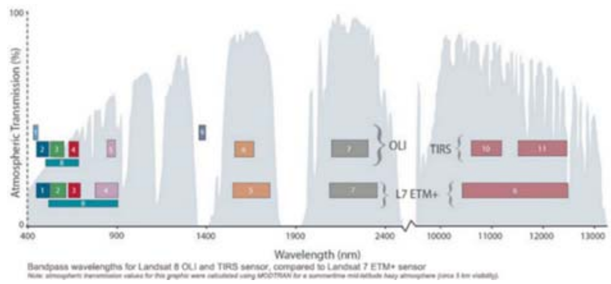

Figure 7. Landsat bands

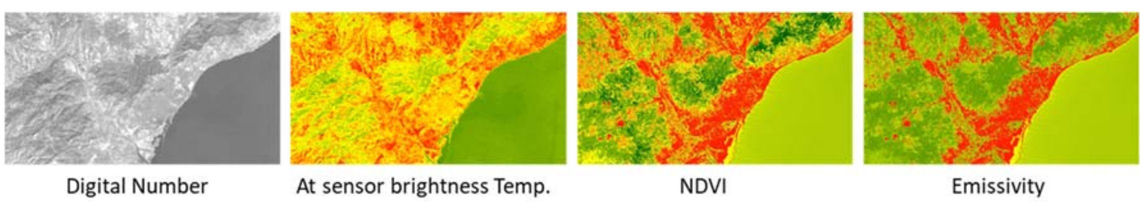

Figure n. 8: LST process

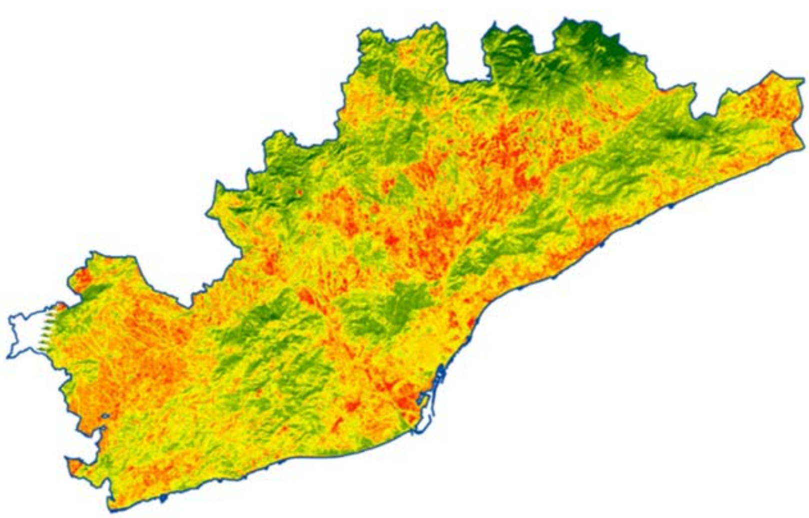

Figure 9. LST

5. METROPOLITAN HEAT ISLAND OF BARCELONA

The LST (Landsat) has allowed to know the UHI (daytime) of Barcelona:

- The “economic activities & logistics” (34.40 ºC), “industrial” (33.29 ºC), “tertiary” and “services” (31.37 ºC) represent the hottest land uses at metropolitan scale.
- At the same time the “roads network” (31.34 ºC) as well as the “compact residential” (31.05 ºC), LST is clearly higher than the average of the MRB (28.58 ºC).
- These land uses contribute to the UHI in a clearly more pronounced way than the "traditional urban residential" (30.43 ºC), “historic center" (30.32 ºC), "residential in grouped houses" (30.30 ºC) or "single family homes"(28.62 ºC).
- The "non-developable land of special protection" (26.17 ºC), the "undeveloped land with protection" (28.16 ºC), the open spaces and greens areas"(28.23 ºC), as well as the "Hydrographic system" (28.61 ºC) are the best rated land uses from a climate perspective.
- On the other hand, the "non-developable rustic land", mainly agricultural land, shows an average LST of 29.08 ºC, higher than the “single family homes“.

In summary: *the artificialized areas observe an average LST that is 7.2% higher than the non-artificialized ones.*

Hottest Uses	LST	Coolest Uses	LST
Logistics Activity	34,4	Rural (Spetial Protection	26,17
Industry	33,29	Rural (Protection)	28,16
Dev. Land (economic ac	31,89	Green Areas	28,23
Tertiary	31,39	Hydrographic system	28,61
Roads and Streets	31,34	Detached Houses	28,62
Compact City	31,05	Agricultural Land	29,08
Mixed Area	31,04	Residential Blocks	29,6
Mixed Use Development	30,82	Dev. Land (residential)	29,71
Old City	30,32	Semi-Detached Houses	30,3

Table 1. LST by land use

Once the LST was obtained at daytime by means of Landsat (30 m / pixel), *the LST at nighttime was obtained through MODIS* (1 km / pixel). Figure n. 10 compares the LST of day (Landsat) with the LST at night. Figure 11 shows the nighttime UHI of MRB.

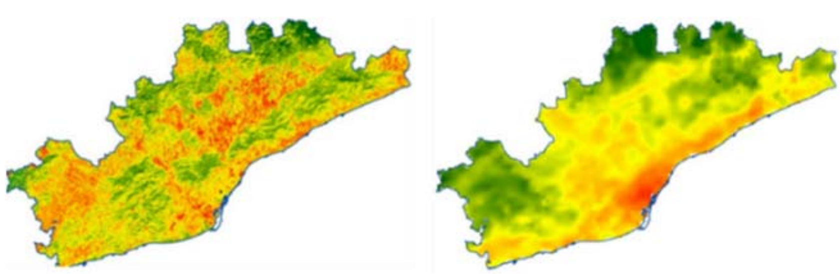

Figure 10. LST (daytime Landsat vs. nighttime Modis)

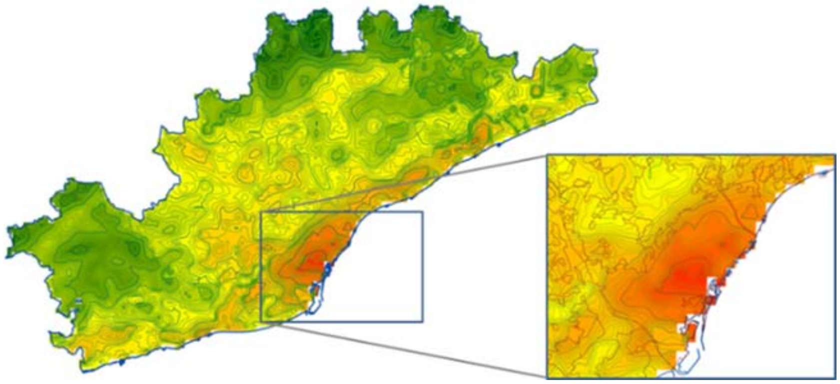

Figure 11. UHI of Metropolitan Region of Barcelona (nighttime)

As can be seen in Figure 10, *the morphology of UHI during daytime differs sharply from nighttime UHI. During the day*, the metropolitan center (the city of Barcelona) does not show the highest metropolitan LST. They are the industrial areas of the first metropolitan ring (that surrounds the city except for the North side, where Collcerola Park closes the ring) that reveal the highest surface temperatures. The extreme LST are also located in the industrial areas and in the compact centers located in the Pre-coastal Depression, which runs parallel to the sea, beyond the Coastal Mountains (Garraf, Collserola and so on). The agricultural areas of the Pre-coastal Depression, especially the vineyards, also observe elevated LST. On the opposite side, the forested areas show the lowest temperatures at metropolitan scale: the spaces characterized by a high quantity and quality of the vegetation observe the most moderate LST in the MRB, as evidenced by the high negative correlation between the NDVI and the daytime LST.

During the night, the spatial distribution of the LST varies in a meaningful way. The compact urban centers, and especially the city of Barcelona, denote the highest LST. On the other hand, in rural areas, the reduction of night temperatures is pronounced. The agrarian zones, and especially the vineyards, observe a much more pronounced cooling than the urban spaces. And the highest LSTs move from the Pre-coastal Depression to the Coastline. The industrial areas, on the other hand, also show a marked reduction of the LST: they cool much more sharply than the compact residential fabrics. And the wooded areas, except for those located at very high altitudes (> 1,000 meters), also observe, like the urban centers, a greater thermal inertia. Forests preserve surface temperature much more than open spaces (table. 2).

CORINE LAND COVERS	LST (Daytime)	LST (Nighttime)	Difference
High and Medium Density	30,35	17,63	12,72
Urban Sprawl	28,8	16,17	12,63
Industrial and Commercial	31,21	16,52	14,69
Other Urban Land Uses	29,72	17,06	12,66
Agricultural Areas	30,07	15,06	15,01
Forest Areas	26,93	15,23	11,7
Other Rural Land Uses	28,35	15,32	13,03

Table 2. LST (day and night) by CLC

6. CASE STUDIES

The cases used in this research are the “planning areas” with a master plan: 1. Parc Central (figure 12) and 2: Coll Favà (figure 13), located in the municipality of Sant Cugat del Vallés (10 km from Barcelona).

The comparison between both planning areas generally provides an improved evaluation of the *traditional urban development indicators* at Coll Favà:

- Built-up area index at Coll Favà (0.61) is lower than in Parc Central (0.85).
- Public land (systems) takes up a greater % of the area (65.87 % with respect to 59.27 %).
- The percentage of open space (roads and green areas) is also higher at Coll Favà (59.21 %) than in Parc Central (53.36 %).
- The percentage of pervious land is 53.99 % in Coll Favà, and 37.26 % in Parc Central.

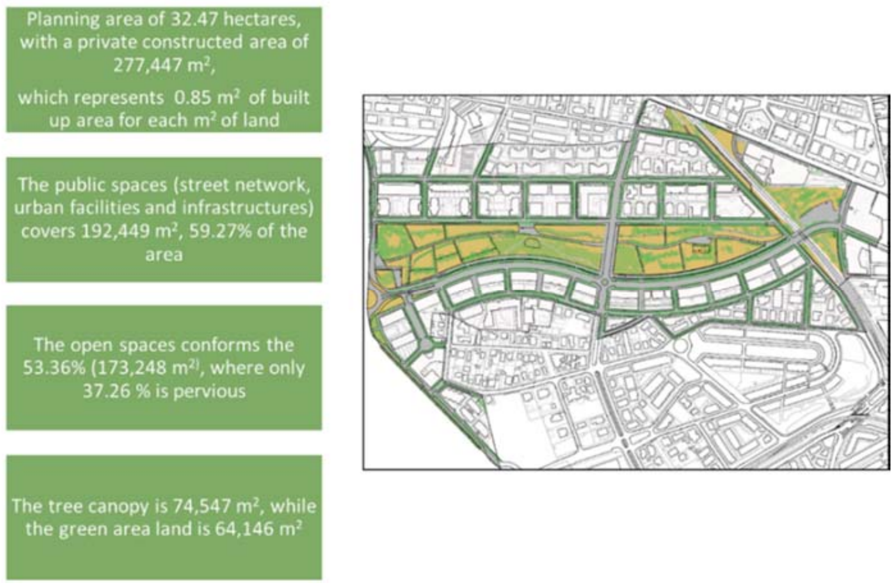

Figure 12. Parc Central

Figure 13. Coll Favà

From an urbanistic point of view, the vast majority of the indicators (table 3) suggests a better climate performance of Coll Favà: lower built up area, greater proportion of public and open space and a higher level of pervious land. *Only one indicator (the tree canopy) favors Parc Central*.

	Area	Public Land	Private Land	% Public	Built-up	Gross Building Index	Net Building Index	Open Land	% Open Land	Pervious	Impervious	% Pervious	Green surface (planning)	Green Canopy
Parc Central	324,696	192,449	132,247	59.27%	277,447	0.8545	20.979	173,248	53.36%	64,546	108,702	37.26%	64,146	74,547
Coll Favà	567,861	374,029	193,832	65.87%	348,9	0.6144	1.800	336,213	59.21%	181,512	154,701	53.99%	176,856	64,878

Table 3. Urban indicators

Despite its worst traditional "planning indicators", *Parc Central is potentially likely to experience a better thermal performance due to the more compact and concentrated nature of their green areas*. In the opposite, *Coll Favà shows a more fragmented structure of the green zones. Parc Central will also probably benefit from an improved microclimate, due to the greater density of its tree canopy, unlike that of Coll Favà, which is much poorer and bare*.

This hypothesis of the best climate performance of Parc Central is confirmed by the following indicators:

- The NDVI analysis reveals a very different structure between Coll Favà and Parc Central. While in the first zone the areas with dense vegetation is marginal, occupying the perimeter limits at the east and west of the area, Parc Central shows abundant vegetation in the central core of the area.
- The average NDVI in Coll Favà is 0.3435, which is less than that of Parc Central, which is 0.4529. This means that PC has an average of vegetation quality far higher than Coll Favà.
- Parc Central has an NDVI close to the municipal average, which includes almost 50% protected natural spaces, Natural Park of Collserola.
- NDVI analysis at a detailed scale (IGCC) confirms (see figure 14) the highly differentiated quality of the vegetation in both areas.
- The aboveground vegetation (canopy tree) in Parc Central fulfils a fundamental role, unlike Coll Favà, where the "green" areas do not have dense foliage in most of the area, even in the central axis of the neighborhood.

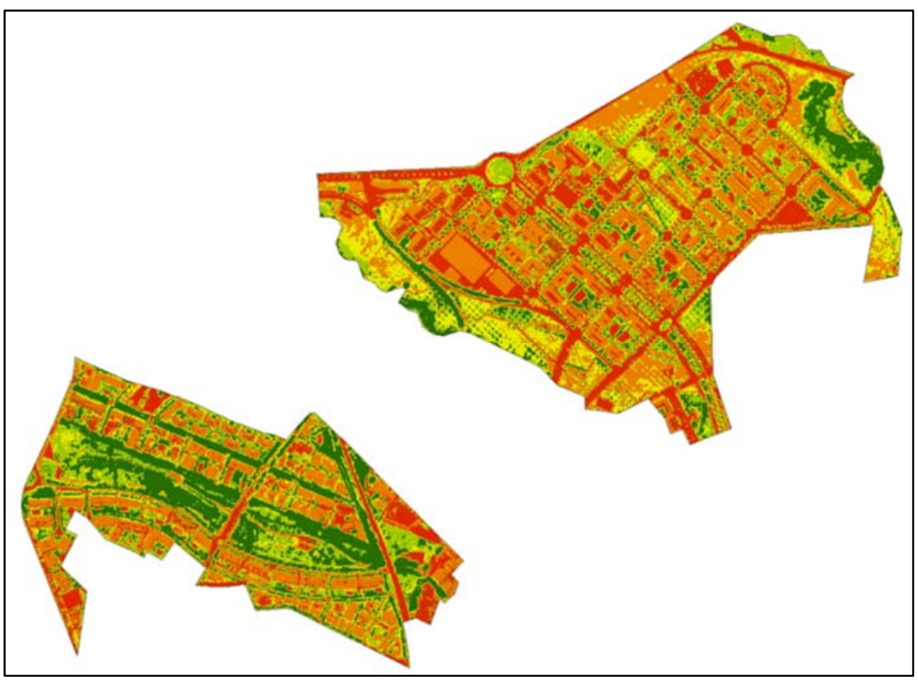

Figure 14. NDVI. Source: IGCC

The LST analysis from the LANDSAT 8 image confirms the better climatic performance of Parc Central, with an average of 32.65 degrees Celsius when compared with Coll Favà, with an average LST of 35.54 degrees:

- This difference of almost 3 degrees is highly significant at an intra-urban level, and does not seem to be the result of differential geographic factors, given the proximity of the two areas.
- The LST histograms for Parc Central and Coll Favà confirm the different climatic results of both areas. LST distribution in Parc Central (blue) is clearly skewed to the left, i.e. towards lower temperatures. Coll Favà (green) however shows a clear structure, with a skew to the right.
- The analysis of both robust averages (32.53 PC and 35.44 CF) and medians (32.55 and 35.48 respectively) confirms the diagnosis.

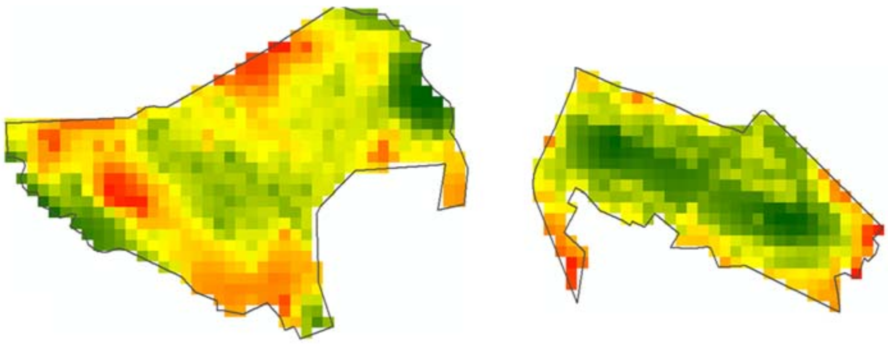

Figure 15. LST (Landsat 8)

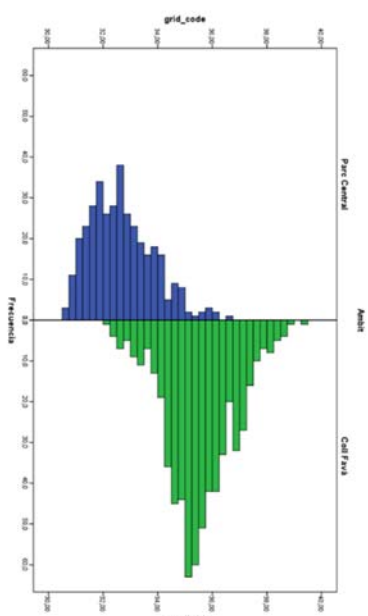

Figure 16. Histograms of land surface temperatures (CF, green; PC, blue)

If we segment the land surface temperatures according to the type of space, both *public and private*, the results are noticeably similar to those found for all areas in Parc Central and Coll Favà. *Public spaces* of Parc Central have an average temperature of 32.32 Celsius, compared to 35.64 in Coll Favà. If we take a look only on *private land*, Parc Central obtains an average LST of 33.15 degrees Celsius, which is also clearly below that of Coll Favà, at 35.25 degrees. *The better thermal* *performance of PC is not limited, therefore, to public space, it also radiates to the rest of the urban fabric, affecting private areas in a singularly significant manner.*

Particularly significant is the fact that public spaces in Coll Favà has an average LST higher than private land, contrary to what would be expected. This shows the inadequate design of the green and open spaces at Coll Favà. One example of this is the “Jaume Tubau” sports zone, whose artificial grass surface makes a negative contribution to the UHI in the area. This is also true for open (pervious) areas without vegetation or bare.

In addition to the analysis based on remote sensing, *"in situ" analysis of the LST and the LSAT* has been carried out in order to verify the climatic performance of Parc Central and Coll Favà. A set of field measurements was taken with this purpose:

- Parc Central - Night (night from 2 to 3/09/16): 19 thermal images were made, 4 videos and 20 measurements of climatic air parameters.
- Parc Central - Day (midday, 3/09/16): 63 thermal images and 20 videos and 12 atmospheric readings.
- Coll Favà - Day (midday, from the 3 and 4/9/16): 31 thermal images, 13 vídeos and 12 atmospheric readings.
- Coll Favà - Night (night 4/9/16): 53 thermal images, 16 videos and 12 atmospheric readings.

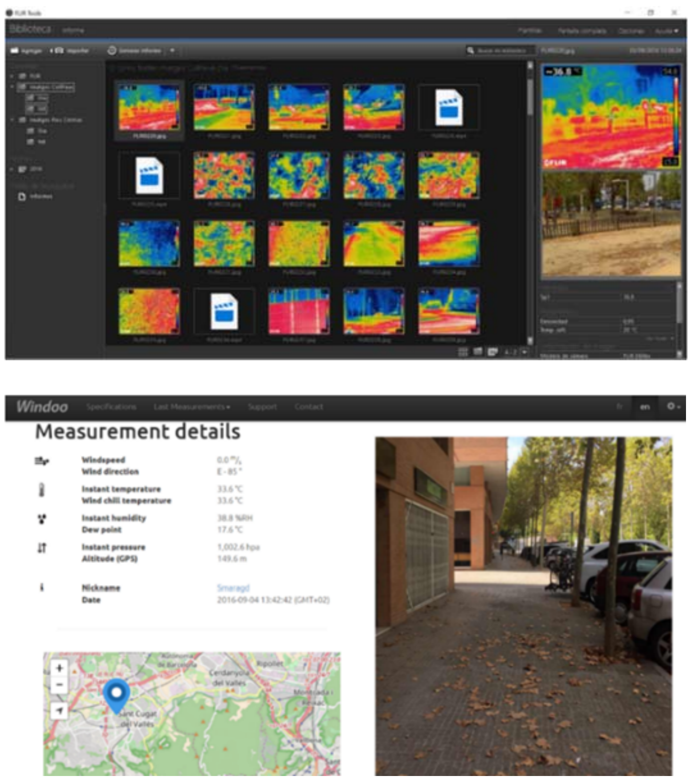

Figure 17. Sample of LST and LSAT measures

The analysis of day-time temperatures of pavements or ground surfaces confirms the better thermal performance of Parc Central. All the surfaces obtain an LST that is lower in Parc Central than at Coll Favà. Bare land obtains greater differences (13.2 degrees), as asphalt (10.3 degrees). The paved areas in parks are in an intermediate level (8.5 degrees), as clay tiles and sidewalk edge (8.2 degrees). Lawn-type areas present a smaller thermal difference (4.7 degrees cooler at Parc Central than at Coll Favà).

The analysis of nocturnal temperatures on ground surfaces confirms the lower temperatures of Parc Central when compared to Coll Favà. Bare ground is the surface type that reveals a higher temperature difference, while grass and asphalt reveal a higher level of similarity in both areas (figure 18).

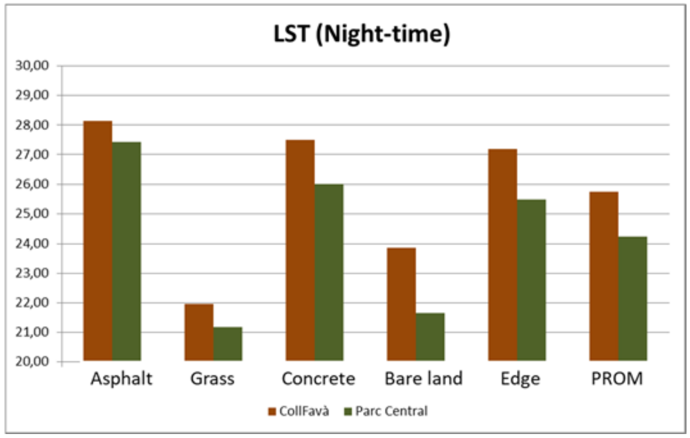

Figure 18: “In-situ” night-time LST (different surfaces)

In conclusion, *the analysis of land surface temperature measurements obtained by using the thermal camera broadly confirms the better performance of Parc Central*:

- The average for the group of measurements obtained for day-time LST levels is 34.08 degrees Celsius, for the Parc Central area, compared to 44.30 for Coll Favà: a difference of more than 10 degrees.
- At night time, the average Parc Central reading is 24.28 degrees, compared to 24.91 for Coll Favà. The temperatures tend to equal at night, probably due to the significant cooling of permeable, vegetation-free surfaces at Coll Favà.
- Average surface temperatures decreases by 9.8 degrees in Parc Central, and by 19.39 degrees in Coll Favà.
- *Parc Central is, therefore, much cooler during the day, although at night temperatures tend to be similar*.

	LST			LSAT		
	Day-time	Night-time	Difference	Day-time	Night-time	Difference
Parc Central	34.08	25.78	8.3	33.12	25785	7.33
Coll Favà	44.3	27.05	17.25	38.14	27.05	11.09
Difference	10.22	1.27		5.03	1.27	

Table 4. LST and LSAT “in situ” measures

The analysis of the air temperatures (LSAT) in-situ confirms the previous conclusions:

- The average daytime temperature of Parc Central was 33.12 degrees Celsius, 5.03 degrees lower than that of Coll Favà (38.14).
- The average nighttime temperature is also cooler in Parc Central (25.78 degrees) than in Coll Favà (27.05 degrees), even though the difference drops to 1.27 degrees Celsius.
- This reduction of the differences is due to the relatively higher cooling areas in Coll Favà (especially bare ground) with respect to Parc Central: 11.09 degrees vs. 7.33.
- However, night-time measurements at Coll Favà exceed the maximum comfort temperatures (24-26 degrees).

The best climate performance of Parc Central compared to Coll Favà is evident in all the analyses carried out. Both the study of the daytime LST resulting from remote sensing, as well as the surface temperatures of day and nighttime resulting from the field study, show that the design of the public spaces and the green areas of Parc Central offers a better thermal performance than Coll Favà. Results that are also confirmed by the LSAT analysis.

7. CONCLUSIONS

The main conclusions of the work can be summarized as follows:

1. *Despite having better traditional "planning indicators", Coll Favà observes a poorer "climate performance" than Parc Central*.
2. *The key factor is the differences in green structures*. The tree canopy is better in Central Park than Coll Favà. In addition, it is likely that Parc Central has a greater thermal reach due to the greater compactness and concentration of the green infrastructure than the fragmentation of Coll Favà.
3. The NDVI (from Landsat 8) analysis reveals a very different structure between Coll Favà and Parc Central. While in the first neighborhood the areas with dense vegetation are marginal, occupying the perimeter limits at the east and west of the area, Parc Central shows abundant vegetation in the central core of the area. Parc Central has a better microclimate due to the greater density of its tree canopy, unlike that of Coll Favà, much poorer and bare.
4. The LST analysis (from the LANDSAT 8) confirms the better climatic performance of Parc Central, with an average of 32.65 degrees Celsius when compared with Coll Favà, with an average LST of 35.54 degrees.
5. "In situ" analysis also confirms the better climatic performance of Parc Central. Both day and night, the LST and the LSAT are cooler in Parc Central than in Coll Favà.

We can conclude that: a) the use of both analysis, remote sensing technologies and "in situ" measures of land and air surface temperatures, can help to identify UHI; b) urban morphology plays a key role to generate and control UHI; and c) landscape design and selection of vegetation has a particular relevance to promote resilience to heat waves.

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